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Monitoring Trends in Biological Invasion, its Impact and Policy Responses

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Introduction

Biological invasions are a major threat to biodiversity, second only to habitat change (Millennium Ecosystem Assessment, 2005), and have been a primary cause of species extinction over the last 500 years (Donlan *et al.*, 2008). For example, invasive alien species are cited as a factor in over 50% of animal extinctions where the cause is known, and for 1 out of every 5 (20%) of extinctions, invasions were the only cited cause (Clavero and Garcìa-Berthou, 2005). Invasive alien species (IAS) are also among the most important threats to globally threatened species. Invasives are the second most important threat to birds, impacting 52% of Critically Endangered species and 51% of all threatened species (BirdLife International, 2008a, 2008b). They are the fourth most important threat to threatened amphibians (possibly even underestimated owing to uncertainty over the origin of chytridiomycosis), and third most important for threatened mammals (Hilton-Taylor *et al.*, 2009). Furthermore, invasions cause huge economic losses – e.g. costs in Europe exceed 12 billion euros per year (Kettunen *et al.*, 2009) – they are responsible for the spread of many diseases, and can disrupt ecosystem services of crucial importance for human well-being, such as food security and access to water (Vilà *et al.*, 2010).

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The number of invasive alien species appears to be increasing in all environments and among all taxonomic groups, with numbers in Europe increasing 76% over the period 1970–2007 (Butchart *et al.*, 2010) – an upward trend that has proven difficult to halt, let alone reverse (DAISIE, 2009; Millennium Ecosystem Assessment, 2005). Prevention of further unwanted introductions is a high priority, and by far the most efficient approach to limiting further invasions. The development of global early warning and rapid response policies (G8, 2009), effective documentation and monitoring of trends, and assessment of the factors correlated with introduction and establishment of invasive alien species are all required to improve our ability to respond to alien species invasions.

The global community has committed to prevent and mitigate the impacts of invasive alien species, and to monitor trends in invasions. In particular, the Convention on Biological Diversity (CBD) has called upon parties to identify invasive alien species, assess the history and ecology of invasion, the origin of alien species, the pathway of arrival, the timing of introduction, the biology of the invaders, and the impacts upon the environment and human well-being, and to monitor temporal trends in these parameters (Decision VI/23 CBD COPVI, The Hague, April 2002). This large body of information is crucial not only for the development of more effective policy and implementation, but is also valuable for testing the efficacy of efforts invested in response to the invasion problem.

Review of indicators of invasions

Following increasing recognition of the impacts of invasive alien species, there have been several attempts to develop indicators of invasion over the last decade (see review in McGeoch *et al.*, 2006). Indicators have been developed across a range of spatial scales and have been based on a range of measures, including the percentage of area covered by alien plant species (Heinz Center, 2002), the density of managed weeds (Natural Heritage Trust, 2006), the distribution and abundance of selected alien species in parks (Parks Canada, 2005), the increase in aquaculture-related introduced species in European marine environments (EEA, 2003), and the percentage of invasive alien species in selected groups (UNEP, 2003). However, there have until recently been very few examples of indicators of invasion that are based on a range of taxa, cover large spatial scales, assess temporal trends in invasions, or consider impacts of invasive species. We discuss attempts to develop such indicators at global, regional, and national scales.

Development of global indicators for biological invasion

At the global scale, development of indicators followed the CBD Decision VI/26 of 2002, which included a commitment to achieve by 2010 a significant reduction of the rate of biodiversity loss. To assess progress against these targets, the CBD initially identified two potential indicators of the threats to biodiversity: nitrogen deposition and 'numbers and cost of alien invasions'. At the 10^{th} meeting of the CBD's Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA), held in 2005, it was agreed to use 'trends in invasive alien species', in addition to nine fully developed biodiversity indicators and an additional seven considered ready for testing (Walpole *et al.*, 2009). As a follow-up, the CBD secretariat in 2006 asked the Global Invasive Species Program (GISP) and the International Union for the Conservation of Nature-Species Survival Commission (IUCN-SSC) to produce a global indicator for biological invasions. For this purpose the CBD's definition of an alien invasive species was used, namely 'a species outside of its [indigenous geographical] range whose introduction and/or spread threatens biodiversity' (UNEP, 2002). Following a review of a range of candidates, the development of four indicators was prioritized in light of data availability and the practicality of reporting against the 2010 target (McGeoch *et al.*, 2009). These comprise a measure of the state of the problem (the number of IAS per country), a measure of the pressures IAS place on biodiversity (the Red List Index of impacts of IAS), and two measures of responses to the problem (trends in the number of international agreements relevant to reducing threats to biodiversity from invasive alien species, and trends in the adoption of national legislation relevant to the control of IAS) (McGeoch *et al.*, 2010).

The number of invasive alien species per country

One of the primary purposes for an invasive alien species indicator is to measure the status of invasion and to monitor change therein. In principle, the number of IAS is a direct and simple 'problem-status' indicator (McGeoch *et al.*, 2006). The rationale for using numbers of IAS is that the identification and designation of species as invasive is often critical for designing and prioritizing control and prevention efforts. There is, however, considerable variation in the amount of available information on IAS in different countries (Figure 7.1). Plants make up over 40% of documented IAS, followed by insects and other invertebrates (over 30%), fish, mammals, and birds (Pyšek *et al.*, 2008). However, there are also large differences in data adequacy between species groups. For example, invasive alien birds and mammals are comparatively well known, whereas invasive invertebrates are much more poorly known, and marine invader diversity is thought to be underestimated by up to 90% in many parts of the world (Carlton, 2008).

The number of documented IAS is undoubtedly an underestimate for many countries globally. Reasons for this include under-sampling, the time delay between identification of a new IAS and publication in national species lists, as well as inadequate information availability, and little investment in research on IAS in many instances (McGeoch *et al.*, 2010). To assess the levels of information available, countries (those signatory to the CBD and members of the United Nations) were classified as data

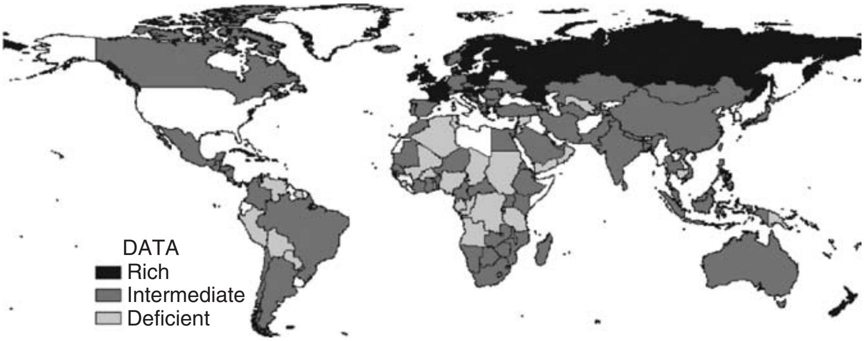

Figure 7.1 **Status of Invasive Alien Species information for countries signatory to the Convention on Biological Diversity. With permission from John Wiley & Sons.**

deficient if they were found to have comparatively little published work on IAS (Pyšek *et al.*, 2008), and National Reports to the CBD stating that the country had not identified IAS, or assessed the risks posed by IAS, in the country. Data-rich countries, on the other hand, were those with comparatively substantial published work on IAS and/or those countries that had listed and in some cases also assessed the risks of IAS. Countries assessed to be data deficient in this way do in fact have significantly fewer listed and reported IAS than data-rich countries (McGeoch *et al.*, 2010). Less than 11% of countries are considered to have adequate data on the IAS present, with almost one-third considered to be data deficient (31%) (see Figure 7.1). This means that the size of the global IAS problem is currently significantly underestimated quantitatively. Nonetheless, controlling for these data biases, island-based countries were shown to have more IAS than their continental counterparts and, as expected, numbers of IAS are positively related to country size (McGeoch *et al.*, 2010).

Although the number of IAS forms a necessary basis for monitoring the status of the invasion problem, trend data are currently not available at a global scale. In addition to the shortage of information in several parts of the world for populating the indicator, variation in criteria used to designate species as invasive as well as delays and biases in species discovery and reporting mean that the construction of a global trend in the size of the problem is currently not possible (Costello and Solow, 2003; Crooks, 2005).

Nevertheless, there are several efforts to monitor trends in invasions at regional and national scales. In Europe, the European Union Council adopted a more ambitious target than the CBD 2010, committing to halt the biodiversity decline in Europe by 2010. In parallel, a European programme was developed to measure the achievements in regard to this commitment, and the European Environment Agency coordinated the development of an indicator-based assessment of European biodiversity – SEBI2010 – that includes invasive alien species as a key variable (EEA, 2009a, 2009b). The SEBI2010 invasive species indicator is the only regional indicator developed to date, and is the 'cumulative number of alien species in Europe since 1900'. This is also the first dataset (containing data for five countries) to contribute to the development of a general indicator of trends in IAS for Europe (ECCHM, 2005). The indicator is based on 163 species identified by a group of experts as causing severe impacts to biological diversity, as well as to health or economy (EEA, 2009b) and illustrates the most invaded countries of the region (Figure 7.2).

The European response to measure the impact of IAS has been further enhanced through the completion of the DAISIE (Delivering Alien Invasive Species Inventories for Europe) project funded by the European Commission (2005–2008). Although not specifically aimed at monitoring trends in invasions, DAISIE provides an inventory of alien species (invasive and non-invasive) recorded in European terrestrial, freshwater, and marine environments. DAISIE was carried out by a team of 18 European scientific institutions and has established the most comprehensive database worldwide on introduced species. The DAISIE database has collated information on over 11 000 introduced species of fungi, plants, vertebrates, and invertebrates, and of more than 50 000 records of introductions. All data have been assembled and verified by leading experts. The database includes information on year of introduction, pathway and vectors of introductions, and documented environmental or socio-economic impacts.

The major findings of the DAISIE project have been synthesized (DAISIE, 2009) to demonstrate that precise and detailed trends in invasions across a range of taxonomic

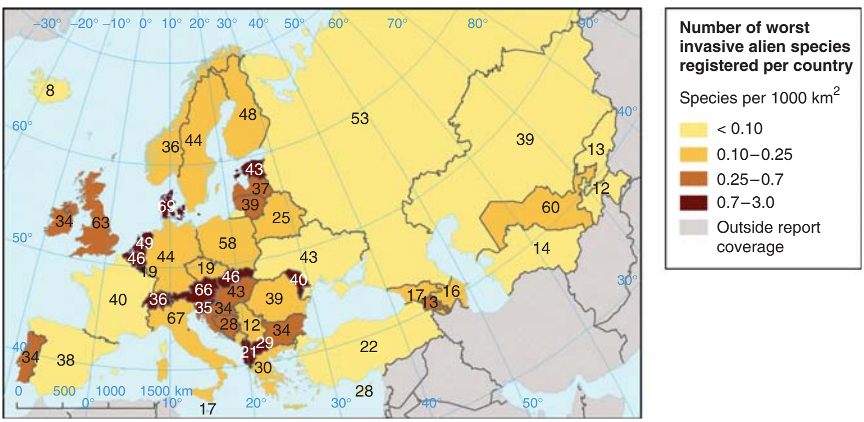

Figure 7.2 **Number of 'worst' terrestrial and freshwater invasive alien species (IAS) threatening biodiversity in Europe. List identified through an assessment process carried on by the Streamlining European Biodiversity Indicators (SEBI) 2010 expert group. From European Environment Agency (2009). Reproduced with permission.**

groups can be measured. This is made possible by three key aspects of the DAISIE dataset: the existence of a comparatively good history of taxonomic record-keeping dating back several decades (and in some cases centuries), the coverage of *all* alien species, not only those that are described as 'invasive', and the inclusion of a date or period of introduction to enable trends over time to be derived.

To provide some examples of the results that this approach permitted, Figure 7.3 reports the trend in established alien invertebrate species in Europe since 1492, expressed as the mean number of alien invertebrates recorded per year.

DAISIE (2009) reports even more detailed trend information for other taxonomic groups such as mammals (Figure 7.4), where it was possible to distinguish between trends of introduction events, and cumulative numbers of new species for Europe.

An integrated analysis of invasion trends in Europe – produced by combining the DAISIE datasets on alien mammals, alien species in European freshwaters, and alien species in the Mediterranean basin – estimated that the numbers of aliens in Europe increased 76% during 1970–2007 (Figure 7.5; Butchart *et al.*, 2010).

Another example of the potential of a retrospective approach is shown in Figure 7.6, which highlights the rate of arrival of new mammal species in Europe over four periods (based on the DAISIE dataset), providing a clear indicator of the patterns of invasion in this taxonomic group.

The DAISIE dataset also allows for much more detailed information on key correlates of introductions, crucial for enforcing response measures, such as the pathways

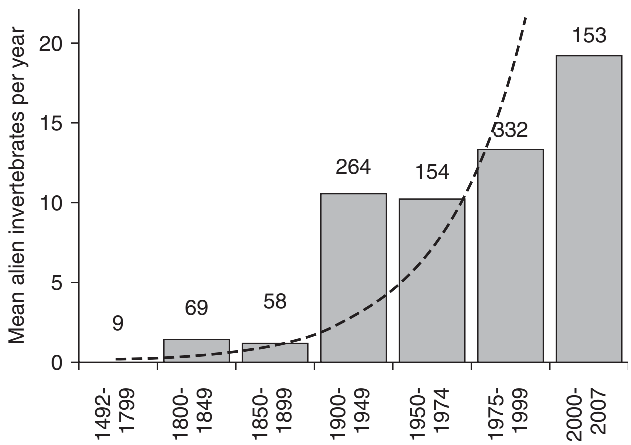

Figure 7.3 **Trends in established alien terrestrial invertebrates in Europe since 1492. Calculations made on 995 species for which precise estimates are available for the first record. The numbers above the bars correspond to the number of new species recorded per period (source: Roques *et al.*, 2009) With kind permission of Springer Science+Business Media.**

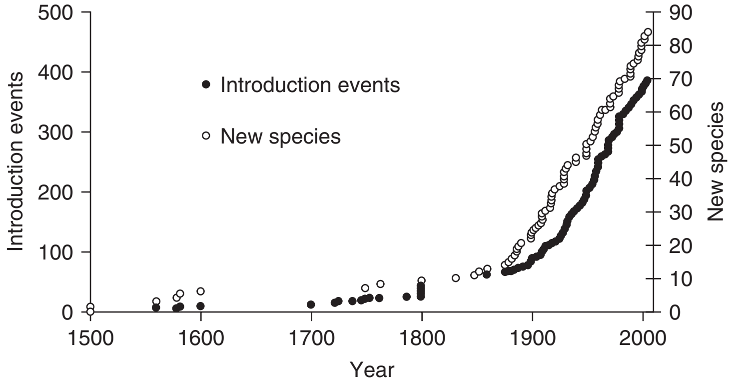

Figure 7.4 **Trends of mammal invasions in Europe: number of introduction events and of new species for Europe recorded since 1500 (source: Genovesi *et al.*, 2009) With kind permission of Springer Science+Business Media.**

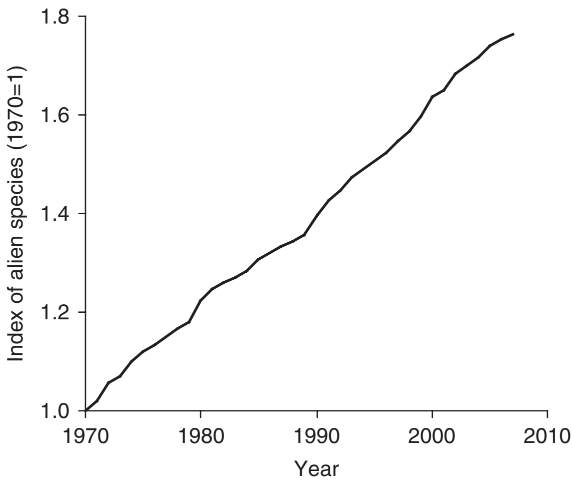

Figure 7.5 **Index of trends in number of alien species in Europe during 1970–2007. From Butchart *et al.*, 2010.**

of arrival (i.e. Figure 7.7). These data show that in recent times the intentional release or escape from captivity of IAS are by far the most common causes of introduction for mammals, and thus demonstrate the importance of more stringent rules on the import of species and on containment facilities.

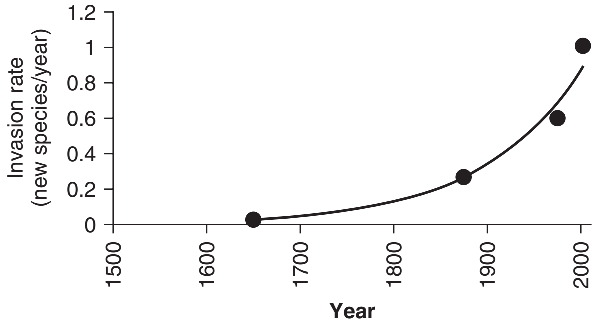

Figure 7.6 **Rate of arrival of alien mammals per year in Europe in four periods: 1500–1800; 1800–1950; 1950–2000; and 2000–2005 (source: Genovesi *et al.*, 2009) With kind permission of Springer Science+Business Media.**

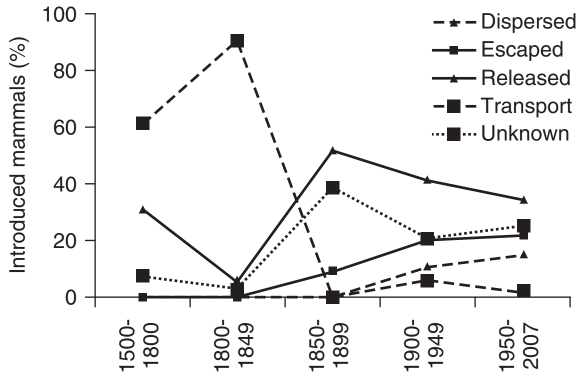

Figure 7.7 **Trends in the modes by which mammal IAS were introduced to Europe (source: Genovesi *et al.*, 2009) With kind permission of Springer Science+Business Media.**

Furthermore, the DAISIE approach, based on retrospective counts, appears to effectively minimize the biases due to the level of available information. For example, if we look at the number of alien marine species for Europe (Figure 7.8), the retrospective count approach highlights the trough in the 1980s in the number of alien species introduced per year in the Mediterranean. This was due to the temporary closure of the Suez Canal, and to the Arab oil embargo, that much reduced the number of vessels transiting the Mediterranean.

The pan-European inventory of alien species created through DAISIE provides a platform for European reporting on biodiversity indicators and highlights areas where

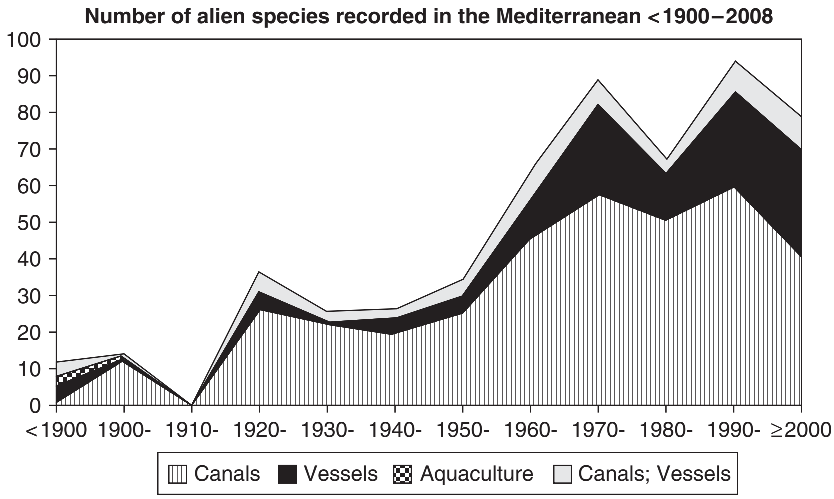

Figure 7.8 **Number of alien species recorded in the Mediterranean Sea (new recorded species by decade), 1900–2007, and their means of introduction (source: Galil, 2009) With kind permission of Springer Science+Business Media.**

Europe will need to direct resources to manage biological invasions. As such it can act as a template for the future development of global indicators.

At a smaller spatial scale, a number of countries reporting to the CBD have established national monitoring programmes for one or more IAS, and have developed national indicators. The United Kingdom, for example, has a number of monitoring programmes, many of which detect the abundance and distribution of alien species, although none are specifically targeted towards monitoring them. Data from five schemes have been combined to measure trends in the proportion of alien (non-native) species in survey samples for birds, mammals, plants, and marine organisms. The index covers trends in Great Britain; data for Northern Ireland were not available. The index (Figure 7.9) shows an increase in the proportion of non-native species (samples from populations of birds, mammals, plants, and marine organisms) in the period 1990–2007, suggesting that alien species are becoming more widespread and/or relatively more abundant.

A second indicator has been developed in the United Kingdom to measure the change in the extent of invasive species. Out of 3500 alien species identified, the 49 with the greatest potential impact on native biodiversity were identified using expert judgment based upon a set of standardized assessment criteria (adapted by the Belgian Forum on Invasive Species; http://ias.biodiversity.be/ias/definitions#harmonia). The number of species identified as highly invasive (i.e. of greatest threat to native biodiversity)

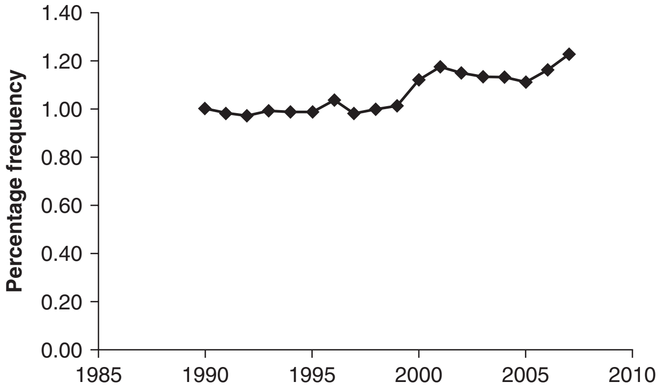

Figure 7.9 **Overall proportion of non-native species in samples of birds, mammals, plants, and marine organisms, 1990–2007 in the United Kingdom (data for Great Britain only). Redrawn from http://www.jncc.gov.uk/page-4246; From the Centre for Ecology & Hydrology, British Trust for Ornithology, Marine Biological Association and the National Biodiversity Network Gateway. © Crown copyright 2011.**

established across more than 10% of the land area of Britain has increased in all ecosystems (freshwater, marine, and terrestrial) (Figure 7.10).

Although such an approach is currently not feasible in many regions of the world, the UK indicators demonstrate the value of standardized monitoring schemes for measuring the status of biodiversity and the adoption of objective systems for classifying alien species as invasive.

The Red List Index of impacts of IAS on biodiversity

The second global indicator for IAS shows trends over time in the impact of IAS on biodiversity using the Red List Index (RLI). Figure 7.11 shows an example for birds, illustrating the overall rate at which birds worldwide are moving towards or away from extinction owing to the balance between the negative impacts of IAS on species and the positive impacts of conservation actions tackling IAS. It is based on repeated assessments of all birds for the IUCN Red List (which have been carried out by BirdLife International for IUCN five times during 1988–2008). Red List categories are assigned to species based on application of quantitative data (relating to the size, structure, and trend of both the population and distributional range) to explicit criteria with quantitative thresholds. Assessments require parameter estimates to be fully documented with sources and explicit estimates of uncertainty (IUCN, 2001, 2010). Only those changes to Red List categorizations resulting from genuine

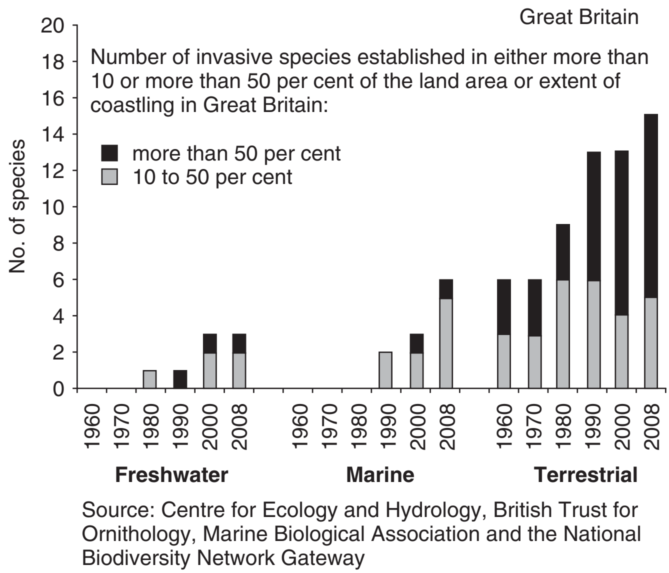

Figure 7.10 **Changes in the number of moderately and very widely established IAS in freshwater, marine, and terrestrial environments, 1960 to 2008 (http://www.jncc.gov.uk/page-4246). From the Centre for Ecology & Hydrology, British Trust for Ornithology, Marine Biological Association and the National Biodiversity Network Gateway. © Crown copyright 2012.**

improvement or deterioration are included in the RLI (category changes driven by improved knowledge or revised taxonomy are excluded). For all genuine category changes, the primary driver (i.e., threat leading to deterioration in status, or threat overcome by conservation action leading to improvement in status) is identified, and the overall decline in the RLI is then apportioned to different primary drivers, with the thickness of the 'slice' indicating the importance of each particular driver (see Butchart, 2008, and McGeoch *et al*., 2010, for further details). Determining the primary driver of category changes is facilitated by the fact that the magnitude of each threat to each species on the Red List is calculated according to its estimated scope (i.e. proportion of the population affected by the threat) and severity (rate of population decline over three generations driven by the threat within the scope), plus the fact that detailed documentation is associated with each genuine status change.

The RLI illustrates the relative importance of IAS compared to other threats to biodiversity. It shows that since 1988 the number of species improving in status as a consequence of successful eradications or control of IAS has been outweighed by the number of species deteriorating in status owing to negative impacts of IAS, leading to a negative overall trend in the RLI for impacts of IAS (Figure 7.11). Comparison with

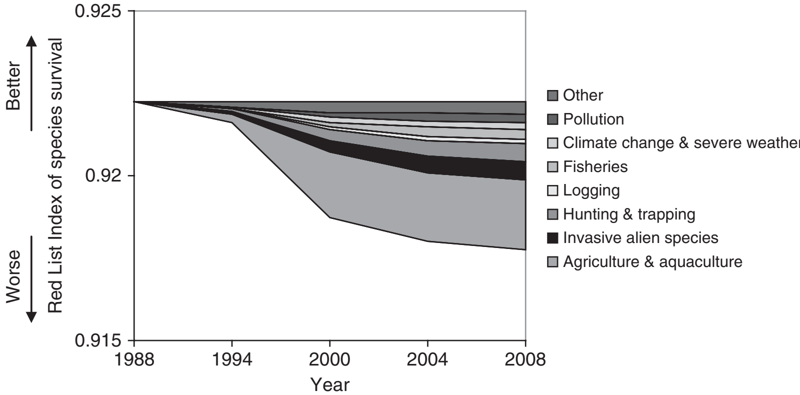

Figure 7.11 **Red List Index (RLI) for birds showing trends driven by the impacts of invasive alien species (IAS) compared with trends driven by other factors, for the proportion of species expected to remain extant in the near future without additional conservation action; *n* = 9785 non-data-deficient extant bird species at start of period. 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 have gone Extinct. The coloured slices show the contribution of different drivers to the overall deterioration in the status of species over the time period. With permission from John Wiley & Sons.**

the magnitude of declines driven by other factors shows that while IAS are among the most important threats to birds, agriculture and aquaculture have had a larger overall negative impact since 1988 (see McGeoch *et al.*, 2010 for results for mammals and amphibians).

This approach can be applied to any group of species on the Red List that has been comprehensively assessed (i.e. all species have been categorized) at least twice. In due course, similar RLIs will be available for corals, cycads, conifers, and a number of other groups, plus for representative samples of a suite of additional taxonomic groups (for which comprehensive reassessments will be challenging owing to the large number of poorly known species) to provide indices more representative of all biodiversity.

Trends in the number of countries party to international agreements relating to invasive alien species

In addition to the CBD, several international agreements either explicitly consider IAS or are relevant to preventing IAS introductions and controlling exiting IAS. Examples of such agreements include the United Nations Convention on the Law of the Sea, the International Plant Protection Convention, and the Protocol on Environmental

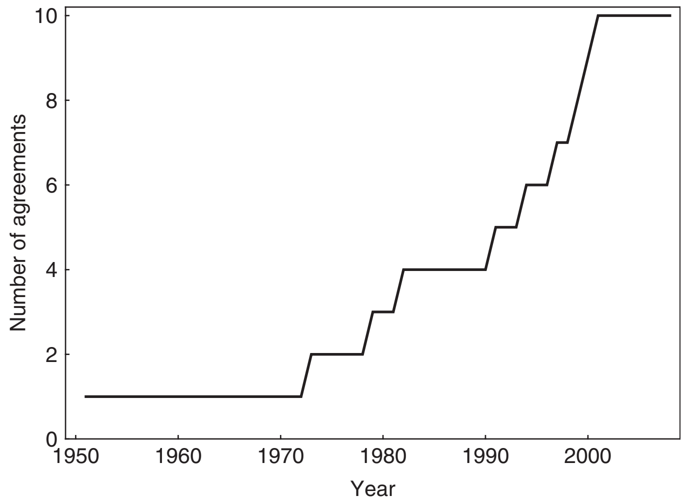

Figure 7.12 **Trends in the number of international agreements relevant to reducing threats to biodiversity from invasive alien species (excluding the Convention on Biological Diversity) (modified from McGeoch *et al.*, 2010, with permission from John Wiley & Sons.).**

Protection to the Antarctic Treaty (McGeoch *et al.*, 2010). None of these agreements were promulgated with the primary intention of reducing the rate of biodiversity impacts from IAS. There has, however, been a significant increase in the number of such IAS-relevant international agreements since the 1950s (Figure 7.12).

Trends in the adoption of national legislation relevant to the control of IAS

There has also been an increase in the development and adoption of policy to control IAS at the national scale over the last two decades (Figure 7.13). Among countries reporting to the CBD, over 80% have national biodiversity strategies and action plans, whereas far fewer have legislation pertaining to the prevention or control of IAS (Figure 7.13). Countries with IAS-relevant policies are assumed more likely to achieve the Convention on Biological Diversity (CBD) Framework Goal of controlling invasive alien species than countries without such policies. However, policy does not necessarily translate into management effectiveness, prevention, or control of IAS (McGeoch *et al.*, 2006). It is therefore insufficient for evaluating the degree to which countries have managed to control pathways for major potential IAS introductions, or whether countries have management plans in place for major alien species that threaten biodiversity. There is thus a need to collate information more directly relevant

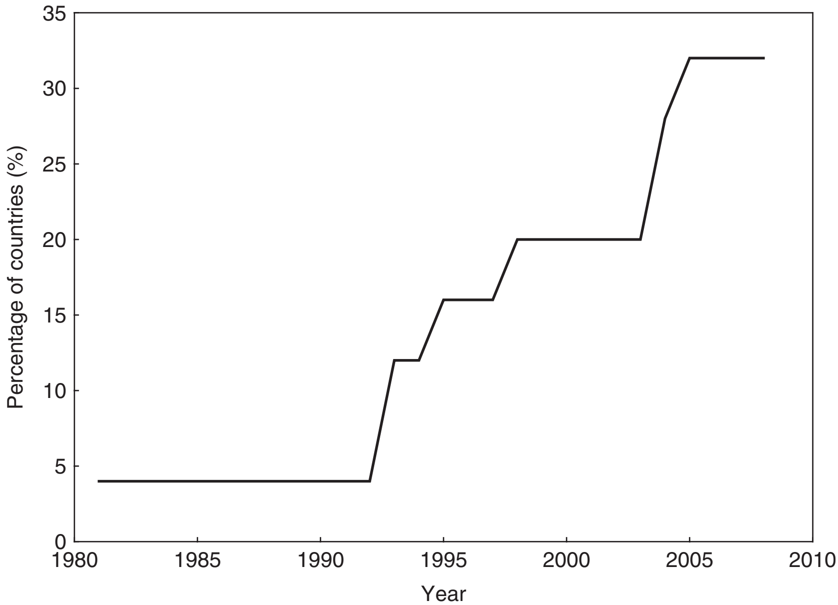

Figure 7.13 **Trend in the adoption of national legislation relevant to the control of invasive alien species by a stratified random subset of countries reporting to the Convention on Biological Diversity. With permission from John Wiley & Sons.**

to management effectiveness of IAS, such as numbers of species successfully controlled and reductions in extent of IAS (McGeoch *et al.*, 2010).

While policy progress towards management of the IAS problem has apparently been significant at both international and national levels, it is currently not possible to assess the efficacy of such policy at reducing the rate at which new IAS are being introduced or establishing worldwide. In fact, trends in the impact of invasive species demonstrate that, in an important way, policy interventions have not been successful. Future efforts by nations to document progress towards achieving IAS targets may shed light on the current mismatch between significant improvements in international and national policy adoption, and ongoing increases in the threat to biodiversity from IAS.

Technical challenges to the development of invasion indicators

Developing indicators to track trends in invasions poses several challenges. Of primary importance is the need for indicators that encompass a range of environments (from marine, to freshwater and terrestrial) and taxonomic groups (from plants to animals; from vertebrates to invertebrates, etc.) that are affected by biological invasions. In particular, global indicators need to be developed further to incorporate information from a broad suite of taxonomic groups to reduce potential bias. One of the features of the substantial variation in the amount and reliability of available information on alien species (Pyšek *et al.*, 2008; Hulme, 2007) is that some taxonomic groups are much better known than others (e.g. vertebrates vs invertebrates). To be more representative, indicators should ideally take such bias into account when collating information on alien species in different taxonomic groups. To illustrate the uneven representation of alien species between taxonomic groups (acknowledging differences in the total species richness between groups), the alien species reported for Europe include 2260 alien terrestrial invertebrates, 737 alien multicellular marine species, and only 45 alien bryophytes (DAISIE, 2009).

Initiatives to develop indicators of invasion started only recently, and until recently (McGeoch *et al.*, 2006, 2010) in most cases have been developed at a local scale. Some of the key technical challenges to developing a global indicator of the status of invasions include the difficulty of designating alien species as invasive, treatment of geographical and taxonomic bias in data availability, the use of a wide range of definitions and criteria for designating species as invasive, the accessibility of data, and problems associated with expert opinion (McGeoch *et al.*, 2009; 2010).

The problem of classification of an alien species as invasive is one of the most crucial issues in the development of indicators. The Convention on Biological Diversity defines an invasive alien species as: a species outside of its native range whose introduction and/or spread threatens biodiversity. This definition does not explicitly include alien species affecting economies and human health, such as those included in the development of a European indicator (EEA, 2009b), even if the definition of biodiversity adopted by the CBD does make reference to the ecosystem services, and could thus cover the effects of invasives on human livelihood. This unclear definition of invasiveness could limit the comparability of future indicators from the regional to the global scale. But the problem of definition is indeed wider than this. The confusion in invasions terminology, and the lack of agreed concepts, have often been highlighted (e.g. Occhipinti-Ambrogi and Galil, 2004; Richardson *et al.*, 2000; Valéry *et al.*, 2008). The different terminologies proposed by various authors are primarily due to the different concepts of invasiveness, based on either biogeographical or impact criteria, that only consider environmental effects, or also include impacts on economy or other non-biological parameters. The effects of the inconsistency in the terms and concepts adopted in different contexts explain the large difference in the number of species listed as invasive within Europe. It must be stressed that the lack of a unanimously agreed definition of IAS does affect the development of reliable indicators. For example, for the same geographical region, EEA (2009b) identified 163 species as invasive, while Vilà and co-authors (2010) reported 1094 alien species of

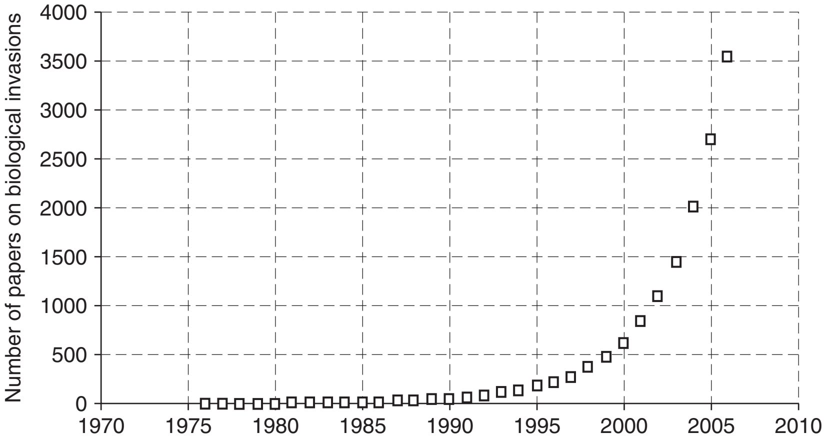

Figure 7.14 **Growth in the number of papers in invasion ecology published up to 2006 and registered on the Web of Science (Richardson and Pyšek, 2008). With permission from John Wiley & Sons.**

Europe known to cause some impacts to biological diversity, and 1347 known to cause some economic impacts.

Lack of data has several effects on indicators, and one of these is that alien species' invasiveness tends to be underestimated because of a lack of data on both invasive and native species, difficulty in the detection of impacts, and unclear criteria for interpreting what constitutes an impact (Vitule *et al.*, 2009; McGeoch *et al.*, 2010). A lack of data on invasiveness of a species could be misinterpreted as that species not being invasive, but may well be misleading (Leprieur *et al.*, 2009). As a consequence, interpretation of the number of IAS for an area only partly depends on the number of invasive species present, but depends much more on the available information – although this is rapidly increasing in some cases (Figure 7.14). Therefore, a crucial challenge in the development of indicators is to distinguish between a real increase in invasions as opposed to improvement in knowledge of invasions (Costello and Solow, 2003).

Another aspect to be considered is that the problem of definitions applies not only to the term invasive, but also to the criteria adopted for selecting the lists of considered species. For example, the use of terms such as 'casual', 'occasional', 'cryptogenic', and 'established' differ in different projects, and this can affect the results in terms of number of species (e.g. over 30% of marine species are of cryptogenic origin; Carlton, 1996).

If indicators are also meant to support more effective responses to invasion, then monitoring efforts need to cover not only the biological patterns of invasions (number of invaders and geographical patterns of spread), but also the impacts they cause (e.g., on threatened species or economic losses), as well as the drivers and correlates of invasion (e.g., trade volumes, pathways of arrival, geographical origin of invaders, correlates of establishment success, etc.) (Jeschke and Genovesi, 2011; Hulme *et al.*, 2008; Pyšek *et al.*, 2010). Understanding the latter permits more effective responses.

Discussion and conclusions

Biological invasions are a major threat to biological diversity and to human well-being (Vilà *et al.*, 2010; McGeoch *et al.*, 2010), affecting all regions of the world, and all ecosystems (Millennium Ecosystem Assessment, 2005; Vié *et al.*, 2009). The number of documented IAS is increasing rapidly, and this is unlikely to be solely because IAS are becoming better documented. The number of alien species appears to be rapidly growing in all taxonomic groups, with no signs of slowing down (Butchart *et al.*, 2010; DAISIE, 2009). Encouragingly, there has been an increase over time in the adoption of international and regional conventions and agreements related to IAS, and of national legal frameworks to address this issue. Furthermore, the technical ability to manage (control or eradicate) IAS has significantly grown over time (i.e. Genovesi, 2007; Howald *et al.*, 2008), and there are now numerous examples of conservation successes resulting from such actions, including species brought back from the brink of extinction (e.g. Butchart *et al.*, 2006). However, IAS are continuing to drive declines in global biodiversity (McGeoch *et al.*, 2010). The results presented here, showing that the status of the world's birds continues to deteriorate owing to the impacts of IAS, are likely to be replicated when RLIs for IAS impacts on other taxa are available. More stringent responses are needed, perhaps in particular through more effective implementation of existing legislation.

To track progress in, and impacts of, such improved responses to IAS, further development of indicators and the underlying datasets is needed. This poses several complex technical challenges that need to be addressed:

1. Non-standardized terminology is still a limit to the development of indicators, and it is therefore important to continue work towards an agreed set of terms for this purpose, in particular on the criteria used to define invasiveness.
2. The availability of information about alien species remains very low in many areas of the world, and for many taxonomic groups, and it is important to address these deficiencies in order to produce comprehensive inventories covering all environments and taxa.
3. Such inventories should include all alien species, not only IAS, and should include information on the year of introduction, pathway of spread, and documented impacts, as implemented by the DAISIE project. At the same time, however, a focus on those species with the greatest negative biodiversity impacts will be most expedient for achieving biodiversity conservation objectives. Developing such comprehensive lists of alien species will require substantial resources. For example,

DAISIE, cost in total €3 450 131 – with a European Union (EU) contribution of €2 400 000 – while the species listing for the project to populate the global indicator of alien invasion (McGeoch *et al.*, 2009) cost approximately €84 000 (57 countries). However, this would be an effective investment, because it informs the development of more stringent policies and interventions to control the spread and impacts of IAS.

4. The RLI showing impacts of IAS should be extended to other taxonomic groups in which all species have been assessed for the IUCN Red List. More taxonomic groups should be completely assessed to expand taxonomic coverage, and where this is not feasible, the sampled approach of Baillie *et al.* (2008) should be implemented.
5. Data on the adoption of national policy and legislation tackling IAS needs to be expanded and kept up to date, in order to update this indicator. In addition, more direct measures of IAS management effectiveness should be adopted once such information becomes more readily available.
6. Additional indicators should be developed when feasible to track trends in the costs (economic consequences) of IAS, and their impacts on ecosystem services, and on human health and well-being, as well as more direct measures of management effectiveness. A better understanding of these will help to convince decision-makers to invest the substantial resources that are needed to tackle adequately the threats from IAS.

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