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Developing and testing alien species indicators for Europe

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ABSTRACT

Alien species indicators provide vital information to the biodiversity policy sector on the status-quo and trends of biological invasions and on the efficacy of response measures. Applicable at different geographical scales and organizational levels, alien species indicators struggle with data availability and quality. Based on policy needs and previous work on the global scale, we here present a set of six alien species indicators for Europe, which capture complementary facets of biological invasions in Europe: (a) an combined index of invasion trends, (b) an indicator on pathways of invasions, (c) the Red List Index of Invasive Alien Species (IAS), (d) an indicator of IAS impacts on ecosystem services, (e) trends in incidence of livestock diseases and (f) an indicator on costs for alien species management and research. Each of these indicators has its particular strengths and shortcomings, but combined they allow for a nuanced understanding of the status and trends of biological invasions in Europe. We found that the scale and impact of biological invasions are steadily increasing across all impact indicators, although societal response in recent years has increased. The Red List Index is fit-for-purpose and demonstrates that overall extinction risks (here shown for amphibians in Europe) are increasing. Introduction pathway dynamics have changed, with some pathways decreasing in relevance (e.g., biological control agents) and others increasing (e.g., horticultural trade) providing a leverage for targeted policy and stakeholder response. The IAS indicators presented here for the first time on a continental basis serve as a starting point for future improvements, and as a basis for monitoring the efficacy of the recent EU legislation of IAS. This will need a better workflow for data collection and management. To achieve this, all main actors must work toward improving the interoperability among existing databases and between data holders.

1. Introduction

The human-mediated introduction of species into previously inaccessible regions has become a defining feature of global environmental change (Tittensor et al., 2014). Invasive alien species (IAS) are the subset of these species that poses a risk to biodiversity (Blackburn et al., 2014; CBD, 2002) and related ecosystem services (Vilá et al., 2010; EU, 2014), human, animal or plant health or the economy (Scalera, Genovesi, Essl, & Rabitsch, 2012). According to the most recent global analysis of the Red List (IUCN, 2012), IAS constitute the fifth most severe threat to amphibians, the fourth to reptiles, the third to birds and mammals, and the second to freshwater fish species (Vié, Hilton-Taylor, & Stuart, 2009).

Globally, the scale and impacts of biological invasions are increasing (Butchart et al., 2010; McGeoch, Chown, & Kalwij, 2006; McGeoch et al., 2010). In particular, increasing trade and delayed responses in establishment and spread of alien species (Essl et al., 2011) and other drivers of global change as climate change (Bellard et al., 2013; Walther et al., 2009) will likely foster future introductions of invasive organisms. In response to these increasing

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pressures, the European Union (EU) has recently adopted a dedicated legislation on IAS (EU, 2014), which aims to reduce the future impacts of alien species (Genovesi, Carboneras, Vilà, & Walton, 2015). To assess the scale and temporal trajectories of alien species impacts in Europe and to provide a baseline assessment for the future evaluation of EU IAS-policy, developing and testing indicators on alien species has become an urgent need.

Biodiversity indicators, and more specifically alien species indicators, are an integral part of the biodiversity policy sector and used for providing information on the trends, status-quo and likely future development of the drivers, pressures, status, impact and response that relate to the subject (Butchart et al., 2010; Genovesi, Butchart, McGeoch, & Roy, 2012a; Tittensor et al., 2014; Armon & Zenetos, 2015). In recent years, there was substantial progress in developing and applying alien species indicators. In particular, the Global Biodiversity Outlook 3 for the first time introduced an indicator based on the cumulative number of alien species to measure the global progress toward the 2010 biodiversity targets (Butchart et al., 2010). Subsequently, this indicator has been presented in detail by McGeoch et al. (2010). Within the Biodiversity Indicators Partnership (http://www.bipnational.net/) invasive alien species indicators are developed further to ensure that CBD-Aichi Target 9 ("By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment") can be monitored at the global level. Recently, a mid-term assessment was provided by Tittensor et al. (2014) for the Global Biodiversity Outlook 4 providing further evidence of the increasing pressure executed by IAS.

In Europe, a set of IAS indicators corresponding to the 'Driving Forces-Pressures-State-Impacts-Responses' (DPSIR) framework was developed within the 'Streamlining European Biodiversity Indicators 2010′ process (EEA, 2012). Subsequently, Rabitsch, Essl, Genovesi and Scalera (2012) proposed the development of a set of indicators to measure progress toward both the Aichi biodiversity targets, and the targets adopted in Europe within the EU Biodiversity Strategy to 2020 (EC, 2011). Building on these preceding initiatives, we test the applicability of six alien species indicators which capture complementary facets of biological invasions in Europe: (a) a combined index of invasion trends, (b) an indicator on pathways of invasions, (c) a Red List Index of IAS, (d) an indicator of IAS impacts on ecosystem services, (e) trends in incidence of livestock diseases and (f) an indicator on costs for alien species management and research. We hence discuss the suitability of these indicators in relation to the following questions: (i) What are their specific strengths and constraints? (ii) Does the indicator answer the posed policy question? (iii) Can the indicator be applied in a European and global context? and (iv) What are the gaps in data coverage and which avenues allow for closing these?

2. Material and methods

2.1. Combined index of invasion trends

This trend indicator provides information on accumulation rates of alien species in Europe over time. To ensure a broad taxonomic coverage, we used data on the year of first observation records from five groups: mammals (Genovesi, Carnevali, Alonzi, & Scalera, 2012b; P. Genovesi, unpubl.), marine metazoans (VECTORS project, S. Olenin, unpubl.), terrestrial arthropods (Roques et al., 2010 with updates in 2012), vascular plants (data until 2005, J. Pergl, unpubl.), and bryophytes (Essl, Steinbauer, Dullinger, Mang, & Moser, 2013). Whereas records on arthropods and mammals only included established species, records on the other groups also included casuals and species with unknown invasion status. To calculate the relative increases in species numbers from 1900 onwards, we standardized the numbers of alien species recorded in Europe in 1900 for each taxonomic group to one. Then, we calculated for each taxonomic group the relative increase in alien species from the year 1900 to 2010 in decadal increments. According to Butchart et al. (2010) we calculated the geometric mean of these taxonomic indices, i.e., each taxonomic group contributes equally to this index, irrespective of the large differences in species numbers for which the year of first record is known: mammals (n = 38 species), marine metazoans (n = 662 species), arthropods (n = 1424 species), vascular plants (n = 3660 species) and bryophytes (n = 87 species).

2.2. Indicator on pathways of invasions

The contribution of specific pathways to invasions often changes substantially over time due to consumer behavior, fashion and economic trends (Nentwig, 2007; Kowarik & von der Lippe, 2007; Rabitsch et al., 2013; Essl et al., 2015). Despite on-going efforts toward harmonized definitions (CBD, 2014; Hulme et al., 2008), a standard pathway terminology has not yet been adopted by the many different alien species data sources. We evaluated the pathway indicator for Europe using data from an updated version of the DAISIE-database (www.europe-aliens.org; as of September 2012), to demonstrate trends in the most important pathways (Horticulture/Ornamentals, Stored product pests, Biological control, Forestry, Unknown) of alien terrestrial arthropod species in Europe. We exemplarily selected arthropod species because of the large number of species, and recent updates of pathway assignments and time of first records in Europe.

2.3. The Red List Index of IAS

The Red List Index (RLI) of IAS permits to calculate overall rates at which species impacted by IAS are moving toward or away from extinction. This indicator was originally developed by Butchart et al. (2007, 2010) and calculated from the number of species in each Red List category and the number of species which were changing categories between Red List assessments. It can only be applied when at least two comprehensive Red List assessments are available. Unfortunately, the IUCN European Red Lists currently have only one data point in time and can therefore not be used for calculating a European RLI for the time being. Therefore, we used the global IUCN Red List assessments and selected amphibians as model group. Many amphibian species are in particularly strong decline worldwide (e.g., Hof, Araújo, Jetz, & Rahbek, 2011; Sodhi et al., 2008), and the proportion of species facing extinction risk is the highest of all vertebrate groups (IUCN, 2012; Stuart et al., 2004). In addition, amphibians are known to be particularly affected by IAS and associated pathogens and diseases (Hof et al., 2011). We extracted a complete list of native European amphibian species from the IUCN database (IUCN, 2012) and compared their Red List assessments of the years 2004 and 2009. We then used the "Major threats" described in the assessments to check if IAS are hold responsible for the deterioration of the status of the native species. For calculations we used the freely available 'RLI-Calculator' (http://www.birdlife.org/action/science/indicators/rli.html) to analyze changes in the RLI.

2.4. Indicator of IAS impacts on ecosystem services

Ecosystem services are the direct and indirect contributions of ecosystems to human wellbeing (TEEB, 2010). Depending on the applied definition, these include provisioning, regulating, and cultural services that directly affect people and the supporting services needed to maintain other services. To develop and test a measure of the impact of IAS on ecosystem services in Europe we analyzed the cumulative increase of ecosystem services negatively affected by IAS over time for two data sets. We used the assignments by Vilá et al. (2010) for the DAISIE '100 of the worst' and cumulated the number of impacted ecosystem services to the decade of the first record of the species in Europe. We followed the same procedure for the '80 representative alien terrestrial arthropod species' selected by Roques et al. (2010). The ecosystem services classification schemes differed slightly between both sources (Appendices A, B in Supplementary material), but are in large parts comparable at higher hierarchical levels.

2.5. Trends in incidence of livestock diseases

The impacts of alien species causing diseases on biodiversity often is particularly detrimental as native species lack co-evolutionary history with the disease-causing agent, and thus high levels of mortality including total population losses may occur (e.g., Rushton et al., 2006; Fisher, Garner, & Walker, 2009). Taking into account policy requirements (Aichi Target 9, Appendix C in Supplementary material), Rabitsch et al. (2012) suggested developing a new indicator on the incidences of livestock diseases caused by IAS over time in Europe based on data reported to the Animal Disease Notification System (ADNS). The ADNS documents infectious animal diseases listed in Annex I of Council Directive 82/894/EC on the notification of animal diseases within the Community (EC, 1982). It is a management tool that ensures detailed information about outbreaks of these diseases in the countries that are connected to the ADNS. The operational objective is to ensure rapid exchange of information between the national authorities responsible for animal health and the European Commission on outbreaks of contagious animal diseases. Participating countries are responsible for reporting outbreaks and annual reports as well as all relevant information to the ADNS.

Annex I of the Council Directive lists 22 diseases of terrestrial animals and 14 aquatic diseases negatively affecting livestock or aquaculture. Among these, there are several European (e.g., classical swine fever) or cosmopolitan (e.g., foot-and-mouth disease) diseases, other diseases have native and alien serotypes in Europe (e.g., bluetongue). Here, we only included diseases which are unambiguously alien to Europe and that only affect livestock, i.e., African swine fever, Dourine, Equine encephalomyelitis, and Equine infectious anaemia. These were used to build a trend indicator (number of reported outbreaks per year within the EU28, Andorra, Faroe Islands, Norway and Switzerland) based on the annual reports provided by ADNS. Diseases that affect wild animals, such as *Aphanomyces astaci* (infecting European crayfish causing crayfish plague) and *Batrachochytrium dendrobatidis* (infecting amphibians causing Chytridiomycosis), are not included in the notification system.

2.6. Indicator on costs for alien species management and research

Developing an indicator for measuring economic impacts caused by invasions is of crucial importance to guide policy making. Monetary costs can comprise direct and indirect loss to economy (e.g., yield loss), but also investments into surveillance, monitoring, research and management activities. However, economic assessments of the costs generated by alien species are scarce and often not collected in a standardized manner. In the European context, as shown by Scalera (2009), the amount spent in EU funding programmes on nature conservation and research provides an opportunity to calculate a cost-indicator on alien species management and research. Investments for EU funding programs between 1992 and 2006 have been analyzed by pre-selecting the relevant projects funded through the LIFE program and the RTD Framework Programme, by searching on the publicly available databases (see details in Scalera, 2009). In a second step, the exact amount of money allocated to IAS management and research in these projects was verified by contacting either the beneficiaries or the financing authorities (this was particularly important for projects including measures other than those on IAS). The data show the trend of financial investments towards IAS management and research through two of the main EU financing tools for nature conservation without corrections (e.g., inflation).

3. Results

3.1. Combined index of invasion trends

This trend indicator shows that the number of alien species has increased linearly in Europe over the last century (Fig. 1), thereby leading to 4-fold increase in alien species numbers since the year 1900. Relative rates of alien species accumulation over time are similarly increasing for all taxonomic groups, with marine metazoa indicating an exponential increase. The magnitude of increase differed widely: numbers of vascular plants increased by 1.4, whereas the numbers of alien marine metazoa increased by 33.1.

3.2. Indicator on pathways of invasions

The cumulative numbers of alien arthropods are steadily increasing for every pathway category, although the slope of accumulation differs between pathway categories (Fig. 2). Whereas numbers of introduced stored product pests, biological control agents and forest pests recently remained stable, the numbers of species introduced by horticultural trade and unknown pathways continue to increase strongly.

3.3. The Red List Index of IAS

We found a decreasing RLI for amphibians in Europe between 2004 and 2009, which implies that overall extinction risks of amphibians in Europe are increasing (Fig. 3a). This decrease in conservation status is largely driven by alien species: of the 15 amphibian species that have changed their conservation status 4 improved and 11 deteriorated; IAS were regarded as threat to 8 of these 11 species between 2004 and 2009 (Fig. 3b). The first available European Red List assessments demonstrate that IAS are considered an important threat in several of the evaluated taxonomic groups. For example, 48% of all European amphibian species and 42% of the threatened species (CR, EN, VU) are under threat from IAS (Table 1). When second assessments will become available, any change in categories can be used to calculate a dedicated European RLI for the given group of organisms.

3.4. Indicator of ecosystem services affected by IAS

This indicator demonstrates that since 1600 the number of affected ecosystem services in Europe steadily increased, accelerating in the mid-19th century and again after World War II. This holds true for all environments and taxonomic groups considered (Fig. 4).

3.5. Trends in incidence of livestock diseases

We found that the number of reported outbreaks per year of livestock diseases in Europe caused by selected alien pathogens between 1984 and 2011 exhibited strong inter-annual variation without any clear trends (Fig. 5).

Table 1
Number of native species threatened by invasive alien species (IAS) according to the European Red Lists (http://www.iucnredlist.org/initiatives/europe).

Group	Total number of species assessed	Year of assessment	Number of threatened species (CR, EN, VU)	Number and proportion of threatened species (CR, EN, VU) and of all species threatened by IAS
Terrestrial mammals	204	2007	29	6 (21%)/24 (12%)
Marine mammals	27	2007	6	1 (17%)/1 (4%)
Reptiles	139	2009	27	10 (37%)/21 (15%)
Amphibians	83	2009	19	8 (42%)/40 (48%)
Freshwater fish	524	2011	194	ca. 80 (41%)/300 (57%)
Butterflies	435	2010	37	8 (22%)/11 (2%)
Dragonflies	137	2010	21	2 (9%)/2 (1%)
Non-marine molluscs	854	2011	373	ca. 60 (16%)/100 (12%)
Saproxylic beetles	431	2010	46	0 (0%)/1 (0%)
Policy Plants[a]	891	2011	400	ca. 80 (20%)/140 (16%)
Crop wild relatives[b]	572	2011	66	19 (29%)/29 (5%)
Aquatic plants	393	2011	26	8 (31%)/24 (6%)

[a] Plants listed under European or global policy instruments such as the Habitats Directive, Bern Convention, Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the EU Wildlife Trade Regulation.
[b] Wild species closely related to crops that are defined by their potential ability to contribute beneficial traits for crop improvement.

3.6. Indicator on costs for alien species management and research

This response indicator shows a strong overall increase in the financial investments for alien species management and research in Europe since 1992 (Fig. 6). The three-annual costs increased from <10 mio € in 1992–1994 to some 100 mio € in 2004–2006. Unfortunately, no IAS management and research data are available from 2007 onwards.

4. Discussion

4.1. Strengths and constraints of the proposed indicators

The application of the proposed IAS indicators faces substantial challenges of data availability and quality. The 'Combined index of invasion trends' is based on the number of a selected set of alien species that ideally should be representative for the region under consideration and their cumulative increase over time (Butchart et al., 2010; McGeoch et al., 2010). It therefore provides an estimate of the rate of increase (or decrease) for different environments and taxonomic groups combined. The index can be calculated for any region and different subsets of species, as long as sufficient data on years of first record are available. While it is straightforward to calculate trends in alien species numbers, this entails several difficulties. Currently, to avoid possible biases due to the non-consistent definitions on 'invasiveness' adopted by different sources (Genovesi et al., 2012a), this indicator is based on all alien species; although there is evidence showing a close correlation between numbers of established and invasive alien species, it is not necessarily so (e.g., Ricciardi, Hoopes, Marchetti, & Lockwood, 2013). In addition, the year of introduction often is unknown, which means that the sampling size is a subset of total alien species number in the region.

The most general separation in pathway terminology is between intentional and unintentional introduction, with the latter clearly prevailing in alien arthropods in Europe (86%, Rabitsch, 2010), but not in vascular plants introduced from outside Europe (37%, Lambdon et al., 2008). In case of intentional introductions, it is often known exactly when and where and sometimes how many individuals were introduced, whereas this is usually not known for species introduced unintentionally. A main limitation for populating the pathway indicator is that there is yet no standardized terminology for pathways which is consistently implemented in European alien species data repositories. Current efforts to harmonize pathway classifications by the Global Invasive Alien Species Information Partnership (GIASIPartnership; http://acronym.co.nz:8086) will likely improve this situation in the near future (CBD, 2014). Although species may use more than one pathway simultaneously, may change their pathways over time, may use them unexpectedly or even may use unknown pathways, the identification and prioritization of alien species pathways is pivotal for management (Hulme, 2009).

There is a well-known knowledge gap regarding the impacts of alien species (e.g., Jeschke et al., 2014; Kenis et al., 2009). Closing this gap and increasing the data base of well-documented impacts of IAS will serve different purposes including the RLI. The methodology of the RLI is perfectly applicable to IAS, but a second assessment period for the European Red Lists is necessary to calculate changes between categories. During the Red List assessments, different causes of threat are described, but currently there is no information of the severity of threat provided. Currently, impacts of alien species on native biota often are poorly documented and only described anecdotally (Jeschke et al., 2014). For example, the global Red List assessment of the Spanish Ribbed Newt (*Pleurodeles waltl*) has deteriorated from Least Concern (LC) (in 2004) to Near Threatened (NT) (in 2009) (IUCN, 2012). The text on the major threats to the species indicates that alien species are a cause of threat, but also other factors are relevant. Introduced fish and crayfish are known to prey on the eggs and larvae of this species, and are implicated in its decline. Assessing the severity of specific threats also allows comparison of different pressures over time and the relative role of IAS (Butchart et al., 2007, 2010).

The main disadvantage of the RLI is its low temporal sensitivity. Local extinction of populations does not necessarily translate into an immediate change of the Red List category. Also, few changes of Red List assessments may not affect the overall trend (in either direction) if sampling size increases, but may be disastrous for a single species (extinction). The application of the RLI of IAS at the European level could provide further incentives to elaborate more detailed information on the impact of IAS on native species, also allowing testing for the effectiveness of conservation measures.

For the indicator of IAS impacts on ecosystem services, the ongoing discussion on ecosystem services terminology is a substantial impediment. If ecosystem service-types are counted, any change of the typology affects the indicator. Here, the counts were made at the highest hierarchical levels, which may reduce sensitivity to changes in typology. Another limitation for the interpretation of the trend data is that the categories are not equidistant nor necessarily equally important. There are also considerable difficulties in understanding the relationships of some ecosystem services with biodiversity (e.g., Norgaard, 2010). For example, the impact (or economic costs) of alien species that are pests on crops or in

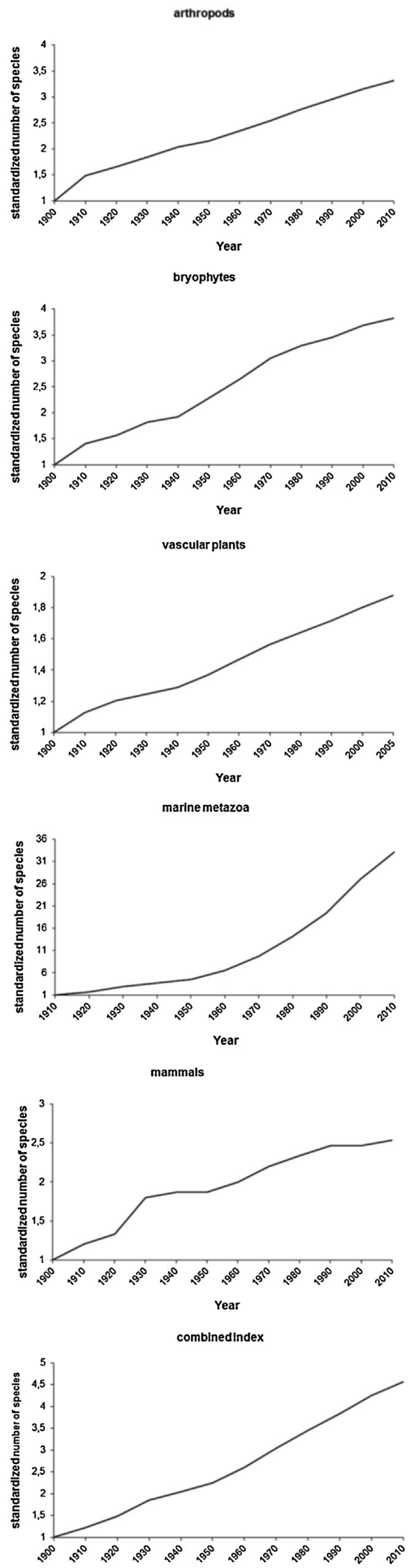

Fig. 1. Cumulative number of recorded alien terrestrial arthropods (n = 1424), bryophytes (n = 87), vascular plants (n = 3660), marine metazoa (n = 662), mammals (n = 38), and their combined index (n = 5871) in Europe between 1900 and 2010. Note that vascular plants data are only included to 2005 and that the geographical scope may differ slightly between the groups. Sources: (a) Roques et al. (2010); (b) Essl et al. (2013); (c) DAISIE project, J. Pergl, unpubl.; (d) VECTORS project, S. Olenin, unpubl.; (e) P. Genovesi, unpubl.

timber production may seriously affect provisioning services, but the consequences for biodiversity are hard to establish. The indicator presented here is tightly related to the overall increase of IAS in Europe, because the subset of analysed species was pre-selected for their known impacts. The method is unable to identify temporal delays between introduction or year of first record and realization of impacts on ecosystem services, which can be substantial, e.g., several decades for bryophytes (Essl, Steinbauer, Dullinger, Mang, & Moser, 2014). However, not all alien species have an impact so serious that ecosystem services may be affected. To increase robustness, more species should be assessed concerning their ecosystem services impact, which is also a pre-requisite for risk assessments within the new EU IAS legislation (EU, 2014; Genovesi et al., 2015).

Although ADNS infrastructure (reporting obligations, database, analytical tools) is well suited to develop a trend indicator on animal diseases caused by alien pathogens at the European level there are several shortcomings. An agreed list of such pathogens needs to be developed that best reflect the intended policy goals. ADNS covers livestock and not wildlife diseases and therefore there is no direct reference to the CBD-indicator 'Trends in incidence of wildlife diseases caused by invasive alien species'.

The indicator on 'Costs for alien species management and research' reveals a strong increase in perception and action in the scientific and applied fields. The increasing financial sums spent on IAS in Europe may also help translating complex ecological relationships into a currency understood by other fields. The major problem restricting a straightforward use of EU-financed project data is a partial lack of data which allow for the identification of IAS-relevant costs within the total lump-sum (the EC is currently developing a set of indicators to help identification of such costs within the newly adopted LIFE projects). The proposed indicator should be seen as a conservative estimate consisting of only two funding schemes. However, it is worth emphasizing that this information still represents a reliable indicator to assess IAS-related costs based on real experiences that can be used also for awareness raising (Scalera, 2009).

4.2. Relevance for policy and conservation and the way forward

The indicators we propose here for Europe cover different features of alien species introductions, spread, impacts and the

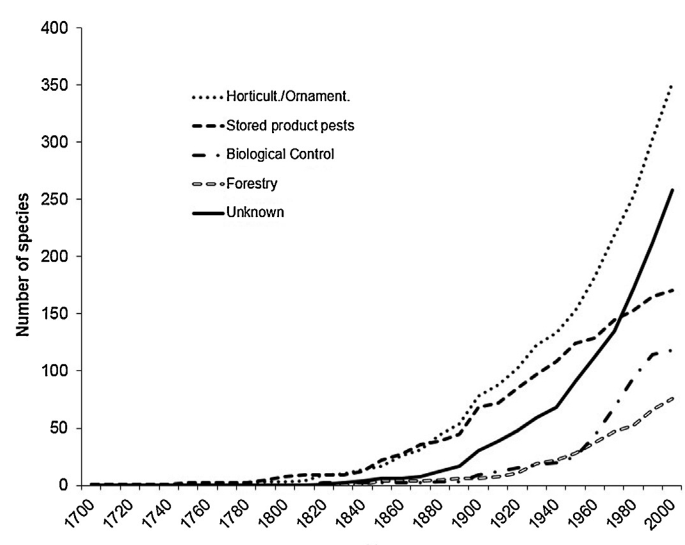

Fig. 2. Cumulative number of alien terrestrial arthropod species (n = 974) in Europe for selected important introduction pathways. Source: DAISIE project (J. Pergl, unpubl.).

ensuing societal response. Thus, they are capturing complementary features of biological invasions, and therefore each indicator is particularly relevant for specific IAS management and policy questions.

The 'Combined index of invasion trends' is a robust measure and conveys a general message, i.e., one of steadily increasing numbers of alien species in Europe. It is, however, only indirectly linked to policy goals, as the causal relationship between number of alien species and impact is not necessarily straightforward. On-going initiatives to update alien species data in Europe may further improve the data base for this indicator within the next years at the European and global level (McGeoch et al., 2006; Tittensor et al., 2014).

Identification, prioritization and regulation of pathways lies at the heart of successful IAS-management. This is acknowledged by Aichi Target 9 of the Strategic Plan of the CBD, Target 5 of the 'EU Biodiversity Strategy 2020' (EC, 2011) and the new EU IAS legislation (EU, 2014). Based on an increasing amount of pathway introduction data for Europe (e.g., Bacon, Bacher, & Aebi, 2012; Maceda-Veiga, Escribano-Alacid, & García-Berthou, 2013), it is feasible to develop a robust pathway indicator within the next years. It is not yet clear how the requested action plans on unintentional pathways, to be developed by Member States within the new EU legislation on IAS (EU, 2014), will provide sound data useful for an indicator, but any guidance provided by the EU should bear in mind this potentially

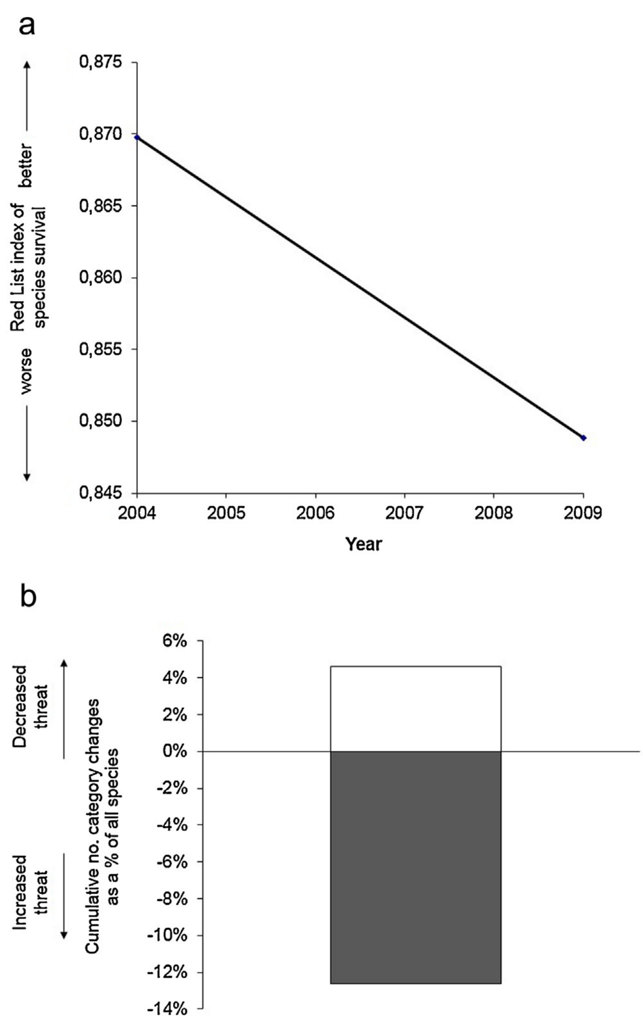

Fig. 3. (a) Changes in the Red List Index (RLI) of European amphibian species (based on data from IUCN, 2012) between 2004 and 2009. RLI values relate to the proportion of species expected to remain extant in the near future without conservation action. An RLI value of 1.0 equates to all species being categorized as Least Concern, and hence that none are expected to go extinct in the near future. An RLI value of zero indicates that all species will have gone extinct. A downwards trend in the graph line (i.e., decreasing RLI values) means that the expected rate of biodiversity loss is increasing. (b) Cumulative percentage of European amphibian species undergoing genuine Red List category changes on the global Red List (IUCN, 2012) between 2004 and 2009. The Red List status of four European amphibian species (5% of all species) improved between the assessments of 2004 and of 2009 (decreased threat), whereas the status deteriorated in 11 species (13% of all species) (increased threat). IAS are considered as relevant threats for 8 of these 11 species.

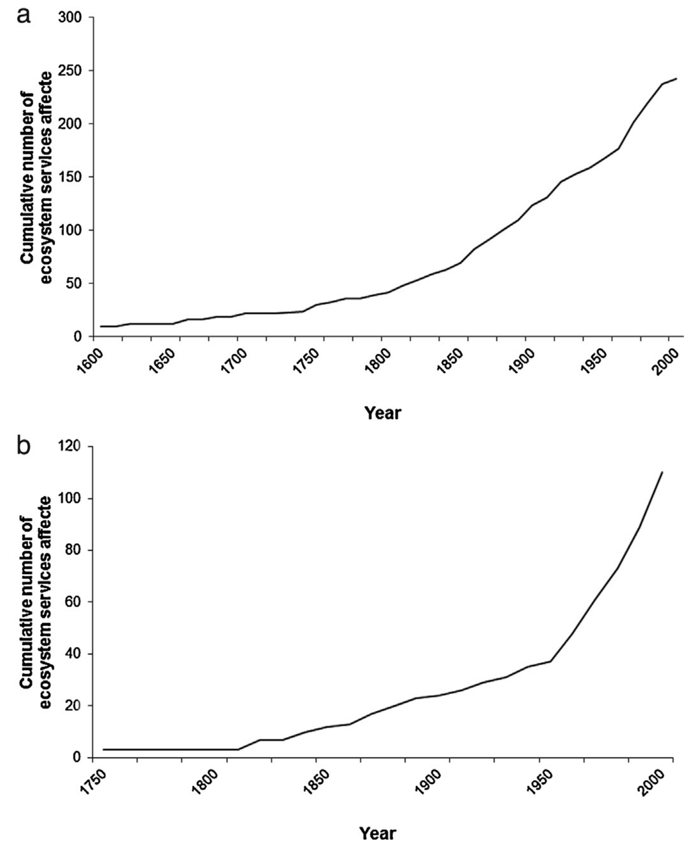

Fig. 4. Cumulative number of ecosystem services affected by IAS for (a) the DAISIE list of the '100 of the worst' IAS (Vilá et al., 2010) and (b) the '80 representative alien terrestrial arthropod species' (Roques et al., 2010). Details are given in Appendices A and B in Supplementary material.

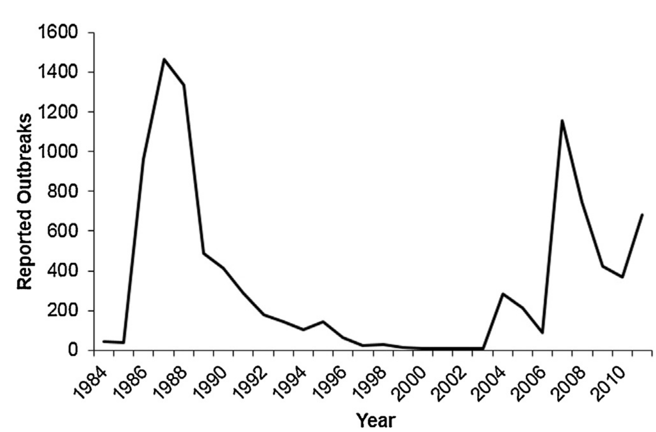

Fig. 5. Number of reported outbreaks per year of selected livestock animal diseases caused by alien pathogens (African swine fever, Dourine, Equine encephalomyelitis, Equine infectious anaemia) in Europe (EU28, Andorra, Faroe Islands, Norway and Switzerland) between 1984 and 2011 as documented in the annual reports to ADNS (2012).

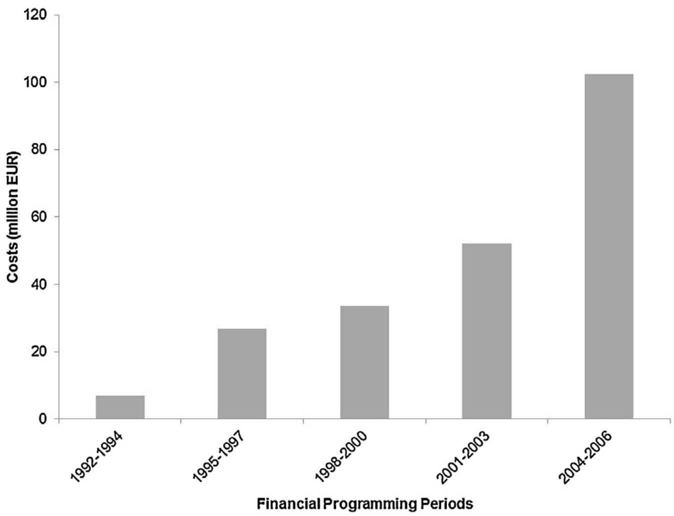

Fig. 6. Costs (million EUR) spent within LIFE and FP projects dealing with IAS since 1992 in Europe. Modified from Scalera (2009).

useful resource. This also includes harmonized terminology and consolidated data flow.

The RLI allows quantifying the impacts of alien species on the conservation status of native species. It is probably the most intuitive of all alien species indicators, which serves well for public awareness and communication to media and stakeholders. In addition, it is directly linked to policy goals (headline targets of the CBD and the EU biodiversity strategy, Appendix C in Supplementary material) and to the threats that IAS may pose on native species. The RLI demonstrates that IAS contribute to the deterioration of species survival not only worldwide (Butchart, 2008; McGeoch et al., 2010), but also in Europe.

The 'IAS and ecosystem services' indicator assigns affected ecosystem services to alien species and their year of first introduction into a region, and thus is a simplified measure of the trend over time. The UNEP-WCMC (2011) proposed four possible IAS indicators tailored to Aichi Target 9 that relate to ecosystem services (e.g., 'Dollar value impact of IAS on crops (pests/disease/pollinators) or % yield'), while admitting that these indicators need further development. An indicator which shows IAS impacts on ecosystem services is therefore directly related to achieving the goals of the EU Strategy and the CBD. The general relationship between ecosystem services and their use as ecological indicators (as 'impact component' within the DPSIR framework) was discussed recently by Müller and Burkhard (2012). Developing indicators based on real money investments however is a challenging task. The indicators proposed by UNEP-WCMC on ecosystem services focusing on real money investments or losses are ambitious, but probably not realisable by 2020. Even a simple measure, such as costs due to impact of IAS on crops, requires a range of different quantitative data and standardization across data. A simplified approach, as suggested here, has its own shortcomings, and should be seen as only indirectly related to policy goals, but eventually can be elaborated within a shorter time. By all means, an agreed ecosystem services classification is required that avoids redundancy when counting services (e.g., TEEB, 2010; http://cices.eu/).

Although of high policy relevance, no methodology for an 'Indicator on trends in livestock diseases' is currently available. Notably, existing notification systems do have a different mandate and focus on domestic animals and livestock rather than wildlife diseases. Considering the CBD and EU biodiversity strategy commitments, it is recommended to develop a methodology for an indicator targeting this policy question within the next years.

The indicator on 'Costs of IAS-management and research' in Europe should be updated with data of the funding period 2007–2013. We recommend that any EU funded project targeting IAS should be adequately flagged to facilitate further analysis as it is currently done with other topics, e.g., climate change.

5. Conclusions

All IAS trend indicators show that numbers and impacts of alien species are increasing in Europe across all taxonomic groups and environments without any signs of saturation in alien species accumulation. This finding is in line with global trends (McGeoch et al., 2010; Tittensor et al., 2014). Trend and response indicators are crucial for assessing if the targets agreed under the Strategic Plan 2020 of the CBD and the EU biodiversity strategy will be met. IAS data quality and availability in Europe has much improved over the last decade, putting Europe in an excellent position to showcase the potential of IAS indicators. As such, the IAS indicators presented here serve as a starting point for future improvements, and as a basis for monitoring the efficacy of the EU legislation of IAS (EU, 2014).

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jnc.2015.12.001.

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