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REVIEW

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Indicators for monitoring biological invasions at a national level

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Abstract

1. A major challenge for the management of biological invasions is to ensure that data and information from basic inventories and ecological research are used alongside data from the monitoring and evaluation of interventions to trigger and improve policy and management responses. To address this issue, South Africa has committed to report on the status of biological invasions and their management every 3 years.
2. We propose a framework of indicators for reporting on biological invasions at a country level; assess the feasibility of the indicators using South Africa as a case study; and outline steps needed for indicator development.
3. We argue that a national status report on biological invasions should explicitly consider indicators for pathways, species, and sites, and should report on interventions in terms of inputs, outputs, and outcomes.
4. We propose 20 indicators based on data currently available, as well as existing international policy initiatives. For each indicator, we have developed a factsheet that includes different hierarchical metrics (considering data availability) and provide suggestions on assigning confidence levels. We also combine these indicators into four high-level indicators to facilitate broader reporting and describe how forecasted indicators based on the concept of invasion debt could assist with scenario planning.
5. We found that many of the data required for these indicators are already available in South Africa, but they have been poorly collated to date. However, data for the indicators of most direct value to policy and planning—those dealing with the impact of biological invasions and the outcome of interventions—are scarce.
6. *Policy implications*. The framework of indicators developed here, for what we believe is the first ever national-level report on the status of biological invasions and their management, will facilitate the inclusion of biological invasions in environmental reporting at national and international levels. By identifying knowledge gaps, a status report will also focus efforts on determining the size of a country's invasion debt and what can be done to reduce it.

KEYWORDS
Aichi Target 9, biodiversity indicators framework, biological invasions, invasive alien species, monitoring and reporting, South Africa, status report

1 | INTRODUCTION

The international community, through the Convention on Biological Diversity (CBD), has committed to monitoring the status of biodiversity and directing efforts to achieve targets aimed at minimising the negative impacts of global change (Tittensor et al., 2014). However, while there are indicators to assess the impact of some of the major drivers (e.g. climate change is measured by essential climate variables; habitat destruction by the rate of conversion of land), work on developing and applying a set of internationally agreed indicators to assess the status of biological invasions is still ongoing (Latombe et al., 2017; McGeoch, Chown, & Kalwij, 2006; McGeoch et al., 2010; Rabitsch et al., 2016). The indicators proposed so far (see Data S1) focus on available data that can be gathered by countries around the world. They provide a snapshot of a few selected aspects of the issue, but often focus on the resources available for control rather than the outcomes of the control (Early et al., 2016). Therefore, more work is needed to develop a conceptual framework underpinning the indicators (Rabitsch et al., 2016).

This paper: (a) develops a theoretical framework for reporting on biological invasions at a national level; (b) describes the application of the indicators to South Africa; and (c) outlines priorities for improving the indicators. Throughout the paper, the terminology used follows that of Richardson, Pyšek, and Carlton (2011), in alignment with the proposed Unified Framework for Biological Invasions (Blackburn et al., 2011).

2 | HOW SHOULD A NATIONAL STATUS REPORT BE STRUCTURED?

The phenomenon of biological invasions is caused by a combination of how taxa are moved around by humans (the introduction dynamics), the traits of individual taxa (which determines levels of invasiveness), and features of the environment (which define the susceptibility of the environment to particular alien species, that is, its invasibility). For example, the current distribution of invasive pines is a function of: (a) how pines have historically been moved to new regions and disseminated within these regions, for example, planted for forestry (Richardson, 1998); (b) which species have particular traits that predispose them to invade (Rejmánek & Richardson, 1996); (c) the fact that large parts of the world are susceptible to invasion by trees [e.g. treeless areas in New Zealand, South Africa, and South America (Rundel, Dickie, & Richardson, 2014)]; and (d) interactions between these factors (Procheş, Wilson, Richardson, & Rejmánek, 2012).

The explicit consideration of biological invasions in terms of pathways, species (or taxa), and sites is also crucial for management (McGeoch et al., 2016). Focussing management efforts on pathways is important to reduce rates of introduction and spread (Essl, Bacher, et al., 2015), but does not address current invasions. Focussing on species can be effective in reducing densities of a single species, but can simply clear the way for other species to invade (Zavaleta, Hobbs, & Mooney, 2001). And focussing on suites of co-occurring species at any given site is vital if impacts are to be managed (van Wilgen, Dyer, et al., 2011), but if pathways of introduction and spread are not also managed, management successes will be ephemeral.

Researchers and managers often separate work on biological invasions along taxonomic, disciplinary, or functional lines. For example, freshwater fish and riparian plants are viewed as separate problems, and particular management plans are developed for particular environments, for example, biomes or realms. There is not, however, a fundamental difference between invasions in aquatic and terrestrial environments nor between invasive fish, frogs, and ferns—the important questions are the same. For example: If propagule pressure can be reduced, will this reduce the likelihood of an invasion; What are the impacts?; Is a species definitely alien? Management can be much more effective if the focus is on entire systems, for example, by simultaneously managing freshwater fish invasions and riparian plant invasions (Impson, van Wilgen, & Weyl, 2013). Therefore, although reports on the state of biodiversity are often split along taxonomic or environmental lines, this is not ideal for a comprehensive report on biological invasions.

Invasions have long been considered as a series of stages. As a recent example, Wilson, Panetta, and Lindgren (2017) considered four main stages—pre-introduction, incursion, expansion, and dominance—that align with the four major management goals—prevention, eradication, containment, and impact reduction. When they overlaid the scheme of pathways, species, and sites with the different stages, there were 12 particular situations where interventions are required. However, while splitting into different invasion stages might be useful in various contexts, it greatly increases the level of complexity, and we found it was not an ideal basis for a report.

A report must also consider how effective interventions have been in reducing the magnitude of current problems. Assessments of the changing status of invasions are sometimes made purely in terms of inputs (e.g. how much money was spent on control efforts?) or outputs (e.g. how many animals were killed?). Input and output indicators tend to be easy to measure and are amenable to auditing, but the effectiveness of interventions must be assessed in terms of the outcomes (i.e. has there been an improvement in indicators that reflect the status of biological invasions, e.g. rates of introduction, densities, or impacts?) and broader consequences (i.e. has there been an improvement in biodiversity indicators not directly related to biological invasions?). The main problem is that the determination of outcomes requires a comparison with what would have happened if different, or no, control measures had been applied (McConnachie et al., 2016).

As such we decided to structure our report in terms of pathways, species, sites, and interventions (the latter separated in terms of inputs, outputs and outcomes).

3 | PROPOSED INDICATORS

Indicators were developed for each of the components of the report as an integral part of the process of compiling the report itself (see Data S2). We proposed 20 indicators (Figure 1; see Data S3 for a more detailed discussion of the rationale for each indicator), and, as per the guidelines of the Biodiversity Indicators Partnership (2011), a factsheet for each indicator was developed, scrutinised, and updated (Data S4, see Appendix S1 for an example).

In terms of pathways, it is important to understand the potential routes into and within a country, as well as the degree to which each pathway is responsible for spreading organisms. On the basis of this, we proposed four indicators: (1) *introduction pathway prominence* (i.e. the sizes of the pathways to a country without taking into account how important each pathway is in terms of the introduction of organisms; Appendix S1); (2) *introduction rates* [essentially colonisation pressure as per Lockwood, Cassey, and Blackburn (2009) at a country level]; (3) *within-country pathway prominence*; and (4) *within-country dispersal rates*. A comparison of the potential routes and the degree to which they facilitate introductions provides an indication of the relative risk posed by pathways in different contexts. For instance, a country might have a large quantity of forestry imports, but few species are introduced through this pathway, either due to effective interventions or because the countries it imports from have a small pool of potential invaders (Bacon, Bacher, & Aebi, 2012; Liebhold, Brockerhoff, & Kimberley, 2017). A major problem in working on invasion pathways has been to determine consistent units of analysis. Therefore, if detailed route-specific data are not available, we propose using the hierarchical pathway classification scheme adopted by the CBD [see Data S5 for the scheme (Hulme et al., 2008; Scalera et al., 2016)].

For species, we also proposed four indicators: (5) *the number and status of alien species* [that requires an assessment both of whether a species is alien (Essl et al., 2018) and its status (e.g. Blackburn et al., 2011)]; (6) *the extent of alien species* (e.g. occupancy at a broad scale); (7) *the abundance of alien species* (e.g. the numbers of individuals for mobile taxa, and cover or biomass for sessile taxa); and (8) *the impact of alien species*. While metrics for indicators 5–7 are well developed, consistent metrics for the impacts of particular alien taxa have only recently been developed through the Environmental Impact Classification for Alien Taxa (EICAT) Scheme, and the Socio-Economic Impact Classification for Alien Taxa (SEICAT) Scheme (Bacher et al., 2018; Blackburn et al., 2014; Hawkins et al., 2015).

We proposed three indicators for sites. The first is (9) *alien species richness*, which gives an indication of the number of species that need to be considered. Second is (10) *relative invasive abundance* to indicate the presence of dominant alien species (Catford, Vesk, Richardson, & Pysek, 2012). For the third indicator, (11) *impact of invasions*, there is no accepted, unified system of classification. We propose to focus on provision of ecosystem services either using qualitative or quantitative estimates, with, if possible, a conversion into the monetary value of any reduction in services due to invasion. However, different countries and regions differ with regard to which ecosystem services they value most. For Europe, the proposed indicators were the incidence of livestock diseases and the impact of invasive alien species on the Red List Index (Rabitsch et al., 2016). For South Africa, a water scarce, mega-diverse country with many rural communities dependent on pastoralism, we chose to measure impact in terms of the reduction in water resources, biodiversity, and grazing capacity (van Wilgen, Reyers, Le Maitre, Richardson, & Schonegevel, 2008).

In terms of policy or management interventions, for inputs we proposed: (12) *the quality of the regulatory framework* [e.g. Roy et al. (2018)]; (13) *money spent* (i.e. expenditure rather than the financial costs of the impacts of invasions); and (14) *planning coverage* (i.e. the degree to which management plans are in place for the full suite of threats posed by biological invasions). For outputs we proposed: (15–17) *pathways*, *species*, and *sites treated*. These are defined as the

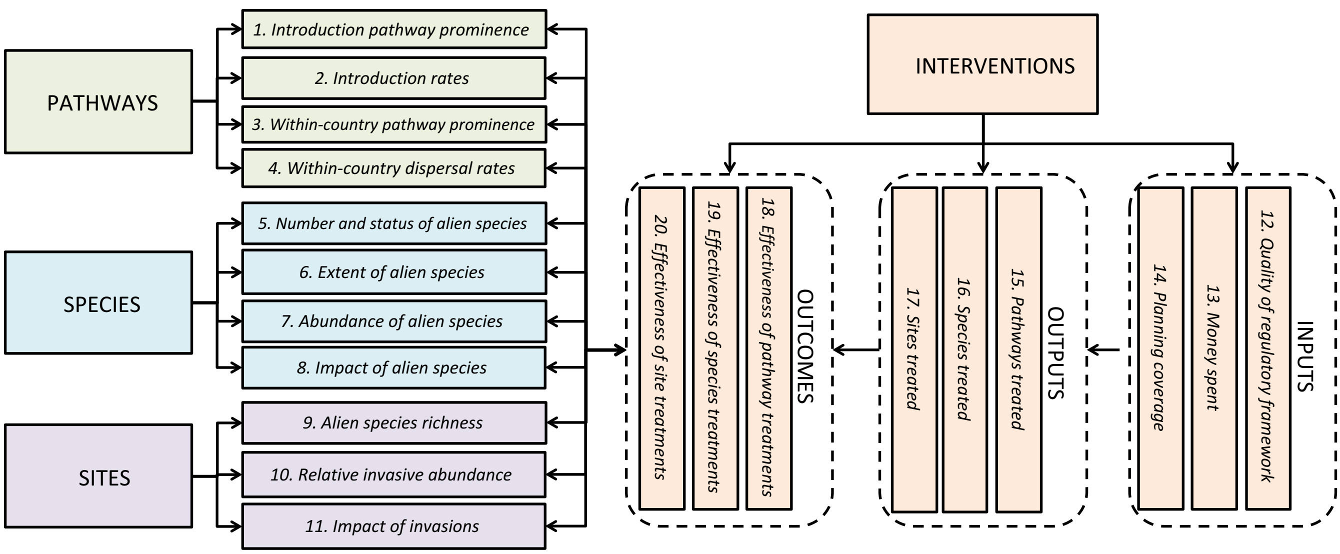

FIGURE 1 A proposed indicator framework for a national status report on biological invasions and their management. There are four main sections (in capital letters)—pathways, species, sites, and interventions—with proposed indicators in italics [Colour figure can be viewed at wileyonlinelibrary.com]

degree to which the pathways, species, and sites that need to be managed are actually subjected to management interventions, ideally with some assessment of the quality of the interventions. For outcomes, the corresponding indicators are: (18–20) *effectiveness of treatments* for *pathways*, *species*, and *sites* (i.e. do policy and management interventions change the status of biological invasions?). For each intervention, there should also be a separate assessment of any negative impacts of control, for example, on non-target organisms or on ecosystem functioning (Zavaleta et al., 2001), as it is important to ultimately assess whether the management was justified.

While we consider the 20 proposed indicators to be necessary to assess biological invasions in their entirety, this is too many for the purposes of general national reports on the state of the environment. We therefore propose four high-level indicators (Table 1)—(A) *rate of introduction of new unregulated species*; (B) *number of invasive species that have major impacts*; (C) *extent of area that suffers major impacts from invasions*; and (D) *level of success in managing invasions*—that align with the pressure, state, response framework. The inclusion of a few high level, invasion-specific indicators in national reports on the state of the environment would raise the profile of biological invasions, improve the prospects for accessing funding for their management, and provide political focus to ensure that interventions are appropriately monitored, reported, and evaluated.

For each indicator, we tried to ensure that, in line with international proposals (Latombe et al., 2017), the status reported is modular, that is, if resources permit, more detailed data can be collected without compromising the ability to compare with situations where fewer data are available. For example, accurate distribution data might be available for birds, but not for microbes, and countries differ in the quality and quantity of biodiversity data collected (McGeoch et al., 2010). We also propose broad guidelines to assign a level of confidence (high, medium, or low) to the metrics, as is accepted practice in environmental assessments. If there is direct, recent evidence, then the confidence will be high, whereas if the evidence is ambiguous, not clearly documented, or based on assumptions, then the confidence will be low (see Data S6). The criteria for the different levels of confidence varies between indicators and is highlighted on the factsheets (e.g. see Appendix S1). Finally, we assessed the practicability of the framework based on our experience compiling the first national status report on biological invasions and their management for South Africa (van Wilgen & Wilson, 2018).

4 | ESTIMATING THE INDICATORS FOR SOUTH AFRICA

To estimate the indicators for South Africa, we used three main tactics to source information: (a) the status report team accessed and collated information themselves; (b) experts were invited to contribute a scientific paper to a journal special issue (Wilson, Gaertner, Richardson, & van Wilgen, 2017); and (c) through direct requests to experts and practitioners for specific inputs. Nonetheless most of our estimates were made with low confidence (Table 2).

While the low confidence suggests that indicators might be impractical, we believe there is substantial value in them. When discussing preliminary results with stakeholders, it was clear that many people felt that data were available (e.g. on management plans), but had not been accessed yet. If such data do exist, then the reporting process will serve an important function in providing a central place to curate and compare experiences. The indicators also provide an impetus to collect such data. The lack of data on the effectiveness of management interventions does not suggest that the indicators should be scrapped, but is rather an indictment of the current levels of project management. If we are to improve management, the efficacy of past interventions must be monitored. Finally, we felt it was important to create a framework that can deal with situations where reliable, relevant data are available, and where data are missing. In the next section, we discuss ways the framework can be improved for future reports.

5 | FUTURE DIRECTIONS

The next steps, as recommended by the Biodiversity Indicators Partnership (2011), will be to communicate and interpret the indicators as part of the final report itself; develop monitoring and reporting systems in an attempt to fill the data gaps; test and refine

TABLE 1 The four proposed high-level indicators for reporting on the status of biological invasions at a national level. See Figure 1 for the 20 proposed indicators that are used to calculate these indicators, and Data S4 for all the indicator factsheets

Indicator name	Section	Units	Indicators used in calculations
A. *Rate of introduction of new unregulated species*	Pathways	Number of species per unit time (e.g. per year)	2, 5, 12, 14, 15, 18
B. *Number of invasive species that have major impacts*	Species	Number of species	5–8, 11
C. *Extent of area that suffers major impacts from invasions*	Sites	Area or % of national sub-divisions	6–11
D. *Level of success in managing invasions*	Interventions	% of pathways, species, and sites that require management and that are managed effectively	1–20

the indicators with stakeholders; and, as recommended by Hill et al. (2016), build simulation models to assess the inter-relationship and value of indicators. More broadly, however, for the indicators to be effective they need to: (a) be amenable to extrapolation; (b) be linked to targets; (c) be able to deal with different contexts; and (d) explicitly consider enabling conditions.

TABLE 2 The level of confidence in our knowledge of the status of biological invasions in South Africa as per the proposed indicator framework (van Wilgen & Wilson, 2018). NA = not assessed. See Data S4 for the indicator factsheets. See Data S6 for a detailed explanation of the confidence levels, but in broad terms, the confidence is high if there is direct, recent evidence, and low if the evidence is ambiguous, not clearly documented, or based on assumptions. A range in confidence values is possible as there might be more reliable evidence for some pathways, taxa, or sites than others

Indicator	Confidence	Notes and recommendations
1. Introduction pathway prominence	Medium	Data were available for introduction pathway prominence and historical data on introduction rates, but the pathway of introduction for most alien species is unknown (Faulkner, Spear, Robertson, Rouget, & Wilson, 2015). Almost no data were available for within-country dispersal.
2. Introduction rates	Low	
3. Within-country pathway prominence	NA	
4. Within-country dispersal rates	NA	
5. Number and status of alien species	Low	Known for a variety of groups such as vertebrates (Picker & Griffiths, 2017) and marine organisms (Robinson et al., 2016), but these assessments often did not include taxa in cultivation and the coding for invasion status was inconsistent. For over 40% of known alien species, it was not possible to indicate whether the species was introduced, naturalised or invasive. Status as per the Unified Framework is known only for a few groups (Jacobs, Richardson, Lepschi, & Wilson, 2017; Robinson et al., 2016). A census of all alien species is needed.
6. Extent of alien species	Low—Medium	Data from atlassing projects for birds, frogs, plants, and spiders allowed the estimation of the distribution of some taxa. There are some data on abundance of alien plants, but these are crude and 20 years out of date.
7. Abundance of alien species	NA	
8. Impact of alien species	NA	There was a remarkable dearth of studies that document the impacts of alien species, despite this having been recognised as a major gap for many years (Richardson & van Wilgen, 2004). Few studies have scored impact according to the Environmental Impact Classification of Alien Taxa Scheme, with data mostly limited to expert opinion (Measey et al., 2017; Zengeya et al., 2017).
9. Alien species richness	Low—Medium	Atlas data at a national scale were available for terrestrial plants and most vertebrates, but abundance data and data on relative invasive abundance were only available for a limited number of sites (e.g. some protected areas).
10. Relative invasive abundance	NA	
11. Impact of invasions	Low	Estimates are entirely based on three studies (de Lange & van Wilgen, 2010; Le Maitre, Forsyth, Dzikiti, & Gush, 2016; van Wilgen et al., 2008).
12. Quality of regulatory framework	Medium	Assessment was done by a semi-independent team of invasion scientists but the team did not include anyone from the legal profession.
13. Money spent	Low	Based solely on funds provided by the Department of Environmental Affairs (and so is an underestimate), data from other governmental and private initiatives need to be collated.
14. Planning coverage	Low—High	Some pathway management plans are in place, species and site plans are well documented where available, but a better system of collation is needed.
15. Pathways treated	Low	Not consistent, agricultural commodities are inspected and legislation relating to the discharge of ballast water has been drafted but not finalised.
16. Species treated	Low	Control operations are often poorly documented, and so the level of treatment is uncertain.
17. Sites treated	Low	Based on a few case studies and extrapolations, management data are of poor quality or not consistently recorded.
18. Effectiveness of pathway treatments	Low	Of the pathways classified as having effective management it is not clear if the intervention was successful or that the pathway declined due to changing socio-economic conditions.
19. Effectiveness of species treatments	Low	Changes in the distribution of invasive species over time recorded in atlas projects have allowed for estimates of the effectiveness of species treatments (e.g. Henderson & Wilson, 2017). Returns on investment from the implementation of control measures have only been adequately assessed for some biological control of invasive alien plants (de Lange & van Wilgen, 2010).

(Continues)

TABLE 2 (Continued)

Indicator	Confidence	Notes and recommendations
20. Effectiveness of site treatments	Low	A small (but growing) number of case studies have sought to assess management effectiveness at the scale of individual protected areas, catchments, or farms (e.g. McConnachie, Cowling, van Wilgen, & McConnachie, 2012; van Wilgen, Fill, Govender, & Foxcroft, 2017). These have demonstrated effective (Te Beest et al., 2017), somewhat effective (Fill, Forsyth, Kritzinger-Klopper, Le Maitre, & van Wilgen, 2017), and ineffective (Kraaij, Baard, Rikhotso, Cole, & van Wilgen, 2017) management interventions.
A. Rate of introduction of new unregulated species	Low	The lack of data on the 20 core indicators meant the confidence in the high-level indicators was inevitably low. Formal impact assessments need to be conducted to allow for a reliable baseline estimate of the *number of invasive species that have major impacts*. The *level of success in managing invasions* could be estimated based on available data from legislated requirements, management plans, and the evaluation of management. We suspect that, relatively small changes to management practices and the monitoring of management could result in substantial improvements in this indicator.
B. Number of invasive species that have major impacts	NA	
C. Extent of area that suffers major impacts from invasions	Low	
D. Level of success in managing invasions	Low	

On the basis of the concept of invasion debt (Rouget et al., 2016), we suggest an additional four indicators that could be used to assist with forecasting—*introduction debt*, *establishment debt*, *spread debt*, and *impact debt*. Over time, a country's invasion debt can result in new introductions, new invasions, more area invaded, and greater impacts. The challenge will be to develop models and techniques that can help improve decision-making and allow for adaptive management at a variety of scales (Figure 2). In particular, although South Africa has started efforts at proactive management (Wilson, Ivey, Manyama, & Nänni, 2013), it is difficult to demonstrate the economic value of avoiding the predicted negative impacts of invasions that do not occur (Leung et al., 2002). We have started to estimate some aspects of invasion debt for South Africa (Faulkner, Robertson, Rouget, & Wilson, 2016; Rouget et al., 2016), but much more work is needed.Figure A1 (Indicator 1.3)—The number of ocean going vessels arriving at South African ports over time. Data from the National Ports Authority of South Africa

While the indicators on their own have value, for them to have impact on management they must also be linked to targets. For example, under the IUCN's Honolulu Challenge on invasive alien species (https://www.iucn.org/theme/species/our-work/invasive-species/honolulu-challenge-invasive-alien-species), the New Zealand Government has committed to eradicate all pests from all island nature reserves by 2025, and to develop a method for eradicating

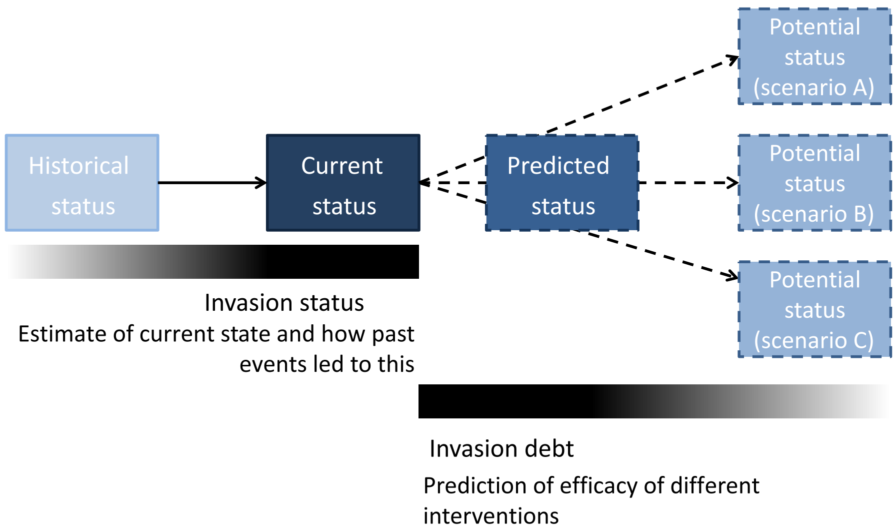

FIGURE 2 A national report on the status of biological invasions, by definition, should focus on what the current state is, but this is often largely a function of historical events and processes. Given that the report will form the baseline for predictions of how problems will evolve under different scenarios, that is, invasion debt, indicators need to be responsive to changes (Essl, Dullinger, et al., 2015). We propose that forecasted indicators [*introduction debt*; *establishment debt*; *spread debt*; and *impact debt* (Rouget et al., 2016)] can form the currency by which to assess management options [Colour figure can be viewed at wileyonlinelibrary.com]

one of the key target pests from mainland New Zealand. These are clearly very specific context-dependent targets that require specific indicators to track progress, but at a broad scale such interventions would be captured in the indicator framework developed here.

Indicators also need to be flexible enough to deal with different contexts. A major motivation for the South African Government's invasive plant control programmes is to provide employment opportunities (van Wilgen, Khan, & Marais, 2011), and therefore the number of jobs created is a core indicator. Similarly, successful interventions require institutional capacity, research, data and information management, and public awareness and engagement (Wilson, Panetta, et al., 2017). For example, for management to maintain sustained political support, decision-making needs to actively involve society (Crowley, Hinchliffe, & McDonald, 2017). Ensuring that such enabling factors are reflected in the indicators is an important area for future work. Ultimately, however, the effectiveness of interventions must still be monitored in terms of the impact on the invasions themselves. The challenge of jointly meeting the social goal of poverty alleviation through job creation, and the biodiversity goal of reducing invasions has not yet been met in South Africa (van Wilgen & Wannenburgh, 2016).

6 | CONCLUSIONS

We believe the framework proposed here is a useful starting point for national-scale reports on biological invasions and their management. Over time the proposed indicators will likely need to be adjusted, but they should capture trends and enable assessments of the efficacy of different interventions. Countries around the world are increasingly focussing on proactive interventions. We feel that such initiatives can be better supported and scrutinised by linking the indicators proposed to the concept of invasion debt (Rouget et al., 2016). We suspect, however, that strengthening the links between research, planning, implementation, monitoring, and reporting will remain the major challenge facing invasion science (Esler, Pozesky, Sharma, & McGeoch, 2010). We hope the indicator framework developed here will help this process.

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AUTHORS' CONTRIBUTIONS

J.R.U.W. conceived the idea and developed the framework in collaboration with D.M.R. and B.W.v.W. S.J.R., T.A.Z., and K.T.F. helped refine the framework. All authors helped develop the factsheets. J.R.U.W. led the writing, and all authors contributed critically to the drafts and gave final approval for publication.

DATA ACCESSIBILITY

Data have not been archived because this article does not contain data.

The National Status Report will be available through the South African National Biodiversity Institute (https://www.sanbi.org/resources/).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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Supplementary Material 1—Indicators proposed to track the status of biological invasions

Biodiversity indicators are used to assess the condition of biodiversity and the factors that affect it (Heink and Kowarik, 2010). Biodiversity indicators also allow researchers and policy makers to check if there are adequate plans in place to alleviate threats to biodiversity and to assess if these plans are making a difference; and to assess progress towards biodiversity conservation targets such the Convection on Biodiversity Diversity 2010 Biodiversity target (https://www.cbd.int/decision/cop/default.shtml?id=7197) and the Aichi Biodiversity Targets (http://www.cbd.int/sp/targets). There has been continual progress in the development of indicators related to biological invasion as a threat to biodiversity and their application to measure progress towards meeting the CBD 2010 and Aichi 9 biodiversity targets (Table 1).

The 2010 Biodiversity Target was “to achieve by 2010 a significant reduction in the current rate of biodiversity loss at the global, regional and national level, as a contribution to poverty alleviation and to the benefit of all life on Earth”. Several biodiversity indicators on biological invasions were developed as part of efforts to monitor progress towards this target (McGeoch et al., 2006, McGeoch et al., 2010). McGeoch et al. (2006) developed an aggregate indicator that informs on the status of alien species invasion at national and global scales. It consists of three component measures: 1) number of invasive alien species; and numbers of operational management plans for 2) invasive alien species, and 3) for introduction pathways. These component measures can be aggregated to evaluate national and global progress towards management targets such as stabilising invasive alien species numbers and implementation of invasive and alien species management plan. McGeoch et al. (2010) further refined this global indicator using a pressure-state-response framework and showed that the 2010 Biodiversity Target of reducing the threat of biological invasions to biodiversity was not achieved. The refined indicators included: 1) number of documented invasive and alien species (pressure); 2) trends in the impact of invasive and alien species on biodiversity (state); 3) trends in the number of international agreements and national policies related to invasive and alien species; and 4) the level adoption of the these agreements and policies by countries.

Aichi Biodiversity Target 9 states “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”. Four primary indicators [trends in the numbers of invasive alien species introduction events; Red List Index (impacts of invasive alien species); legislation for prevention and control of invasive alien species (IAS); and trends in invasive alien species vertebrate eradications] and two secondary indicators [growth in species occurrence records accessible through GBIF and Red List Index (more broadly that just for birds)] have been proposed as part of this target (https://www.bipindicators.net/ accessed 18 May 2018).

Rabitsch et al. (2016) proposed a set of six indicators that can be used to assess the status of biological invasions at a continental scale in Europe and to monitor the efficacy of the European Union regulations on invasive and alien species, viz: 1) a combined index of invasion trends; 2) pathways of invasions; 3) Red List Index of invasive and alien species; 4) invasive and alien species impacts on ecosystem services; 5) trends in incidence of livestock diseases; and 5) cost for alien species management and research.

Latombe et al. (2017) proposed three essential variables for monitoring biological invasions at a national level (alien species occurrence, species alien status and alien species impact). While these should facilitate comparisons across countries, they have not yet been applied in practice and do not explicitly consider invasion pathways or invaded sites (McGeoch et al., 2016). Furthermore, for these variables to be of value, a link to the effectiveness of interventions (policy and management) is required.

Table S1.1. The development of indicators to assess the status of biological invasion and their link to proposed indicators for monitoring biological invasions at a national level

Study	Proposed indicators	Description	Link to indicators presented here
McGeoch et al. (2006)	Status of alien species invasion	An aggregate indicator that informs on the status of alien species invasion at a national and global scales. It consists of three component measures: number of invasive alien species and numbers of operational management plans for invasive alien species and for introduction pathways. The component measures can be aggregated to evaluate national and global progress towards management targets such as stabilising invasive alien species numbers and implementation of invasive and alien species management plan.	5, 14
McGeoch et al. (2010)	Numbers of documented invasive alien species	This indicator lists the number of invasive alien species that impact negatively on biodiversity. The list is composed of six taxa: mammals, birds, amphibians, plants, freshwater fish, and marine organisms. Trends are tracked at national, regional and global scales.	5
	Trends in the impacts of invasive and alien species on biodiversity	Trends in the extinction risks of birds, mammals and amphibians that are driven by invasive an alien species.	8, 11

Study	Proposed indicators	Description	Link to indicators presented here
	Trends in international agreements and national policy adoption	Tracks 1) the number of agreements, legislation and policies that have been enacted to reduce the threat of alien and invasive species and 2) the adoption thereof by different countries.	12, 14–17
Aichi Target 9	Trends in the numbers of invasive alien species introduction events	Trends in the numbers of invasive alien species introduction events in 21 countries. The majority of the records for invasive alien species are for plants, invertebrates, fish, mammals and birds.	2
	Red List Index (impacts of invasive alien species)	This indicator is based on Birdlife International's assessments of extinction risk for all birds for the IUCN Red List. It shows trends in the status of all birds worldwide driven only by the negative impacts of invasive alien species or the positive impacts of their control. Trends for other taxa such as mammals and amphibians are not yet available but will be added in future.	8, 11
	Legislation for prevention and control of invasive alien species (IAS)	This indicator aims to quantify trends in the: 1. Commitments by individual countries to international policies related to invasive and alien species. 2. The percentage of countries with (a) national legislation and policy relevant to invasive and alien species; (b) national strategies for preventing and controlling invasive and alien species and (c) national commitment to invasive and alien species related themes Allocation of resources towards the prevention or control of invasive and alien species.	12–14
	Trends in invasive alien species vertebrate eradications	This indicator tracks the efforts to eradicate and remove invasive vertebrate pests from sensitive ecosystems such as islands countries. These eradication efforts are implemented to protect biodiversity and prevent extinction of threatened native species.	16, 17, 19, 20
	Growth in species occurrence records accessible through GBIF	This indicator tracks the number of species occurrence records that are published and are digitally-accessible on the Global Biodiversity Information Facility (GBIF).	5, 6, 7
	Red List Index	The Red List Index (RLI) shows trends in the extinction risk of suite of species. It is based on data from repeated assessments of species using the Red List categories and criteria. The species data is often aggregated into taxa (e.g. birds) to reduce sampling bias.	8, 11
Rabitsch et al. (2016)	Combined index of invasion trends	Accumulation rates of alien species in a given area over time	2
	Indicator on pathways of invasions	Trends in pathway prominence over time	1

Study	Proposed indicators	Description	Link to indicators presented here
	The Red List Index of invasive and alien species	Overall rates at which species that are impacted by invasive and alien species are moving toward or away from extinction	8, 11
	Indicator of invasive and alien species impacts on ecosystem services	Cumulative increase in ecosystem services that are negatively affected by invasive and alien species over a defined period	8, 11
	Trends in incidence of livestock diseases	Incidences of livestock diseases caused by invasive and alien species over time in a given area	8, 11
	Indicator on cost for alien species management and research	Estimate of financial investment on alien species management and research	13
Latombe et al. (2017)	Species alien status	Knowledge of the historical geographic range of the species that is commonly available in flora and fauna volumes, its historical absence from the introduced range, or genotypic difference from local populations	5
	Alien species occurrence	Taxonomically verified species presence or absence records at a locality with a geographic co-ordinate, or in a prescribed area, management or geopolitical unit or site	5, 6, 7
	Alien species impact	An objective, transparent and repeatable system for classifying alien taxa in terms of the current and maximum realized impact globally of their detrimental effect on any recipient ecosystem, using the EICAT scheme	8

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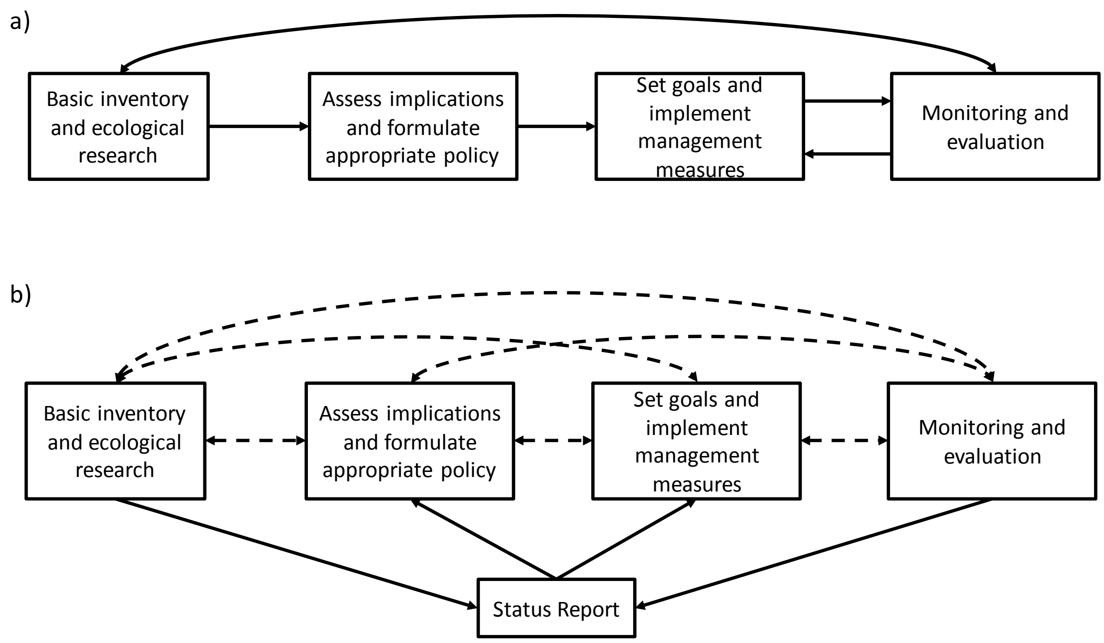
Supplementary Material 2—Background to South Africa's National Status Report on Biological Invasions

South Africa has signed a number of international agreements and developed national policy framework and legislation to manage biodiversity loss. In October 2014, regulations on alien species were made into law (Department of Environmental Affairs, 2014). These regulations require a report on the status of biological invasions every three years, and the first report was finalised at the end of March 2018 (van Wilgen and Wilson, 2018). We believe this is the first comprehensive national status report on biological invasions and their management anywhere in the world.

The need for the development of the reporting framework described in South Africa's first national report on the status of biological invasions arose from the promulgation of legislation out lined above. Our work on the report provided a test of the practicality of this framework. We used three main tactics to source the information: through the status report team accessing and collating information themselves; through encouraging experts to contribute a scientific paper to a journal special issue (Wilson et al., 2017); and finally through sending direct requests to experts and practitioners for specific inputs with some instructions as to which data were required.

The intention of the national status report was to collate foundational biodiversity knowledge and information from the monitoring and evaluation of interventions in a form that is useful for policy-makers and managers (Fig. S2.1). Such a report would then provide the basis for ensuring that management interventions are appropriate (i.e. in line with international best practice) and effective (i.e. lead to an improvement in indicators that characterise biological invasions). Another main goal of the national status report was to stimulate and focus future monitoring efforts, i.e. to increase the links between all the processes (Fig. S2.1). This means that indicators can be proposed for which data are not yet available, but where efforts should be made to collect such data. The framework will thus both facilitate current decision-making, and help identify monitoring and reporting that would improve decision-making.

Figure S2.1—The role of a national status report in the science-policy interface. In an ideal world (a), there is a smooth flow of information from research to policy formulation, to management, to monitoring and evaluation and back to research. But in reality (b) links are often incomplete or broken. A national status report is one formal way of increasing the links between research, policy and implementation.



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Supplementary Material 3—Detailed description and discussion around the selection of the 20 indicators and 4 high-level indicators

Pathways

We used the hierarchical pathway classification scheme adopted by the UN Convention on Biological Diversity as the unit of measurement for pathways (Hulme et al., 2008, Scalera et al., 2016) (Supplementary Material 5), and consider four pathway indicators.

First *introduction pathway prominence* estimates the size of the pathway to a country (e.g. number of vessels or volume of goods) without taking into account how important the pathway is in terms of the spread of organisms. At a basic level, this will be a qualitative assessment, but ideally there should be some quantitative assessments such that different pathway sub-categories can be ranked. If possible, spatially and temporally explicit data on the prominence of different pathways should be available. This will facilitate appropriate allocation of resources for prevention (e.g. Faulkner et al., 2017).

Next, *introduction rates* is estimated for each pathway to a country [essentially colonisation pressure as per Lockwood et al. (2009)]. At a basic level this will be a quantitative assessment of the number of species introduced, but it should be temporally explicit (e.g. number per year) and ideally linked both to spatial location and to on-going introductions of each taxon (i.e. propagule pressure). Importantly, rates of introduction can reflect changes in survey efforts over time—the first record is often much more recent than the date of first introduction—this needs to be accounted for in the uncertainty measure.

A comparison of *introduction pathway prominence* and *introduction rates* provides an indication of the relative risk posed by pathways in different contexts. For instance, a country might have a large quantity of forestry imports, but few species are introduced through this pathway, either due to effective interventions or to a small pool of potential invaders from the countries it imports from (Bacon et al., 2012, Liebhold et al., 2017).

A similar process should be followed for dispersal within a country, i.e. *within-country pathway prominence* and *within-country dispersal rates*.

These indicators provide a measure of transport opportunities and of the degree to which these are responsible for past introductions and within-country dispersal (Essl et al., 2015). Projecting these forward will be vitally important, but will be speculative (discussed below). Given changes to transport links (e.g. new shipping routes and new roads) and changes to the pathways of introduction, (e.g. from solid ballast, to ballast water, to treated ballast water), *introduction pathway prominence* and *introduction rates* (and the corresponding within-country indicators) will change over time, and in some cases independently from each other.

Species

The indicators in this section are based on a species level classification. However, for practical (e.g. difficulties of identification) and theoretical (e.g. entities differ significantly in the risks they pose) reasons, it can be important to consider entities at a taxonomic level other than species (Petit, 2004).

The first proposed indicator is the *number and status of alien species*. This combines elements of the proposed essential variable *alien status* with a very coarse categorisation for *alien species occurrence* (Latombe et al., 2017). At a basic level, it is a combination of whether a species is: 1) native or alien to a region; and 2) present. The first part, i.e. determining nativity, is often fairly straight-forward for vertebrates and many higher plants but for some taxa (e.g. many microbes), determining native ranges will require extensive sampling and/or molecular analysis, with no guarantee of a definitive answer.

Determining presence can be similarly straightforward in many cases, but highly challenging in others. The minimum standards required for a species to be included on a list of alien species varies between lists, and in many cases no physical specimen is required. At least historically, there has often been no requirement for deliberately introduced species to be recorded. Moreover alien species, even those that have established, do not always persist (Simberloff and Gibbons, 2004). For example, the Chilean black urchin, *Tetrapygus niger*, was recorded in South Africa in 2007, but could not be found during more recent surveys (Mabin et al., 2015). Given the habitat previously occupied had been transformed, and there were no indications of the urchin having reached nearby potentially suitable habitats, it is considered that the species is no longer present in the country (Robinson et al., 2016). This points to the need to document when, where, and on what basis, the presence (or absence) of a taxon was noted. Such information underpins decisions relevant to biosecurity.

While many countries have very comprehensive lists of invasive species, we know of no country that has a single consolidated and comprehensive list of all alien taxa, i.e. including those in captivity or cultivation [though see Pyšek et al. (2012) for a list of alien plants in the Czech Republic]. The Global Register for Introduced and Invasive Species (Pagad et al., 2018) provides a valuable starting point, but lists for individual countries are ultimately still based on incomplete and often out-of-date surveys and in most cases taxa in captivity or cultivation are not included. Such lists are an important basis for biosecurity policies based around prevention of new imports, and for assessing future risks (i.e. invasion debt). Lists of invasive species are more commonly produced, but these are often restricted to unequivocally widespread invaders (as they are relatively easy to detect) that are considered to have a negative impact (though this is usually poorly supported by evidence). As sampling protocols improve, less widespread invaders and those that are more difficult to identify can then be included (Henderson and Wilson, 2017). However, this poses a problem for monitoring. To what extent does an increase in the number of invasive taxa reflect new invasions or detections of long-established invasives?

At a more advanced level, it is important to know the actual stage of the invasion. To this end, Blackburn et al. (2011), as part of a Unified Framework for Biological Invasions, produced an alpha-numeric coding system (A–E) to describe how far a particular alien taxon had progressed along the introduction-naturalisation-invasion continuum. Guidance on how to implement this has been provided by Wilson et al. (2014) for trees, and Robinson et al. (2016) for marine taxa.

Next we propose two indicators for species' distributions—*extent of alien species* and *abundance of alien species*. As the full distribution of alien species is rarely known and is unlikely to be static (especially in early stages of invasion), measuring the *extent of alien species* based on a convex hull of the distribution will rarely be accurate. However, occupancy data collected at different spatial scales can provide useful insights. At the broadest scale this will reflect occupancy at a high-level administrative region (e.g. province or state), a high-level biodiversity unit (e.g.

biomes in the case of South Africa), or a geomorphological unit (e.g. primary water catchment). For taxa that have been surveyed in more detail, data are often available for occupancy at a slightly finer scale [e.g. quarter-degree grid cells (qdgcs) (630–710 km^2 at the latitude of South Africa); hectads (100km^2); or even smaller as appropriate]. The *abundance of alien species* can be measured as the numbers of individuals for mobile taxa, and as cover or biomass for sessile taxa (e.g. plants). Such data are, of course, neither always available nor reliable which means that a categorical approach might be needed (e.g. absent, rare, occasional, abundant).

In a few cases data are available to show how occupancy of alien taxa changes with spatial scale, enabling projections of population changes and estimates of abundance (Veldtman et al., 2010, Donaldson et al., 2014). Ideally, data should enable the construction of spatially-explicit stage-structured maps of organisms that incorporate both extent and abundance (Caplat et al., 2012, Wilson et al., 2014), but such data are rare.

Finally, we consider the *impact of alien species* based on the Environmental Impact Classification for Alien Taxa (EICAT) Scheme, and the Socio-Economic Impact Classification for Alien Taxa (SEICAT) Scheme (Blackburn et al., 2014, Hawkins et al., 2015, Bacher et al., 2018). The EICAT Scheme, which has recently been adopted by the IUCN, is a consistent method for rating impact across different mechanisms (e.g. competition or changes to chemical, physical or structural features of the ecosystem). The SEICAT, by contrast, is based on documented evidence of how an invasive species has led to changes in peoples’ activities. More work is required to translate the species-level impacts into ecosystem-level impacts, to devise robust and transparent methods for reporting on socio-economic impacts

(Bacher et al., 2018), and to determine how to jointly consider environmental and socio-economic impacts when making decisions.

Sites

There are a variety of ways to categorise sites. While administrative regions are useful for management and planning, they do not necessarily follow biogeographical zones. But even traditional biogeographical zones are not necessarily relevant as the mechanisms that determine the ranges of native and alien species can differ (Rouget et al., 2015). As such, sites are often defined for practical reasons, e.g. municipalities or protected areas, or a simple grid is used. As for species data, we suggest two levels: broad scale (provinces/states, biomes, marine regions, or primary catchments as appropriate) and finer scale (qdgcs or hectads). This is based largely on the availability of data, noting that for specific purposes other classifications will be needed, e.g. protected areas. We also note that for many conservation planning and assessment purposes finer scale measures are needed to account for variation in conditions and habitats.

We propose three indicators for sites. The first is simply *alien species richness*, which gives an indication of the number of species that need to be considered. Second is *relative invasive abundance* to indicate the presence of dominant alien species and the trajectory of their invasion over time (Catford et al., 2012). The simplest metric for *relative invasive abundance* is a qualitative categorical assessment from alien-free to alien-dominated. However, more work will be required to understand the implications of equivocating taxa of different body sizes and taxonomic groupings.

Catford et al. (2012) also proposed the use of relative alien species richness. However, as part of the consultation exercise around the indicators, it was not clear to us or our colleagues how this indicator provided additional management and policy insights. It can also be difficult to interpret as it is influenced by several processes (Stohlgren et al., 2003). We therefore omitted it from the framework.

For the third indicator (*impact of invasions*) there is no accepted, unified system of classification. Simply aggregating species level impact to site level does not work as invasive species interact, impacts are not necessarily additive, and all the individual impacts are rarely known in any case. There are an increasing number of attempts to quantify the impacts of biological invasions on economies (e.g. Pimentel et al., 2001, Sinden et al., 2004, Williams et al., 2010, Wittmann and Flores-Ferrer, 2015), and such assessments have been widely used by policy-makers. However, these assessments tend to focus on a few species with high impacts that can be easily monetised. It is much more difficult to assess all the different types of impacts that invasions cause (Bacher et al., 2018). Similarly, the importance of specific impacts will vary between sites. For example, the threat to native biodiversity is of critical importance for protected areas, while impacts on river flow might be more important for city planners concerned with securing a stable water supply and preventing floods. Reductions in particular ecosystem services by invasions have been expressed both in terms of benefit flows and financial flows [e.g. the amount of water flowing from a catchment or the number of livestock supported on a rangeland (van Wilgen et al., 2008)]; and in terms of monetary value (de Lange and van Wilgen, 2010). Finally, the effects of invasive species can be assessed in terms of their impact on human livelihoods at a given site (Shackleton et al., 2007).

Based on these findings we propose three metrics for measuring the *impact of invasions*. First, a categorical factor based on qualitative impacts on ecosystem services; second, a quantitative estimate of reductions in ecosystem services; and third, and substantially more complicated, a monetary value of these reductions. Different countries and regions will differ in which ecosystem services are the most important to include. For Europe, the proposed metrics were the incidence of livestock diseases and the impact of invasive alien species on the Red List Index (Rabitsch et al., 2016). For South Africa (a water scarce, mega-diverse country with many rural communities dependent on pastoralism) we chose to measure impact in terms of the reduction in water resources, biodiversity, and grazing capacity.

Interventions

For a report to be valuable, it should also assess the effectiveness of policy or management interventions in terms of inputs, outputs, and outcomes.

For inputs we propose three indicators. The first is the *quality of the regulatory framework* measured in terms of the completeness of the regulations (e.g. whether all pathways are considered); whether regulations meet international standards [e.g. Roy et al. (2018) outline a scheme to assess risk assessments]; whether there are mechanisms to enable implementation; and whether there are appropriate mechanisms for update, review, and appeal. The *quality of the regulatory framework* is obviously politically sensitive. It must therefore be based on objective criteria and assessed in a fair and transparent way as it is an extremely important base-line for interventions.

The second proposed input indicator is the amount of *money spent* on interventions. *Money spent* is a measure of expenditure, and therefore an input. This spending might change the status of biological invasions in a desired direction or not, but if the *effectiveness of treatments* (see below) is to be estimated in monetary terms, an initial calculation of how much money was actually spent is needed. Sometimes the money spent on control is used as a surrogate for the economic impact of invasions. While the need to spend resources on managing invasions is partly a consequence of the invasions themselves (albeit affected by policy and management decisions), the impact of invasions and the costs of responding to invasions should not be conflated (not least because there is no guarantee that the money spent responding to a problem is directly proportional to the size of the problem).

Finally, we propose using *planning coverage* as an indicator to assess the degree to which plans are in place to deal with the full suite of threats posed by biological invasions.

For outputs, we propose three measures of what has happened as a result of the inputs. *Pathways treated* is an estimate of the degree to which the pathways have been subjected to management interventions (either through regulation, or inspections), with the potential to refine this to estimate the proportion of vectors per pathway subjected to management, and assess the quality of these interventions. We propose that the *species treated* is, at a basic level, the proportion of species that require treatment that are treated (with the requirement defined by regulations or ideally some assessment of risk). At a more advanced level, *species treated* can be measured as the proportion of populations treated for each species, with an assessment of the quality of the interventions (Higgins et al., 2000, Taylor and

Hastings, 2004, McConnachie et al., 2016). For *sites treated*, we similarly propose that the indicator would be measured as the total area subjected to control measures that needed control at a basic level, and at a more advanced level, assessed in terms of the quality of the interventions.

Finally, we propose specific indicators of the *effectiveness of treatments* for *pathways*, *species*, and *sites*. The aim of these outcome indicators is to highlight whether the policy and management interventions are changing the state of biological invasions (Fig. 1). At a basic level has an intervention: 1) exacerbated the problem; 2) been ineffective; 3) reduced the impacts relative to a counterfactual situation where there was no management (e.g. McConnachie et al., 2016); 4) reduced the extent and impact of biological invasions to an acceptable level or achieved the goals set; or 5) not only achieved the goals set but done so in a permanent way (e.g. a species is eradicated). For each intervention there should also be an assessment of any negative impacts of control, e.g. on non-target organisms or on ecosystem functioning (Zavaleta et al., 2001, Simberloff, 2012). This is rarely done but is needed to assess whether an intervention was justified, e.g. the environmental consequences of large-scale herbicide use to combat plant invasions is poorly known (Wagner et al., 2017).

Advanced metrics would ideally quantitatively estimate control effectiveness (i.e. return on investment). Although the use of this indicator at a national level would require further development, there are examples of such estimates for individual species (van Wilgen and De Lange, 2011) and sites (Hosking and du Preez, 2004). Similarly, interventions should be monitored and progress reported in terms of relevant biodiversity indicators that are not specifically related to biological invasions, i.e. the socio-economic or conservation outcomes. For example, the Red List Index has been proposed as an indicator to assign the impact of invasions on the conservation status of native species (Butchart, 2008, Rabitsch et al., 2016). The challenge is to have sufficient evidence to be able to ascribe a change in such indicators to biological invasions or to the interventions taken against them. In the case of the Red List Index this is done by noting when conservation assessments include invasive alien species as a threatening process. A similar process is needed to monitor potentially adverse impacts of management interventions.

Finally, the value of these indicators will depend on the degree to which outcomes are monitored. For example, it was possible to demonstrate that ballast-water regulation led to a cessation in ballast-mediated invasions in the Laurentian Great Lakes of North America (Bailey et al., 2011); and the contribution of classical biological control to the control of invasive species is often relatively well known (Zachariades et al., 2017).

High-level indicators

A. Rate of introduction of new unregulated species (pathways): This provides an indication of potential future biological invasions (i.e. species-based invasion debt). In this context new refers to new to a given region, and unregulated refers to those taxa which were not legally imported. Species which have been introduced following a proper detailed and independently assessed risk analysis are not included. As such this indicator does not assess the wisdom of decisions to deliberately allow the import of new alien species, this would require a separate (perhaps somewhat post-hoc) analysis of the effectiveness of measures to regulate imports (i.e. part of indicator 17).

B. Number of invasive species that have major impacts (species): The total number of alien species that have been reported to have a Major (MR) or Massive (MV) impact under either the EICAT or SEICAT schemes provides an indication of the current size and complexity of the problem. A growth in the number of species would indicate an increase in consequences and management complexity.

C. Extent of area that suffers major impacts from invasions (areas): The extent of invaded area that suffers major impacts is an indication of the overall extent of the impacts of biological invasions. Invaded areas are expected to deliver fewer or diminished ecosystem services, and/or to support lower levels of biodiversity. As per indicator 11, the nature of the impacts considered might be specific to the region under consideration.

D. Level of success in managing invasions (interventions): The degree of success achieved by control measures will vary from place to place, and this indicator is intended to provide an assessment of overall control effectiveness across all projects. High levels of effectiveness would indicate that control measures are appropriate and that the goals of management are realistic and achievable. Low levels of effectiveness would indicate inefficiencies in management, or unrealistic expectations and goals, or both. It should trigger a thorough examination of the component projects with a view to re-allocating national-level resources to projects where the goals are more likely to be achieved, or to re-defining more realistic goals.

We propose that it should be calculated based on 1) calculating the proportion of pathways, species, and areas that require management and where a plan is in place; 2) assessing and scoring treatments based on their effectiveness; 3) multiplying the result from steps 1 and 2 to give an overall percentage success for pathways, species, and sites; and 4) finally in some way combining the percentage scores for pathways, species, and sites to give an overall figure that will vary between 100% (i.e. all aspects of biological invasions that need to be managed are being managed effectively) and 0% (i.e. there is no management or it is completely ineffective), with the option for negative values if management is counter-productive.

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Supplementary Material 4—Fact sheets for the proposed indicators for reporting on the state of biological invasions at a country level

These fact sheets are based on the guidelines of the Biodiversity Indicators Partnership (Biodiversity Indicators Partnership, 2011), with the addition of explicit sections on how to define the confidence interval for each metric. A matrix showing the direct links between the indicators (i.e. where one indicator is dependent on another indicator) is shown in Fig. S4.13. There are several additional facilitating mechanisms that are vital for successful interventions, specifically *accessibility of data and information*, *research*, *organisational and human capacity*, and *public awareness and engagement*. Indicators for these are not included as they are not used for measuring outcomes or outputs of the interventions themselves.

1. INTRODUCTION PATHWAY PROMINENCE

Use and interpretation

This indicator concerns the pathways that could facilitate the introduction of alien species to a country from another region. The indicator considers the size or prominence of the pathway of introduction (how active it is socioeconomically) but does not take into account how important the pathway is for the introduction of alien organisms. Depending on the available data, the indicator can be used to answer three questions:

- what is the size of the pathway of introduction?;
- how prominent is the pathway of introduction relative to the other pathways?; and
- how does the size of the pathway of introduction vary across space and time?

The indicator is important for measuring progress towards meeting Aichi Biodiversity Target 9 of the Convention on Biological Diversity.

Potential for aggregation

This indicator was developed for use at a national level. However, as data might be available at larger (e.g. regions or continents) or smaller (e.g. provinces or districts) spatial scales, the indicator can also be used at a wide range of scales.

Possible reasons for upward or downward trends

Upward or downward trends can be caused by changes to the routes travelled by vessels that transport goods and people. These changes could be due to factors such as the development of new, more favourable routes or political changes. Changes to the amount or type of goods being imported or the number of people entering a country could also result in upward or downward trends, and could be driven by political (e.g. trade agreements), socio-economic (e.g. consumer and travel trends) or environmental (e.g. droughts) factors.

An increase in the size or relative prominence of a pathway could mean that there has been an increase in the likelihood that alien organisms could be introduced through this pathway. However, this is not always the case, and various factors (e.g. the phytosanitary polices of the exporting nations and the size of the pool of potential invaders) will influence the strength of this link.

Implications for biodiversity management of change in the indicator

Upward or downward trends could lead to changes in the pathways that are prioritised for management and, as a consequence, to changes in the allocation of biosecurity resources (money and personnel).

Units in which it is expressed (from basic to advanced)

1.1	Five categories demonstrating the size of each pathway with pathways split along the CBD pathway categorisation (Scalera et al., 2016). • Not known • Pathway not present • Minor • Moderate

	• Major
1.2	A ranked order of pathways in terms of their prominence.
1.3	Spatially explicit vectors that detail the amount, number, and value of goods or vessels moving into the country per pathway, with information on the sources, routes, destinations, and timings.

Description of source data

Online global or national databases containing trade or transport data run by national governments, intergovernmental or global organisations and companies (e.g. http://www.fao.org/faostat/en/#data). Yearly data are often available, however, often not for the most recent years. Data can also be obtained from peer-reviewed journal articles and from the websites and reports of national governments, intergovernmental or global organisations and companies.

Calculation procedure

1.1	Experts use collected data to categorise each pathway as: • Not known • Pathway not present • Minor • Moderate • Major
1.2	For each pathway, calculate the amount, number or value of imported goods, vessels or infrastructure that connects the country to regions it was previously isolated from. Pathways are then ranked.
1.3	As above for different entry points and periods of time, no ranking.

Guide for applying confidence levels

1.1	High	Data collated specifically on a particular pathway and recorded regularly (e.g. annually); and evaluated by at least three relevant experts with agreement in almost all cases.
	Medium	Data available across larger time-scales (e.g. decades), or have to be interpreted based on other data sources; and/or evaluation by one expert; and/or a few cases of disagreement with multiple experts
	Low	Few direct estimates of the data or estimated entirely based on expert opinion.
1.2	High	Data collated for all pathways in comparable units and recorded regularly (e.g. annually).
	Medium	Data available across larger time-scales (e.g. decades), or substantial interpretation across different data sources is required for comparisons.

	Low	Few direct estimates of the data or rank is based on expert opinion.
1.3	High	Regularly recorded, detailed data for every pathway with the destination of the vessels or imports and date of arrival.
	Medium	Data available across larger spatial (e.g. provinces) or temporal scales (e.g. decades), or have to be interpreted based on other data sources.
	Low	Errors in data apparent or clear that some data are inconsistently recorded.

Most effective forms of presentation

1.1	A table with the CBD pathway subcategories and for each pathway the assigned pathway size
1.2	A table with the CBD pathway subcategories and the rank of each pathway, or a figure demonstrating the size of the pathways, with the pathways ordered according to their rank
1.3	Maps or figures demonstrating spatial and temporal variation in pathway size

Table S4.1 (Indicator 1.1)—Introduction pathway prominence for South Africa (data from van Wilgen and Wilson (2018)). The overall confidence was medium as while for most pathways good data exist, only one expert did the assessment.

Pathway category and sub-category		Pathway prominence
Release in nature	Biological control	Moderate
	Erosion control/dune stabilization (windbreaks, hedges…)	Not known
	Fishery in the wild (including game fishing)	Major
	Hunting	Moderate
	Landscape/flora/fauna "improvement" in the wild	Pathway not present
	Introduction for conservation purposes or wildlife management	Not known
	Release in nature for use (other than the above, e.g. fur, transport, medicinal use…)	Not known
	Other intentional release	Not known
Escape from confinement	Agriculture (including Biofuel feedstocks)	Major
	Aquaculture/mariculture	Minor
	Botanical garden/zoo/aquaria (excluding domestic aquaria)	Minor
	Pet/aquarium/terrarium species (including live food for such species)	Minor
	Farmed animals (including animals left under limited control)	Major
	Forestry (including afforestation or reforestation)	Major
	Fur farms	Minor
	Horticulture	Moderate
	Ornamental purpose other than horticulture	Not known
	Research and ex-situ breeding (in facilities)	Minor

Pathway category and sub-category		Pathway prominence
	Live food and live baits	Not known
	Other escape from confinement	Not known
Transport - Contaminant	Contaminant nursery material	Moderate
	Contaminated bait	Not known
	Food contaminant (including of live food)	Major
	Contaminant on animals (except parasites, species transported by host/vector)	Major
	Parasites on animals (including species transported by host and vector)	Major
	Contaminant on plants (except parasites, species transported by host/vector)	Moderate
	Parasites on plants (including species transported by host and vector)	Moderate
	Seed contaminant	Moderate
	Timber trade	Major
	Transportation of habitat material (soil, vegetation…)	Not known
Transport - Stowaway	Angling/fishing equipment	Major
	Container/bulk	Moderate
	Hitchhikers in or on airplane	Moderate
	Hitchhikers on ship/boat (excluding ballast water and hull fouling)	Moderate
	Machinery/equipment	Not known
	People and their luggage/equipment (in particular tourism)	Major
	Organic packing material, in particular wood packaging	Not known
	Ship/boat ballast water	Moderate
	Ship/boat hull fouling	Moderate
	Vehicles (car, train…)	Major
	Other means of transport	Not known
Corridor	Interconnected waterways/basins/seas	Minor
	Tunnels and land bridges	Minor
Unaided	Natural dispersal across borders of invasive alien species that have been introduced through pathways 1 to 5	Major

Table S4.2 (Indicator 1.2)—An example of the ranking of pathway prominence. Data from the National Ports Authority of South Africa and Airports Company of South Africa, accessed 22 March 2017.

Pathway sub-category	Rank	Rationale
Hitch-hiker on or in airplane	1	In 2015, there were ~50,000 vessels entering South Africa from international destinations
Hitchhiker on ship/boat	2	In 2015, there were ~10,000 vessels entering South Africa from international destinations, while these ships or boats might be expected to be generally larger than each airplane, the difference in opportunities for hitchhikers is not expected to be as much as fivefold.

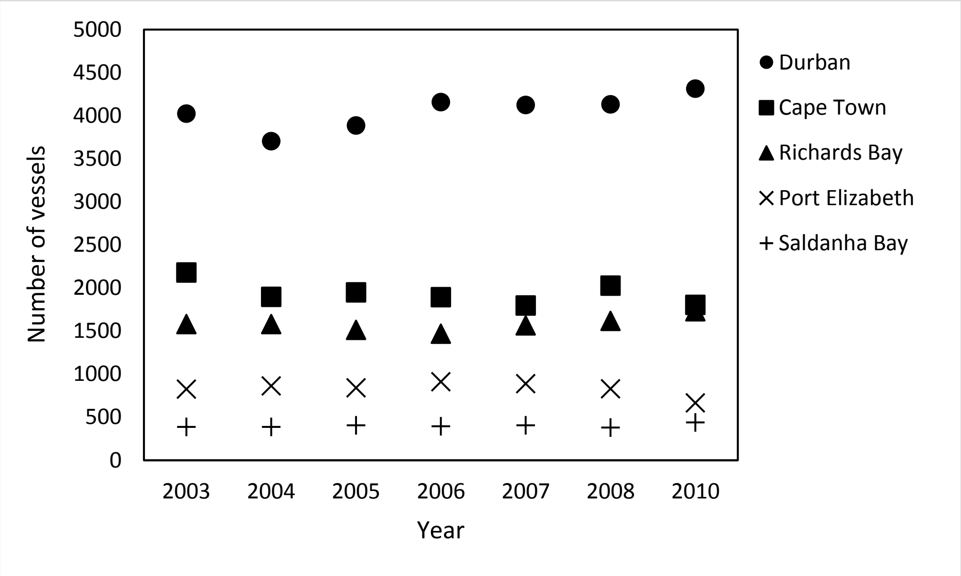

Figure S4.1 (Indicator 1.3)—The number of ocean going vessels arriving at South African ports over time. Data from the National Ports Authority of South Africa.

Limits to usefulness and accuracy

Reliant on data provided by national and global databases, for which data quality might not be known. Data quality can vary between countries, leading to more accurate assessments for some countries than others. Databases that are infrequently updated might cause difficulties when estimating upward or downward trends, or will not be useful if updated less frequently than the indicator is updated. Data that are only available at regional or larger scales, will be unsuitable for national scale assessments. Useful measures of pathway prominence might not be available for all pathways, particularly for less specific pathways such as 'other escape from confinement'. For some pathways there may be various types of data available, and this could lead to differing estimates. Often there is not a direct link between the data that are available and the pathway subcategories, such that it is difficult to aggregate or split data.

Updating the indicator

The indicator could be updated yearly or at coarser, but regular time intervals. At the least, the indicator should be updated as often as is required for reporting on the status of biological invasions.

Closely related indicators

Depends upon	Links with	Required for
none	*2. Introduction rates* *3. Within-country pathway prominence* *A. Rates of introduction of new unregulated species*	*12. Quality of regulatory framework* *14. Planning coverage* *15. Pathways treated* *18. Effectiveness of pathway treatments* *D. Level of success in managing invasions*

Additional information and comments

For some pathways it might be difficult to access data. For example, some transport data are owned by companies and to gain access to the data or databases a fee is often required. Transport data can be commercially sensitive.

2. INTRODUCTION RATES

Use and interpretation

This indicator concerns the pathways that facilitate the introduction of alien species to a country from another region, and specifically the introduction of new alien species (i.e. from the introduction debt, Rouget et al. (2016))

Depending on the available data, the indicator can be used to answer three questions:

- how many species have been introduced through each pathway;
- how has the number of species introduced through the pathway changed over time; and
- how has the number of individuals (of a specific species) introduced through the pathway varied over time and space (i.e. both propagule pressure and colonisation pressure)

The indicator is of particular use for measuring progress towards meeting Aichi Biodiversity Target 9 of the Convention on Biological Diversity (CBD, 2014).

Potential for aggregation

This indicator was developed for use at a national level, however, as the national level data can be aggregated, the indicator can also be used at larger spatial scales (e.g. regions or continents). For example, the number of species introduced through a pathway to different countries could be summed to get an indication of the importance of the pathway for a region or continent. As data could be available at both large (e.g. regions or continents) or small spatial scales (e.g. provinces or districts), the indicator can be used at a wide range of scales.

Possible reasons for upward or downward trends

Upward or downward trends could be caused by political (e.g. changes to trade agreements), environmental and socio-economic changes (like consumer trends and changes in travel trends), as well as changes to the biosecurity or policies (e.g. phytosanitary policies) of the importing and exporting nations. Upward or downward trends could also be linked to changes in research interest in alien species and in the number or intensity of surveys for these organisms.

An upward trend in this indicator can mean that the number of species introduced to the country through the pathway has increased. A downward trend in this indicator demonstrates that the number of species introduced to the country through the pathway has decreased.

Implications for biodiversity management of change in the indicator

Upward or downward trends could lead to changes in the pathways that are prioritised for management (as required under Aichi Biodiversity Target 9 of the Convention on Biological Diversity (CBD, 2014)) and, as a consequence, to changes in the allocation of biosecurity resources (money and personnel).

Units in which it is expressed (from basic to advanced)

2.1	The total number of alien species introduced through each CBD pathway sub-category over all time (CBD, 2014).
2.2	Five categories demonstrating changes over a recent period of time (e.g. since the 1980s or in the past decade) in the number of species introduced through each pathway. • Not known • No introductions • Increase • Decrease (if there were no introductions then specify) • Minimal change (if there were no introductions then specify)
2.3	Number of individuals of each species introduced through the pathways and place and date of introduction

Description of source data

Published peer-reviewed journal articles, alien species lists and databases. These could include local, national or global databases (e.g. the Global Invasive Species Database (http://www.iucngisd.org/gisd/), CABI Invasive Species Compendium (http://www.cabi.org/isc/)). Some alien species databases are regularly updated (every few years), however, this is not always the case.

Calculation procedure

2.1	For each pathway, calculate the total number of alien species introduced.
2.2	For each pathway and time period, calculate the total number of alien species introduced that were not present in the country at the time of introduction. Ideally different alternative models are fitted to the data and compared in a Bayesian framework or using the Aikaike Information Criterion (Seebens et al., 2017), but as a rule of thumb: • Not known • No introductions (during the last decade) • Increase (increase of ≥ 5 species over the last decade) • Decrease (decrease of ≥ 5 species over the last decade) • Minimal change (increase or decrease of < 5 species over the last decade)
2.3	For each entry point and period of time, calculate the number of individuals of each species introduced through each of the pathways

Guide for applying confidence levels

2.1	High	Direct evidence of the introduction pathway for most alien species and the species can easily be assigned to the pathway subcategories

	Medium	Pathway of introduction for most species can be inferred as the species appeared when and where a single pathway was in operation and there is no other explanation. Species can easily be assigned to pathway subcategories
	Low	Pathway of introduction is inferred for most species based on information on species traits and information from other regions or species cannot easily be assigned to the pathway subcategories. Data are not available for many species, qualitative estimates or based on expert opinion
2.2	High	Specific records exist for each pathway of all the introductions per year
	Medium	Species introductions can be inferred from data on numbers of alien species introduced with knowledge of likely introduction dates (in the order of several years)
	Low	The change in rate is from expert opinion, or data are not available for many species
2.3	High	Detailed, regularly recorded records exist for each introduction for all pathways on the point of introduction and number of individuals introduced
	Medium	Data available across larger spatial (e.g. provinces) or temporal scales (e.g. decades), or have to be interpreted based on other data sources
	Low	Based on expert opinion

Most effective forms of presentation

2.1	A figure demonstrating the number of alien species introduced through each pathway
2.2	A table with the CBD pathway subcategories and for each pathway the assigned change in introductions (i.e. Increase, decrease, minimal change, no introductions and not known)
2.3	Maps or figures demonstrating spatial and temporal variation in the number of individuals introduced through a pathway

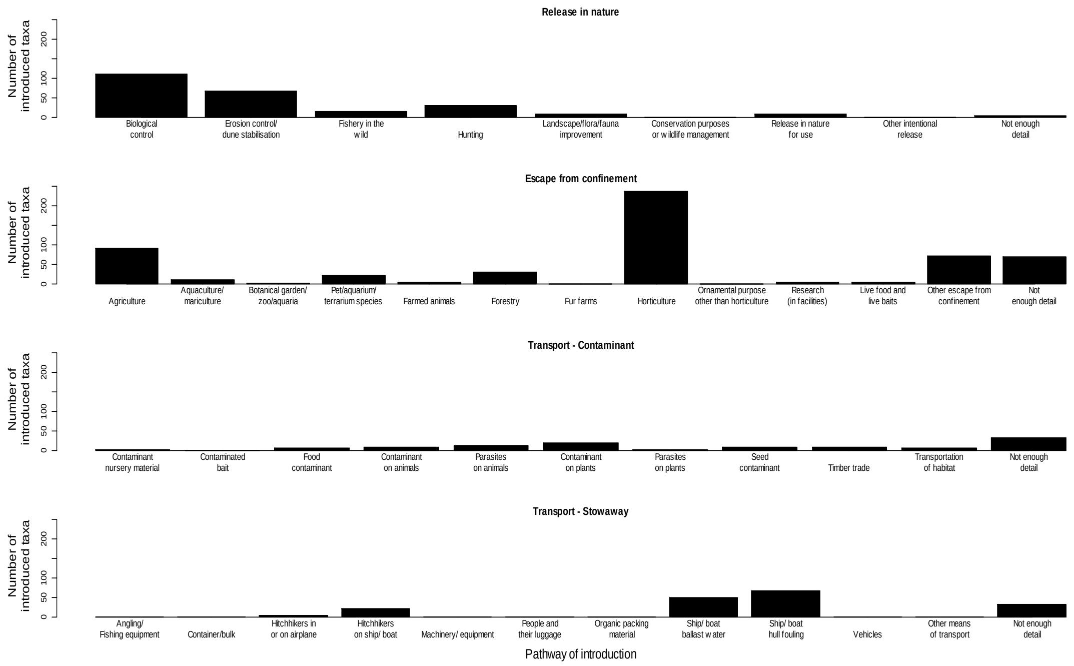

Figure S4.2 (Indicator 2.1)—Number of alien taxa introduced to South Africa through the pathways of introduction, and the number for which designation at the pathway subcategory level was not possible due to insufficient information. The graphs show the results for the pathway subcategories of the, from top to bottom, ‘Release in nature’, ‘Escape from confinement’, ‘Transport – Contaminant’ and ‘Transport – Stowaway’ pathway categories. Results for the unaided pathway are not shown. Figure from Chapter 3 of van Wilgen and Wilson (2018).

Table S4.3 (Indicator 2.2)—Changes to the rates of introduction in the last full decade in comparison to that of the previous decade. Data from Chapter 3 of van Wilgen and Wilson (2018).

Pathway category	Pathway sub-category	Change in introduction rates
Release in nature	Biological control	Decrease
	Erosion control/dune stabilization (windbreaks, hedges…)	Not known
	Fishery in the wild (including game fishing)	No introductions
	Hunting	Increase
	Landscape/flora/fauna "improvement" in the wild	No introductions
	Introduction for conservation purposes or wildlife management	No introductions
	Release in nature for use (other than the above, e.g. fur, transport, medicinal use…)	Not known
	Other intentional release	No introductions
Escape from confinement	Agriculture (including Biofuel feedstocks)	Not known
	Aquaculture/mariculture	No introductions

	Botanical garden/zoo/aquaria (excluding domestic aquaria)	No introductions
	Pet/aquarium/terrarium species (including live food for such species)	Minimal change
	Farmed animals (including animals left under limited control)	No introductions
	Forestry (including afforestation or reforestation)	Not known
	Fur farms	No introductions
	Horticulture	Not known
	Ornamental purpose other than horticulture	No introductions
	Research and ex-situ breeding (in facilities)	Not known
	Live food and live baits	No introductions
	Other escape from confinement	Not known
Transport - Contaminant	Contaminant nursery material	Not known
	Contaminated bait	No introductions
	Food contaminant (including of live food)	Not known
	Contaminant on animals (except parasites, species transported by host/vector)	Minimal change
	Parasites on animals (including species transported by host and vector)	Minimal change
	Contaminant on plants (except parasites, species transported by host/vector)	Minimal change
	Parasites on plants (including species transported by host and vector)	Minimal change
	Seed contaminant	Not known
	Timber trade	Not known
	Transportation of habitat material (soil, vegetation…)	Minimal change
Transport - Stowaway	Angling/fishing equipment	No introductions
	Container/bulk	No introductions
	Hitchhikers in or on airplane	Not known
	Hitchhikers on ship/boat (excluding ballast water and hull fouling)	Minimal change
	Machinery/equipment	No introductions
	People and their luggage/equipment (in particular tourism)	No introductions
	Organic packing material, in particular wood packaging	Not known
	Ship/boat ballast water	Minimal change
	Ship/boat hull fouling	Increase
	Vehicles (car, train…)	Not known
	Other means of transport	No introductions

Corridor	Interconnected waterways/basins/seas	No introductions
	Tunnels and land bridges	No introductions
Unaided	Natural dispersal across borders of invasive alien species that have been introduced through pathways 1 to 5	Minimal change

Limits to usefulness and accuracy

Difficulties associated with categorising species into the CBD pathway subcategories could lead to inaccuracies, these difficulties could be due to the similarity of some of the pathway subcategories, or as data are not of sufficient detail to make the designations. If pathway and date of introduction information are not available for many species, upward or downward trends in this indicator might be inaccurate. Trends may be influenced by the frequency or intensity of surveys for alien species. It does not consider whether such introductions are desirable or not. If the risk of an introduction was assessed and deemed acceptable prior to introduction, then that species is likely of less concern than accidental or unregulated intentional introductions.

Updating the indicator

The indicator should be regularly updated as data on alien species introductions becomes available, or as often as is required for reporting on the status of biological invasions.

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species	1. Introduction pathway prominence 4. Within-country dispersal rates	12. Quality of regulatory framework 14. Planning coverage 15. Pathways treated 18. Effectiveness of pathway treatments A. Rates of introduction of new unregulated species D. Level of success in managing invasions

Additional information and comments

Species might use multiple pathways. Yearly data might be available on alien species introductions, but this temporal scale might be too fine to calculate introduction trends.

It would be useful to record large inter-annual variations in the numbers of introductions per pathway sub-category, but this is not explicitly dealt with here.

The cut-off is in terms of absolute numbers of species, but relative measures could also be used.

3. WITHIN-COUNTRY PATHWAY PROMINENCE

Use and interpretation

This indicator concerns the pathways that facilitate the movement of alien species from one part of a country to another. The indicator considers the size or prominence of the pathway (how active it is socioeconomically) but does not take into account how important the pathway is for the dispersal of alien organisms. Depending on the available data, the indicator can be used to answer three questions:

- What is the size of the pathway?;
- How prominent is the pathway relative to the other pathways?; and
- How does the size of the pathway vary across space and time?

Potential for aggregation

This indicator was developed for use at a national level. However, as data might be available at large (e.g. regions or continents) or small (e.g. provinces or districts) spatial scales, the indicator can be used at a wide range of scales.

Possible reasons for upward or downward trends

Upward or downward trends could be caused by changes to the routes travelled by vessels that transport goods and people, these changes could be due to the development of new, more favourable routes or to local socio-economic changes (e.g. in the demand for certain products or travel trends). Changes to the number of people or the amount or type of goods being transported within the country could also influence these trends. With these changes possibly driven by socio-economic or environmental factors.

An increase in the size or relative prominence of a pathway could mean that there has been an increase in the likelihood that alien organisms are being dispersed within the country through this pathway. However, this might not be the case as various factors (e.g. the number and type of alien species introduced to the country) will influence the strength of this link.

Similarly, a downward trend in this indicator could mean that there has been a decrease in the likelihood that alien organisms are being moved around the country through a given pathway.

Implications for biodiversity management of change in the indicator

Upward or downward trends could lead to changes in the pathways that are prioritised for management and, as a consequence, to changes in the allocation of resources (money and personnel).

Units in which it is expressed (from basic to advanced)

3.1	Five categories demonstrating the size of each pathway with pathways split along the CBD pathway categorisation (CBD, 2014). • Not known • Pathway not present

	• Minor • Moderate • Major
3.2	A ranked order of pathways in terms of their prominence.
3.3	Spatially explicit vectors that detail the amount, number and value of goods or vessels moving around the country per pathway, with information on the sources, routes, destinations and timings.

Description of source data

Online global or national databases containing trade or transport data run by national governments, intergovernmental or global organisations and companies (e.g. the FAOSTAT database of the Food and Agricultural Organisation of the United Nations (http://www.fao.org/faostat/en/#data)). Yearly data are often available, however, often not for the most recent years. Data can also be obtained from peer-reviewed journal articles and the websites and reports of national governments, intergovernmental or global organisations and companies. Spatial data on transportation networks.

Calculation procedure

3.1	Experts use collected data to categorise each pathway as: • Not known • Pathway not present • Minor • Moderate • Major
3.2	For each pathway, calculate the amount, number or value of transported goods, vessels or infrastructure that connects previously unconnected regions. Pathways are then ranked.
3.3	As above for different routes and periods of time, no ranking

Guide for applying confidence levels

3.1	High	Data collated specifically on a particular pathway and recorded regularly (e.g. annually). Evaluated by at least three relevant experts with agreement in almost all cases
	Medium	Data available across larger time-scales (e.g. decades), or have to be interpreted based on other data sources and/or evaluation by one expert; and/or a few cases of disagreement with multiple experts
	Low	Few direct estimates of the data or estimated entirely based on expert opinion.

3.2	High	Data collated for all pathways in comparable units and recorded regularly (e.g. annually).
	Medium	Data available across larger time-scales (e.g. decades), or substantial interpretation across different data sources is required for comparisons.
	Low	Few direct estimates of the data or rank based on expert opinion.
3.3	High	Regularly recorded, detailed data for every pathway with the destination of the vessels or goods and date of arrival.
	Medium	Data available across larger spatial (e.g. provinces) or temporal scales (e.g. decades), or have to be interpreted based on other data sources.
	Low	Errors in data apparent or clear that data are inconsistently recorded.

Most effective forms of presentation

3.1	A table with the CBD pathway subcategories and for each pathway the assigned pathway size.
3.2	A table with the CBD pathway subcategories and the rank of each pathway, or a figure demonstrating the size of the pathways, with the pathways ordered according to their rank.
3.3	Maps or figures demonstrating spatial and temporal variation in pathway size.

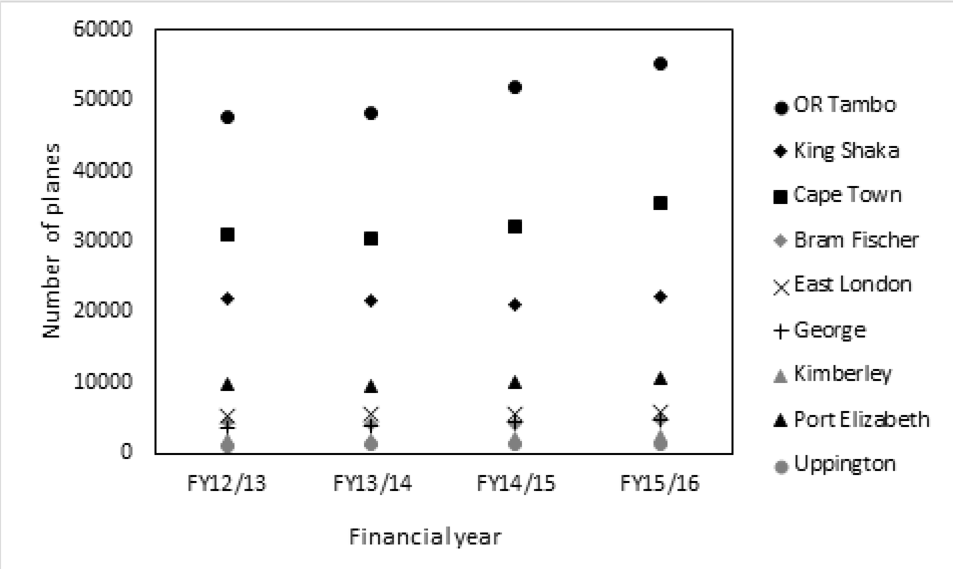

Figure S4.3 (Indicator 3.3)—Number of domestic flight arrivals at South African airports. Data were obtained from Airports Company South Africa, accessed 22 March 2017.

Limits to usefulness and accuracy

Reliant on data provided by national and global databases, for which data quality might not be known. Data quality might vary between countries leading to more accurate assessments for some countries than others. Databases that are infrequently updated might cause difficulties when estimating upward or downward trends, or will not be useful if updated less frequently than the indictor is updated. Data that are only available at regional or larger scales, will be unsuitable for national scale assessments. Useful measures of pathway prominence might not be available for all pathways, particularly for less specific pathways such as 'other escape from confinement'. For some pathways there may be various types of data available, and this could lead to differing estimates.

Updating the indicator

The indicator could be updated yearly or at coarser, but regular time intervals. At the least, the indicator should be updated as often as is required for reporting on the status of biological invasions.

Closely related indicators

Depends upon	Links with	Required for
	1. Introduction pathway prominence 4. Within-country dispersal rates	12. Quality of regulatory framework 15. Pathways treated 14. Planning coverage 18. Effectiveness of pathway treatments A. Rate of introduction of new unregulated species D. Level of success in managing invasions

Additional information and comments

For some pathways it might be difficult to access data. For example, some transport data are owned by companies and to gain access to the data or databases a fee is often required. Transport data can be commercially sensitive.

4. WITHIN-COUNTRY DISPERSAL RATES

Use and interpretation

This indicator concerns the pathways that facilitate the dispersal of alien species within a country, and in particular, the importance of the pathway for the dispersal of alien organisms. Depending on the available data, the indicator can be used to answer three questions:

- How many species have dispersed through the pathway?;
- How has the number of species dispersing through the pathway changed over time?; and
- How has the number of individuals (of a specific species) dispersing through the pathway varied over time and space?

The indicator is of particular use for measuring progress towards meeting Aichi Biodiversity Target 9 of the Convention on Biological Diversity (CBD, 2014).

Potential for aggregation

This indicator was developed for use at a national level, however, as the national level data can be aggregated, the indicator can also be used at larger spatial scales (e.g. regions or continents). For example, the number of species dispersing through a pathway within different countries could be summed to get an indication of the importance of the pathway for dispersal in a region or continent. As data could be available at both large (e.g. regions or continents) and small spatial scales (e.g. provinces or districts), the indicator can be used at a wide range of scales.

Possible reasons for upward or downward trends

Upward and downward trends could be caused by environmental and socio-economic changes (like changes to consumer or travel trends). Variations in the trends could also be linked to changes to research interest in alien species and to the number or intensity of surveys for these organisms.

An upward trend in this indicator demonstrates that the number of species dispersing through the pathway has increased. A downward trend in this indicator demonstrates that the number of species dispersing through the pathway has decreased.

Implications for biodiversity management of change in the indicator

Upward or downward trends could lead to changes in the pathways that are prioritised for management and, as a consequence, to changes in the allocation of resources.

Units in which it is expressed (from basic to advanced)

4.1	The total number of alien species dispersing through each pathway over all time, with pathways split along the CBD pathway categorisation (CBD, 2014).

4.2	Five categories demonstrating changes over a recent period of time (e.g. since the 1980s or in the past decade) in the number of species dispersing through each pathway. • Not known • No dispersal • Increase • Decrease (if there was no dispersal then specify) • Minimal change (if there was no dispersal then specify)
4.3	Number of individuals of each species dispersing through the pathways and place and date of arrival

Description of source data

Published peer-reviewed journal articles, alien species lists and databases. These could include local, national or global databases (e.g. the Global Invasive Species Database (http://www.iucngisd.org/gisd/), CABI Invasive Species Compendium (http://www.cabi.org/isc/)). Some alien species databases are regularly updated (every few years), however, this is not always the case.

Calculation procedure

4.1	For each pathway, calculate the total number of alien species that have dispersed though the pathway.
4.2	For each pathway and time period, calculate the total number of alien species dispersing through the pathway. Ideally different alternative models are fitted to the data and compared in a Bayesian framework or using the Akaike Information Criterion (Seebens et al., 2017), but as a rule of thumb: • Not known • No dispersals (over the last decade; note it can also be decrease or minimal change) • Increase (increase of ≥ 5 species over the last decade) • Decrease (decrease of ≥ 5 species over the last decade) • Minimal change (increase or decrease of < 5 species over the last decade)
4.3	For each period of time, calculate the number of individuals of each species dispersing through each of the pathways, and map the various routes followed

Guide for applying confidence levels

4.1	High	Direct evidence of the dispersal pathway for most alien species and the species can easily be assigned to the pathway subcategories

	Medium	Pathway of dispersal for most species can be inferred as the species appeared when and where a single pathway was in operation and there is no other explanation. Species can easily be assigned to pathway subcategories
	Low	Pathway of dispersal is inferred for most species based on information on species traits and information from other regions or species cannot easily be assigned to the pathway subcategories. Data are not available for many species, qualitative estimates or based on expert opinion
4.2	High	Specific records exist for each pathway for all the dispersal events per year
	Medium	Inferred from data on numbers of alien species with knowledge of likely dispersal dates (in the order of several years)
	Low	The change in rate is from expert opinion, or data are not available for many species
4.3	High	Detailed, regularly recorded records exist for each dispersal event for all pathways on the point of introduction and number of individuals dispersing
	Medium	Data available across larger spatial (e.g. provinces) or temporal scales (e.g. decades), or have to be interpreted based on other data sources
	Low	Based on expert opinion

Most effective forms of presentation

4.1	A figure demonstrating the number of alien species dispersing through each pathway
4.2	A table with the CBD pathway subcategories and for each pathway the assigned trend in the number of species dispersing through the pathway (i.e. increase, decrease, minimal change, no dispersal and not known)
4.3	Maps or figures demonstrating spatial and temporal variation in the number of individuals dispersing through a pathway

No examples provided here.

Limits to usefulness and accuracy

Poor data quality (e.g. no direct evidence of the dispersal pathway) might lead to the inaccurate designation of the pathways of dispersal. Difficulties associated with categorising species into the CBD pathway subcategories could lead to inaccuracies, these difficulties could be due to the similarity of some of the pathway subcategories, or as data are not of sufficient detail to make the designations. If pathway and date of introduction information are not available for many species, upward or downward trends in this indicator might be inaccurate. Trends may be influenced by the frequency or intensity of surveys for alien species.

A positive value will not necessarily be undesirable (e.g. for biological control agents), as the redistribution of effective and safe biological control agents is desirable.

Species might use multiple pathways, and this indicator does not distinguish between alien species that pose a risk.

Updating the indicator

The indicator should be regularly updated as data on the dispersal of alien species becomes available, or as often as is required for reporting on the status of biological invasions.

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species 6. Extent of alien species	2. Introduction rates 3. Within-country pathway prominence	12. Quality of regulatory framework 14. Planning coverage 15. Pathways treated 18. Effectiveness of pathway treatments. A. Rate of introduction of new unregulated species D. Level of success in managing invasions

Additional information and comments

None.

5. NUMBER AND STATUS OF ALIEN SPECIES

Use and interpretation

The basis for constructing lists of alien species for a country.

Such information is important for biosecurity to be able to target species which are not yet present and to identify threats based on what is already in the country. If the status is known this can be used to estimate the establishment part of the invasion debt, i.e. how many species are likely to naturalise in future.

Potential for aggregation

Can be presented per taxonomic group or aggregated across all species. Can be used at a variety of spatial scales, depending on the scale at which data are available.

Possible reasons for upward or downward trends

Increases can be due to new taxa being introduced; taxa that were already introduced being detected for the first time; improvements in identification or taxonomic revision.

Increases in status can be the result of species exiting a lag phase (e.g. there was a mechanistic reason preventing naturalisation or invasion that has been lifted); having sufficient time in a country for them to exhibit their invasive potential; or a new record.

Decreases can be due to eradications as a result of active management; populations being unintentionally wiped out (e.g. by the removal of habitat); as individuals and populations naturally die and collapse; or again due to revisions in identifications.

Implications for biodiversity management of change in the indicator

Biosecurity resources can be reallocated to preventing the introduction of taxa which are no longer in the country.

If status increases it might indicate a need to reassess the invasive risk of an alien taxa, or to precipitate an incursion response.

Gives an indication of the effectiveness of species-focused control measures.

Units in which it is expressed (from basic to advanced)

5.1	Number of invasive species
5.2	Number of alien species in one of three categories: • Alien but not naturalised • Naturalised but not invasive • Invasive
5.3	Number of species at different stages of the Unified Framework (Blackburn et al., 2011). Ordered factor with 12 categories, note in the Unified Framework there are 11 categories, we have split and rephrased category A so it is with reference to the region of interest

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and there is a distinction between species that are no longer in the region and those that were never in the region. If there is some uncertainty a range can be given or a number omitted. In the original scheme the term “in the wild” was used, but the term “outside of captivity or cultivation” is preferred here (F. Essl, pers. com. Sep. 2017)

A0: Never introduced beyond limits of native range to region;
A1: Has been introduced beyond limits of native range to region, but no longer present;
B1: Individuals transported beyond limits of native range, and in captivity or quarantine (i.e. individuals provided with conditions suitable for them, but explicit measures of containment are in place);
B2: Individuals transported beyond limits of native range, and in cultivation (i.e. individuals provided with conditions suitable for them but explicit measures to prevent dispersal are limited at best);
B3: Individuals transported beyond limits of native range, and directly released into novel environment;
C0: Individuals released outside of captivity or cultivation in location where introduced, but incapable of surviving for a significant period;
C1: Individuals surviving outside of captivity or cultivation in location where introduced, no reproduction;
C2: Individuals surviving outside of captivity or cultivation in location where introduced, reproduction occurring, but population not self-sustaining;
C3: Individuals surviving outside of captivity or cultivation in location where introduced, reproduction occurring, and population self-sustaining;
D1: Self-sustaining population outside of captivity or cultivation, with individuals surviving a significant distance from the original point of introduction;
D2: Self-sustaining population outside of captivity or cultivation, with individuals surviving and reproducing a significant distance from the original point of introduction;
E: Fully invasive species, with individuals dispersing, surviving and reproducing at multiple sites across a greater or lesser spectrum of habitats and extent of occurrence.

Introduced but not naturalised corresponds to B1–C2. Naturalised but not invasive corresponds to C3. Invasive corresponds to D1–E.
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Description of source data

Physical samples lodged in collections. DNA barcodes linked to a field collection. Field observations. Archival records. Results from assessments of the status of alien populations.

Calculation procedure

5.1	The total number of species known to be invasive. There must be evidence for alien status (i.e. that it is not native), presence (i.e. there is a confirmed record in the location), and invasiveness (i.e. there is some natural spread from sites of introduction)
5.2	As above, with additional field observations as to the status of populations, in the absence of information the assumption is made that taxa have not naturalised, or are not invasive.
5.3	As above, with detailed field observations using appropriate protocols (e.g., Wilson et al., 2014, Robinson et al., 2016).

Guide for applying confidence levels

5.1	High	Physical sample lodged in recognised collection identified by expert or molecular sample confirmation in the last 50 years; and All databases state that the taxon is alien and there is no evidence of debate about nativity; and Field notes in the past decade confirming invasiveness based on biogeographic definition of invasive (Blackburn et al., 2011).
	Medium	No physical sample, or sample but collected over a decade ago with no recent field confirmations; and/or Categorised as alien in most authoritative source, although some references report as native with no detailed published analysis confirming nativity; and/or Invasiveness inferred from records.
	Low	Recorded as present but record either questioned or last record from a substantial time ago (e.g. not in the most recent update); and/or Nativity in dispute.
5.2	High	Based on recent published field observations
	Medium	Based on recent unpublished field observations
	Low	Based on expert opinion only with no clear indication of last field observations
5.3	High	Based on recent field observation specifically using the coding of the Unified Framework
	Medium	Based on historical field observations with enough information to code populations according to the Unified Framework.
	Low	Interpreted from distribution data in a data-set

Most effective forms of presentation

5.1	As a number
5.2	In a bar chart
5.3	As a table, or as a bar chart (can be plotted as a bar chart noting changes)

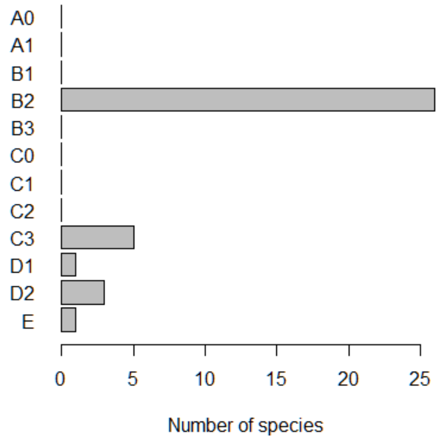


Figure S4.4 (Indicator 5.3)—The status of introduced *Melaleuca* species in South Africa as per the Unified Framework. Only species that are known to still be in South Africa are included, so A0 and A1 are not quantified here. Data from Jacobs et al. (2017).

Limits to usefulness and accuracy

It can be highly sensitive to search effort and taxonomy, so for under-studied taxonomic groups, the number of alien species in a country will be a function of how much material has been collected and whether taxonomists have worked on it.

Assumes an equivalency between species, e.g. one alien tree species is the same as one mite species. It also relies on species being well defined concepts and similarly does not encapsulate invasion at a gene level (Petit, 2004).

There can be inconsistencies in the use of the terminology, e.g. in some databases the definition of “invasive” requires populations to be found in “natural” areas or that a negative impact of some sort has been recorded.

Updating the indicator

Should be done on an on-going basis as new detections are made and new instances of naturalisation or invasions are noted. However, it might be necessary for a specific effort to be made to update records according to the Unified Framework, and guidelines for scoring different taxa are still needed. The Unified Framework and protocols for the framework might develop over time.

Closely related indicators

Depends upon	Links with	Required for

6. Extent of alien species (for 5.3) 7. Abundance of alien species (for 5.3)	None	2. Introduction rates 4. Within-country dispersal rates 6. Extent of alien species 7. Abundance of alien species 8. Impact of alien species 9. Alien species richness 10. Relative invasive abundance 11. Impact of invasions 12. Quality of regulatory framework 13. Money spent 14. Planning coverage 15. Pathways treated 16. Species treated 18. Effectiveness of pathway treatments 19. Effectiveness of species treatments 20. Effectiveness of site treatments A. Rate of introduction of new unregulated species B. Number of invasive species that have major impacts C. Extent of area that suffers major impacts from invasions D. Level of success in managing invasions

Additional information and comments

At a basic level, the metric is number of invasive species rather than number of alien species. This is because for many groups only invasive species will be known with any level of accuracy (they tend to be much more detectable). However, it does require additional information that taxa are actually invasive.

Species which are both native and alien to a region, and cryptic invasions need to be dealt with consistently.

Should link to various databases, e.g. the Global Register of Introduced and Invasive Species, that provide checklists of alien species in a country. Such checklists are often taxon specific, but the data should be aggregated across all taxonomic groups.

While regulatory lists can provide some indication of alien species, it is often difficult to trace these to verified physical records, and they might be the result of some prioritisation exercise (so are only a subset of species that have undesirable impacts).

6. EXTENT OF ALIEN SPECIES

Use and interpretation

Provides an indication of how widespread alien species are and provides information that can be used for metrics of how invaded sites are and where impacts might be occurring.

Species that are more widespread or that are increasing in range might be considered to be of greater concern (Parker et al., 1999), though there can often be a weak link between extent and impact across species (Hulme, 2012).

Potential for aggregation

Can provide an overall picture of which alien species are the most widespread. Can be split along taxonomic or functional lines to provide an indication of which are the most widespread alien taxa.

Possible reasons for upward or downward trends

The extent will increase with greater survey effort and species dispersing (either naturally or particularly through human-mediated within-country dispersal at broader spatial scales).

The extent will decrease as populations die out (either through natural means, e.g. stochastic climatic events and directional shifts in climate, or through control measures leading to extirpation). It is possible that errors in reporting could also lead to declines in species extents.

Implications for biodiversity management of change in the indicator

Provides an indication of the area over which management interventions are needed for a given species. Declines (or a relative reduction in spread rates) can indicate the effectiveness of control interventions.

Units in which it is expressed (from basic to advanced)

6.1	Number of large-scale national subdivisions (provinces, primary catchments or bioregions as appropriate) occupied per species
6.2	Number of finer-scale national subdivisions (quarter-degree grid cells or hectads) occupied per species
6.3	Range size for each species (e.g. km^2 or ha)

Description of source data

Data from atlas projects, or distribution surveys

Calculation procedure

6.1	Data are collected at large-scale resolution or point data need to be interpreted in terms of which large-scale sites are occupied (e.g. using a GIS)
6.2	As above
6.3	A technique is applied to observation data in a GIS using an appropriate projection. In some cases a convex hull approach might be sufficient, but might need to use an alpha-hull approach for species with disjunct distributions (likely for many aliens).

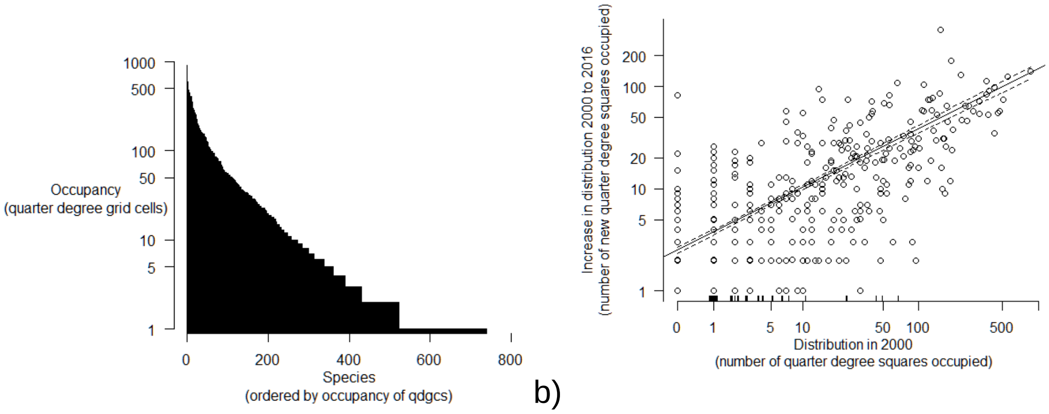
Guide for applying confidence levels

6.1	High	Included in a formal verified atlas or mapping project based on recent surveys with adequate ground-truthing. There is some indication that there have been surveys at sites that are marked as absent
	Medium	Data from an atlas project, though it is not explicit that absences would have been recorded/some sites might not have been surveyed
	Low	Interpreted from expert opinion
6.2	High	As for 6.1
	Medium	As for 6.1
	Low	As for 6.1
6.3	High	Data based on a project within the last decade specifically designed to map the range of the taxon in question, with search effort explicit and sufficient to determine where taxa are and where they are not. Might include citizen science component for easily identified taxa. Appropriate statistical technique used to estimate total range size (particular if disjunct distributions)
	Medium	Data from atlas project or general mapping project with indication of sampling effort, but data not complete or not recent (e.g. >10 years old)
	Low	No absence data, no clear statistical methodology for estimating range size, or very broad estimate.

Most effective forms of presentation

6.1	Bar chart showing frequency distribution of range per taxon; plot of how ranges have changed over time
6.2	As for 6.1

6.3	As for 6.1



a) b)

Figure S4.5 (Indicator 6.2)—In panel a is the extent of naturalised plants in South Africa in 2010 based on the Southern African Plant Invaders Atlas as a frequency distribution of occupancy per species (Wilson et al., 2013); panel b shows changes in the distribution of occupancy of naturalised plants in South Africa from 2000 to 2016 from the Southern African Plant Invaders Atlas (SAPIA; Henderson and Wilson, 2017). In panel b taxa with no change in range size are shown as tick marks on the x-axis, declines in range were not recorded in SAPIA (but could have happened).

Limits to usefulness and accuracy

An alien taxon might be present at a site but restricted to particular environments (in some cases human influenced), or at very low density, so the indicator does not map directly to impact.

The accuracy of the data will depend on large-scale repeated surveys. Often need to assume absences, and in many databases these are not recorded.

Updating the indicator

This can be done ad hoc, but ideally should be linked to set survey frequency or at least with respect to repeat surveys.

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species	None	4. Within-country dispersal rates 5. Number and status of alien species 7. Abundance of alien species 8. Impact of alien species 9. Alien species richness 10. Relative invasive abundance 11. Impact of invasions 12. Quality of regulatory framework

		13. Money spent 14. Planning coverage 15. Pathways treated 16. Species treated 17. Area treated 18. Effectiveness of pathway treatments 19. Effectiveness of species treatments 20. Effectiveness of site treatments A. Rate of introduction of new unregulated species B. Number of invasive species that have major impacts C. Extent of area that suffers major impacts from invasions D. Level of success in managing invasions

Additional information and comments

At a finer-scale it can be important to consider presence in ecologically relevant sub-divisions, e.g. habitats or vegetation types.

The abundance can be used in concert with the extent to look at dynamics across scales (Kunin, 1998). Such area-occupancy curves can be used to explore mechanisms affecting dispersal dynamics (Veldtman et al., 2010, Donaldson et al., 2014).

7. ABUNDANCE OF ALIEN SPECIES

Use and interpretation

Provides an indication of how many individuals there are of particular species. Can be used as part of prioritisation efforts for species-specific control measures.

Potential for aggregation

Can be split into taxonomic groups.

Possible reasons for upward or downward trends

Changes can be due to population growth or decline; more survey work; or changes in survey techniques.

Implications for biodiversity management of change in the indicator

Core outcome variable for the effectiveness of species-based interventions. Changes could lead to the reallocation of resources.

Units in which it is expressed (from basic to advanced)

7.1	Categorical measure of abundance per species per locality in one of five categories: • not known • absent • rare • occasional • abundant
7.2	Number of individuals for mobile organisms or condensed area occupied for sessile organisms
7.3	Abundance estimates divided into appropriate stage or age cohorts. At a basic level numbers of individuals which are reproductive or not.

Description of source data

Field or remotely sensed observations, some representative sub-sampling of populations that are then used to extrapolate total population estimates (e.g. mark-recapture), or direct counts of individuals.

Calculation procedure

7.1	Based on expert opinion or crude broad-brush observations
7.2	Sub-sampling and extrapolation using models; or direct total counts
7.3	As for 7.2

Guide for applying confidence levels

7.1	High	Recent survey, technique used well documented, and several people confirming the value obtained (e.g. included in a formal verified atlas or mapping project based on recent surveys with adequate ground-truthing)
	Medium	data from an atlas project, or recent survey but only one person
	Low	interpreted from expert opinion, or no clear basis for the value given, or over 10 years ago.
7.2	High	Accurate and recent population census, using appropriate statistical techniques.
	Medium	Estimation based on sampling that uses assumptions and makes extrapolations
	Low	expert opinion
7.3	High	As for 7.2
	Medium	As for 7.2
	Low	As for 7.2

Most effective forms of presentation

7.1	Bar chart of different species/tables
7.2	Frequency histogram of different species
7.3	Size distribution graphs for each taxon, with indications of which individuals are reproductively active.

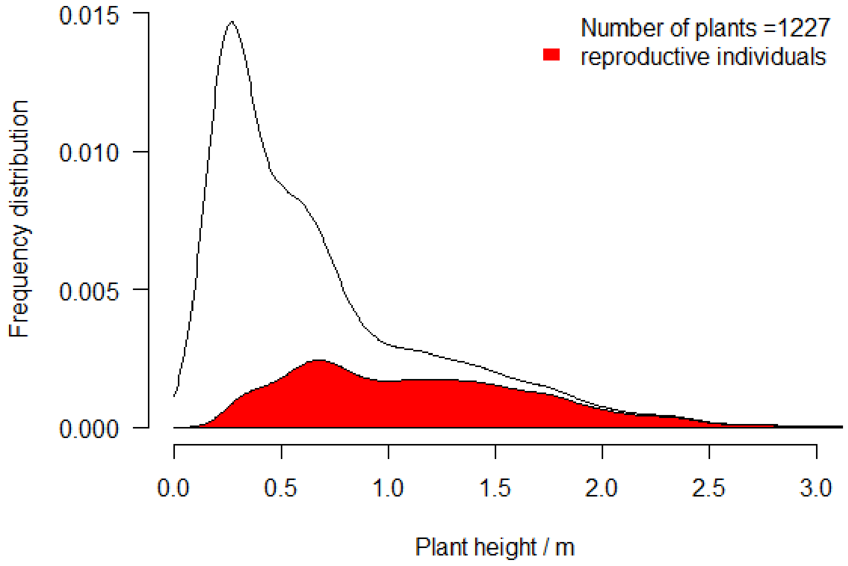


Figure S4.6 (Indicator 7.3)—Size frequency distribution from naturalised populations of *Genista monspessulana* in South Africa in 2012 (Geerts et al., 2013). Data are pooled from several sites, and roughly a tenth of the total population estimate (~10,000 plants) were measured. In addition, *G. monspessulana* was estimated to have a seed-bank of several million.

Limits to usefulness and accuracy

Without stage-structured information (7.1 and 7.2), coarse numbers can be a bit misleading as there might be a large number of juveniles and few reproductively active adults (so population growth will at least initially be slow).

As for extent, abundance does not necessary map on to impact.

Updating the indicator

Can be updated after individual surveys, might be part of annual progress reports.

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species 6. Extent of alien species	None	5. Number and status of alien species 8. Impact of alien species 9. Alien species richness 10. Relative invasive abundance 11. Impact of invasions 12. Quality of regulatory framework 13. Money spent 14. Planning coverage 16. Species treated 17. Area treated 19. Effectiveness of species treatments 20. Effectiveness of site treatments A. Rate of introduction of new unregulated species B. Number of invasive species that have major impacts

		C. Extent of area that suffers major impacts from invasions D. Level of success in managing invasions

Additional information and comments

The abundance can be used in concert with the extent to look at dynamics across scales (Kunin, 1998). Such area-occupancy curves can be used to explore mechanisms affecting dispersal dynamics (Veldtman et al., 2010, Donaldson et al., 2014).

8. IMPACT OF ALIEN SPECIES

Use and interpretation

Identify which alien species are causing the largest negative impacts.

Helps identify which types of impacts are most common (i.e. the impact mechanisms).

If the current impact level is less than the maximum impact level ever recorded this provides an indication that any interventions to reduce impacts might have been successful.

Potential for aggregation

Can be scaled up, i.e. if impact is massive at a local scale it will be massive at a global scale. However, it can be difficult to scale down as it might be unclear where the impacts are.

Possible reasons for upward or downward trends

Better reporting of impacts. Mitigation or management effective in reducing impacts. Changes to the extent and abundance of alien species leading to greater impacts. Impacts accruing over time due to lagged biodiversity responses (Essl et al., 2015).

Implications for biodiversity management of change in the indicator

There might be a change in which species should be prioritised for management. If the impact of a species declines, then it might be indicative of successful asset protection.

Units in which it is expressed (from basic to advanced)

8.1	Categorical factor with eight levels. A single value should be given which is the maximum current recorded impact in the region. The impact will be the highest of either the Environmental Impact Classification of Alien Taxa (EICAT) or Socio-economic Impact Classification of Alien Taxa (SEICAT) schemes (Blackburn et al., 2014, Bacher et al., 2018) • **NE**: Not evaluated • **NA**: No alien populations in the region • **DD**: Data deficient • **MC**: Minimal Concern (note: there is no category for no impact) • **MN**: Minor • **MO**: Moderate • **MR**: Major • **MV**: Massive
8.2	For each species the current and maximum ever impact score for each possible impact mechanism.

Description of source data

Published literature on impacts of alien species.

Calculation procedure

8.1	See Hawkins et al. (2015) for EICAT and Bacher et al. (2018) for SEICAT. The current maximum recorded impact might be different from the maximum ever recorded.
8.2	As for 8.1, but current and maximum ever impact recorded for all impact mechanisms.

Guide for applying confidence levels

8.1	High	See guideline in Hawkins et al. (2015) for EICAT and Bacher et al. (2018) for SEICAT. Impact assessment formally conducted for the relevant country and reviewed by IUCN EICAT team (a similar SEICAT team is still to be set up). To be based on data within the last decade.
	Medium	As above, with evidence that the impact assessment was conducted according to EICAT procedure, but not formally reviewed; and/or data within the last 50 years was used.
	Low	As above, and it is not clear how the assessment was arrived at, it was entirely extrapolated from impacts in other regions, or the data are over 50 years old.
8.2	High	As for 8.1.
	Medium	As for 8.1.
	Low	As for 8.1.

Most effective forms of presentation

8.1	A histogram or table of species per category.
8.2	A histogram showing which mechanisms are most frequently recorded for a given group at a given level of impact.

Table S4.4 (Indicator 8.1)—Global impact assessment for selected alien frog species. This is based on a combination of EICAT and SEICAT assessments (Kumschick et al., 2017, Bacher et al., 2018).

Species	*Impact of alien species* (confidence)
Rhinella marina	**MR** (high)

Duttaphrynus melanostictus	**MR** (low)
Eleutherodactylus coqui	**MO** (high)
Eleutherodactylus planirostris	**MN** (low)
Hyla meridionalis	**MO** (low)

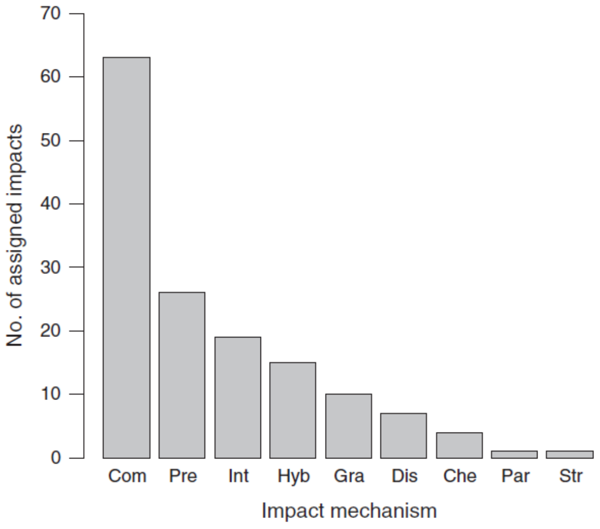


Figure S4.7 (Indicator 8.2)—The number of impact mechanisms recorded for alien birds (Evans et al., 2016). Com, Competition; Pre, predation; Int, interaction with other alien species; Hyb, hybridization; Gra, grazing/herbivory/browsing; Dis, transmission of disease to native species; Che, chemical impact on ecosystem; Par, parasitism; Str, structural impact on ecosystem.

Limits to usefulness and accuracy

Highly dependent on the availability of published assessments of impact. As such it will normally represent an observed minimum, and underestimate impacts. It only represents observed historical impact and not future threat.

EICAT and SEICAT assessment are only possible for well-studied species, and so there can be a bias introduced.

Updating the indicator

Can be updated as new studies are published.

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species 6. Extent of alien species 7. Abundance of alien species 11.Relative alien abundance	12. Quality of regulatory framework 13. Money spent 16. Species treated	11. Impact of invasions 14. Planning coverage 16. Species treated 19. Effectiveness of species treatments 20. Effectiveness of site treatments B. Number of invasive species that have major impacts C. Extent of area that suffers major impacts from invasions D. Level of success in managing invasions

Additional information and comments

The IUCN is in the process of ratifying EICAT and working towards potentially adopting SEICAT as official IUCN products. Global assessments might be slightly different from assessments at a local level. There will need to be a substantial on-going investment in impact studies for this indicator to be sufficiently reactive to allow the monitoring of trends on the scale of years rather than decades.

9. ALIEN SPECIES RICHNESS

Use and interpretation

This is an indicator of the number of alien species at a particular site. Higher numbers of invasive species indicate the number of issues to be addressed, while higher numbers of all alien species indicate a higher risk of invasion, as a proportion of these species can be expected to become invasive over time. The indicator can be used at a range of scales to track invasion debt.

Potential for aggregation

This indicator is expressed at a particular spatial scale (for example a country, a province, or a municipality; or at primary, secondary or tertiary catchment scales) and can be aggregated upwards from data collected at finer scales.

Possible reasons for upward or downward trends

Upward trends are to be expected as more alien species are introduced and spread around the region. Downward trends would occur if alien species were extirpated from a region, or failed to establish self-sustaining populations and disappeared locally. Changes to taxonomy or survey efforts might affect values.

Implications for biodiversity management of change in the indicator

As alien species richness increases, the number of species that need to be managed increase. As resources to manage all species over the whole site would probably be limiting, species would need to be prioritised in terms of potential impacts on biodiversity.

If the invasion stage is known, it can also be used to identify potential hotspots of future naturalisation.

Units in which it is expressed (from basic to advanced)

9.1	The total number of invasive species per large-scale national sub-division.
9.2	The total number of invasive species per finer-scale national sub-division.
9.3	The number of alien species in different stages of the Unified Framework per finer-scale national sub-division

Description of source data

Records of alien species distribution at scales suitable for upward aggregation. In South Africa, the prominent example is the Southern African Plant Invaders Atlas (SAPIA), in which presence and absence are recorded at the scale of quarter degree grid cells (QDGCs), and these can be examined at higher spatial scales.

Calculation procedure

9.1	A count of invasive species within a large-scale national subdivision.
9.2	A count of invasive species within a finer-scale national subdivision.
9.3	A count of alien species at different stages of the Unified Framework within a finer-scale national subdivision.

Guide for applying confidence levels

9.1	High	Based on recent (within the past 5 years) data from across the entire site, populations are formally recorded as invasive.
	Medium	Based on recent data from surveys that cover portions of all or most habitat types within the site and/or there is documentation that some populations are invasive.
	Low	Based on older data (collected more than five years ago), or data gathered from some, but not all, habitat types within the site.
9.2	High	Based on data in which at least 80% of the finer-scale units have been surveyed over the past five years.
	Medium	Based on data in which at least 40% of the finer-scale units have been surveyed over the past five years.
	Low	Based on data in which less than 40% of the finer-scale units have been recently surveyed, or where data from finer-scale units are older than five years
9.3	High	As for 9.2 with confidence level for alien species status from 5.3
	Medium	As for 9.2 with confidence level for alien species status from 5.3
	Low	As for 9.2 with confidence level for alien species status from 5.3

Most effective forms of presentation

9.1	A table or map of invasive species richness per large-scale national subdivision.
9.2	A table or map of invasive species richness per finer-scale national subdivision.
9.3	Tables or maps of alien species at different stages of the Unified Framework within finer-scale national subdivisions.

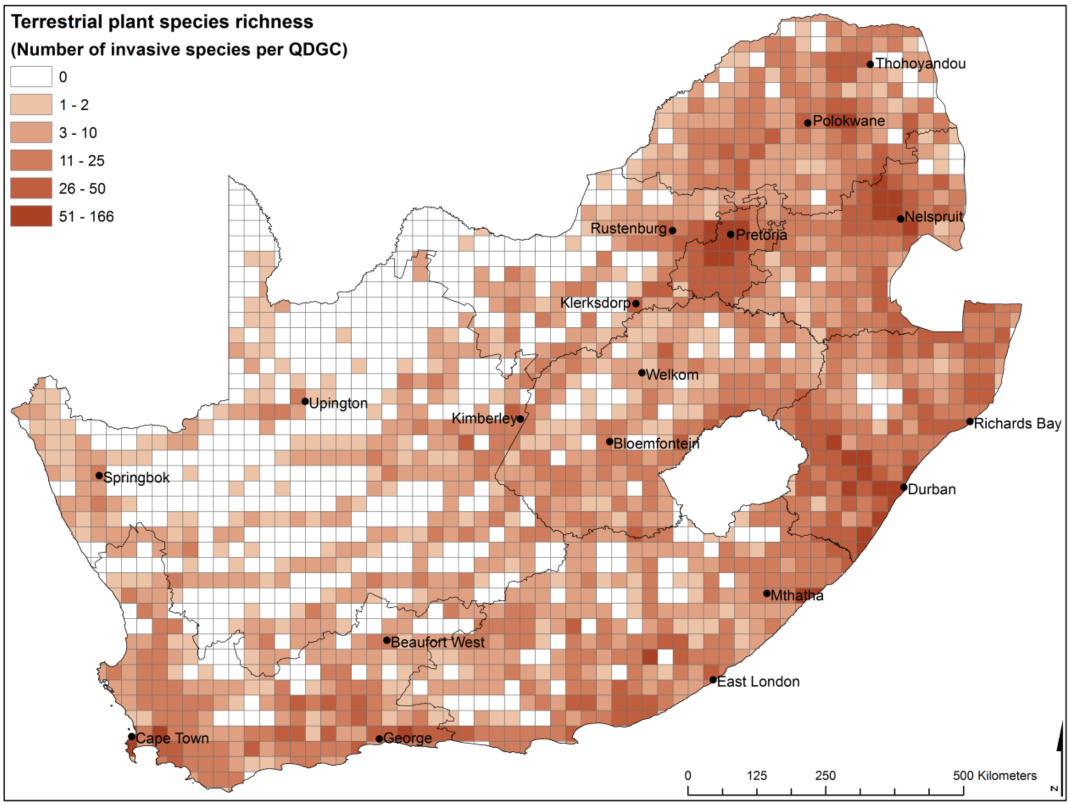


Figure S4.8 (Indicator 9.2)—Invasive plant species richness at a quarter-degree grid cell scale in South Africa. Data are from the Southern African Plant Invaders Atlas extracted May 2016, figure from Chapter 5 of van Wilgen and Wilson (2018).

Limits to usefulness and accuracy

Large sites would have to be covered on a regular basis to detect trends.

The indicator works well for highly visible taxa (terrestrial plants, birds), but not for others.

In some cases it is not clear if records represent invasive populations or presence within captivity or cultivation.

Updating the indicator

Can in theory be updated dynamically, but likely only done for reports on status, e.g. three years at a national level for South Africa. This would be useful for highly visible taxa, but for other taxa a longer period between updates would be more appropriate.

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species 6. Extent of alien species 7. Abundance of alien species	None	11. Impact of invasions 12. Quality of regulatory framework 14. Planning coverage 16. Species treated

		19. Effectiveness of species treatments 20. Effectiveness of site treatments C. Extent of area that suffers major impacts from invasions D. Level of success in managing invasions

Additional information and comments

The indicator at lower levels does not make a distinction between records of invasive populations and alien populations. Most data, however, are collected on invasive populations (e.g. excluding plants in people's gardens).

10. RELATIVE INVASIVE ABUNDANCE

Use and interpretation

This indicator measures the degree to which a site is invaded by considering the combined abundance of all invasive populations present relative to the abundance of indigenous and invasive organisms. *Relative invasive abundance* is a useful indicator of the degree of stress on an ecosystem, and it can be used at a range of spatial scales.

Potential for aggregation

Can be split into taxonomic groupings.

Possible reasons for upward or downward trends

Changes in the relative proportion of area in different categories would indicate trends in the abundance of invasive species along a continuum from alien free to dominated by invasives. Increases in area in low-level categories should be accompanied by decreases in high-level categories, and vice-versa, providing a means for assessing the effectiveness of control measures.

Implications for biodiversity management of change in the indicator

Management would presumably seek to reduce the *relative invasive abundance* at high priority sites. If trends indicate that management is not effective, it would inform decisions about the prioritisation and allocation of scarce funds to sites where they would be more effectively used.

Units in which it is expressed (from basic to advanced)

10.1	The proportion of the abundance (measured as cover, biomass, or number of individuals depending on the taxonomic group under consideration) that is invasive expressed at six levels for a given spatial unit • not known • invasive-free • minor • moderate • extensive • dominant
10.2	A quantitative estimate of the percentage abundance that is invasive for a given spatial unit

Description of source data

The relative invasive abundance would be assessed for particular sites. The data required would depend on the basis of measurement chosen. For example, the use of plant cover could be derived from mapping exercises, or from remote sensing; estimating numbers of individuals would require a population census; and estimating biomass would require physical sampling or remote sensing. Ideally these kinds of data should be assembled during the development of management plans, and tracked through regular monitoring of progress towards management goals.

Calculation procedure

10.1	Basic information for this indicator should be collected at the scale of management units, for example protected areas or tertiary or quaternary catchments. Each unit is assigned to a single category of relative abundance based on the proportion of the abundance of alien species to indigenous species, as follows: • Invasive-free: No invasive populations occur at the site • Minor: Invasive plants cover < 2% of the area that is covered by plants; or invasive species make up < 2% of the biomass of the entire community; or populations of invasive animals make up < 2% of all individual animals at the site. • Moderate: Invasive plants cover 2 - 10% of the area covered by plants, or invasive species make up 2 - 10% of the biomass of the area; populations of invasive animals make up 2 - 10% of all individual animals at the site. • Extensive: Invasive plants cover 10 - 50% of the area covered by plants, or invasive species make up 10 - 50% of the biomass of the area; populations of invasive animals make up 10 - 50% of all individual animals at the site. • Dominant: Invasive plants cover > 50% of the area covered by plants, or invasive species make up > 50% of the biomass of the area; populations of invasive animals make up > 50% of all individual animals at the site.
10.2	As above, but with a quantitative estimate

Guide for applying confidence levels

10.1	High	Cover estimates are based on mapping or the use of remote sensing that samples > 80% of the area of the site; biomass estimates are made on the basis of sampling a representative set of habitats, and extrapolated on the basis of reliable habitat maps; population estimates are made on the basis of sampling that covers > 80% of the area of the site.
	Medium	Cover estimates are based on mapping or the use of remote sensing that samples 20 - 80% of the area of the site; biomass estimates are made on the basis of limited sampling, and/or extrapolated on the basis of coarse habitat subdivisions; population estimates are made on the basis of sampling that covers 20 - 80% of the area of the site.
	Low	All estimates are based on local knowledge of the area concerned, or on limited sampling that covers < 20% of the area of the site.
10.2	High	As for 10.1

	Medium	As for 10.1.
	Low	As for 10.1

Most effective forms of presentation

10.1	Bar chart or map
10.2	Bar chart or map

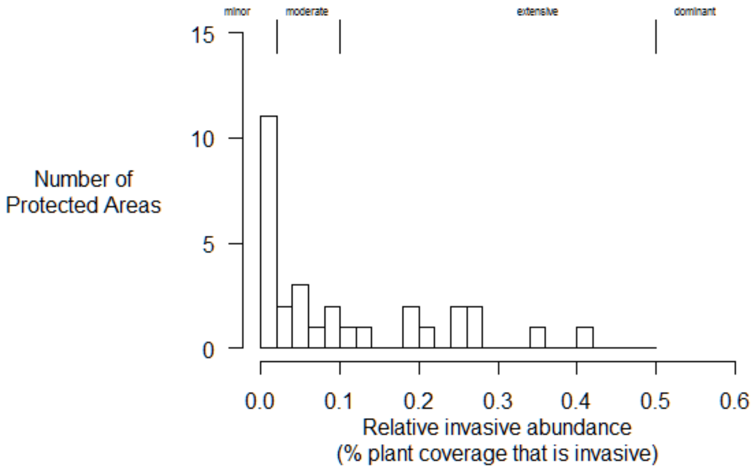


Figure S4.9 (Indicator 10.2)—The relative invasive abundance of plants in provincial protected areas in the Western Cape Province, South Africa. Based on extrapolations from mapping exercises and assuming that indigenous plant cover would be 100% in the absence of invasion (although there is both bare ground and different vegetation structural layers at the sites). Data from CapeNature.

Limits to usefulness and accuracy

This indicator requires detailed mapping. It is thus most likely to be used at smaller spatial scales. It will nevertheless be useful for assessing the levels of invasion in particular types of areas, for example protected areas.

It requires information on indigenous abundances as well, and when dealing with coverage data, the total coverage might either be much greater than 100% (i.e. overlapping canopies), or less than 100% (i.e. bare rock).

The impact of different levels of relative abundance will also vary. An understory shrub at 50% coverage might have much lower impacts than a vine that overtops and smothers vegetation which is also at 50% coverage.

Updating the indicator

This indicator would be assessed at the scale for which management plans are available, and where goals are set to achieve reductions in the relative abundance of alien species. Monitoring and updating of the database on which this indicator is based should be continuous, as management is ongoing, likely as part of annual planning updates. In South Africa it is proposed to update indicators every three years.

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species 6. Extent of alien species 7. Abundance of alien species	None	8. Impact of alien species 11. Impact of invasions 14. Planning coverage 18. Effectiveness of pathway treatments 19. Effectiveness of species treatments 20. Effectiveness of site treatments B. Number of invasive species that have major impacts C. Extent of area that suffers major impacts from invasions D. Level of success in managing invasions

Additional information and comments

The data can be linked to other GIS layers to look at possible interactions, e.g. with human footprint.

Rather than broad taxonomic groups, it can be important to consider functional groups, or function itself, e.g. what proportion of photosynthesis in a given region is due to alien species (and how has this changed post-invasion).

11. IMPACT OF INVASIONS

Use and interpretation

This indicator assesses the combined impact of all invasive species at a particular site on the delivery of selected ecosystem services, or on biodiversity. It should have a focus on those ecosystem services that are important in the context of the site concerned (for example on water resources in dry regions, livestock production in rangelands, or biodiversity in protected areas) and can be used to prioritise sites for management interventions. At a more advanced level, the value of impacts can be expressed in monetary terms and so used for calculations of costs and benefits of control.

Potential for aggregation

Impacts on ecosystem services that are made at finer scales can be aggregated upwards at larger scales.

Possible reasons for upward or downward trends

Increases in impact (decreases in ecosystem service delivery) can be associated with the physiological or competitive consequences of invasions. For example, displacement of plants that are able to conserve water with species that are less efficient water users can reduce streamflow and deplete groundwater resources; and unpalatable or thicket-forming species can displace palatable grass species in rangelands, reducing the livestock carrying capacity.

Upwards trends can also be the result of increases in the spread of alien species; shifts in which alien species are invasive towards more damaging species; or due to the accrual of impact over time, as even if extent or abundance of invasions do not change over time, biophysical thresholds can be crossed leading to ecosystem level impacts (Suding & Hobbs, 2009).

Implications for biodiversity management of change in the indicator

The size and value of impacts would be important factors to consider when allocating scarce management resources to address and hopefully reduce, or slow the growth of, harmful impacts. Management resources should be directed to those sites where attractive returns on management interventions could be realised (potentially, but not necessarily) including areas where the impacts are greatest).

Units in which it is expressed (from basic to advanced)

11.1	Factor with five levels of impact, • Not known • Minor • Moderate • Major • Massive
11.2	The reduction caused by the invasions expressed quantitatively in the units in which the ecosystem service is measured (for example, water

	yield expressed in m^3 per ha, and rangeland carrying capacity in livestock units per ha).
11.3	Monetary values (in net present value) of the reduction in the relevant ecosystem service or biodiversity indicators.

Description of source data

The use of this indicator requires data on the spatial distribution and magnitude of ecosystem services, and on the impact of invasions on that service. While the magnitude of a wide range of ecosystem services can be assessed, good information on the impacts of invasions on those services is not easily obtained, as relatively few studies have been conducted.

Calculation procedure

11.1	Ecosystem services should be mapped at appropriate scales, and this is more easily achieved for some services (for example water or timber extraction, or livestock or fish production) than for others (for example aesthetic or cultural values). The impact of invasions on these services should be modelled based on research results where they are available, and extrapolated. • Not known: there has been no estimate of whether there has been a reduction in the relevant ecosystem service or biodiversity indicators attributable to the invasions. • Minor: there has been a < 2% reduction in the relevant ecosystem service or biodiversity indicators attributable to invasions. • Moderate: 2 - 10% reduction. • Major: 10 - 50% reduction. • Massive: > 50% reduction.
11.2	As for 11.1 but where the data are of sufficient resolution and models of sufficient reliability that a quantitative percentage can be obtained.
11.3	Conversion of ecosystem services to monetary values would require further research in which the value of sustainable yields (of water, livestock, or harvested products) would have to be estimated for the scale concerned.

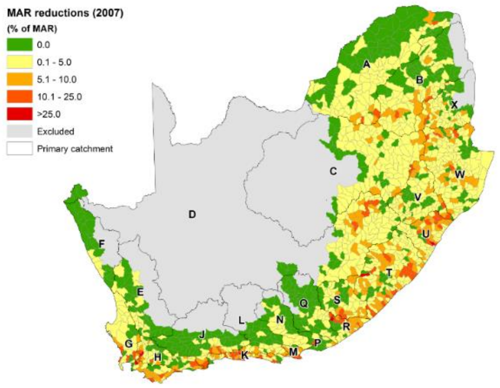
Guide for applying confidence levels

11.1	High	Based on well documented impacts of particular alien species combined with quantitative information on relative invasive species abundance with a medium or high level of confidence (see 10.2)
	Medium	Based on well documented impacts of particular alien species combined with qualitative information on relative invasive abundance (see 10.1)

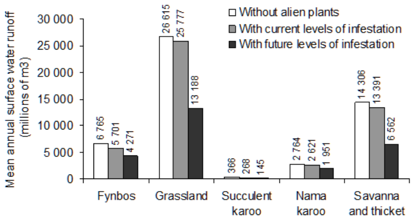
	Low	Based on expert opinion
11.2	High	Based on levels of ecosystem services that have been measured and quantified across the region; and on robust studies that quantify the impact of invasions on these services
	Medium	Based on levels of ecosystem services that have been measured for representative parts of the region, with well tested spatial models used to extrapolate to the whole region.
	Low	Based on estimates of ecosystem services derived from spatial modelling, and/or on modelled estimates of the impact of alien species on these services.
11.3	High	Based on direct valuation of measured and quantified ecosystem goods and services at the site concerned.
	Medium	Based on indirect estimations of the market value of modelled levels of ecosystem services (for example, by comparison to values for similar services estimated elsewhere).
	Low	Based on market values of ecosystem services derived from expert opinion.

Most effective forms of presentation

11.1	Spatially (on maps) or graphically by means of bar graphs showing trends over time or under different scenarios of invasion.
11.2	As for 11.1
11.3	Tables



a)



b)

Figure S4.10 (Indicator 11.2)—Estimates of the impact of invasions on water resources in South Africa. In panel a) are estimates of the reductions in mean annual runoff (MAR) due to invasive alien plants in the quaternary catchments of South Africa. The quaternary catchments where data were not available to estimate impact are shown in grey; in panel b) are estimates of the current and potential impacts of invasive alien plants on surface water runoff in five terrestrial biomes in South Africa (van Wilgen et al., 2012, Le Maitre et al., 2016).

Limits to usefulness and accuracy

The extent to which this indicator can be used is constrained by limited spatial information on a wide range of ecosystem services (although information on some of the more important services is available at a range of scales), accurate distribution maps for biological invasions, and studies that have accurately quantified impacts, and on which models can be based. However, as better information becomes available, this could become an influential indicator for informing policy-makers of the consequences of invasion.

Updating the indicator

This indicator should be updated at the same frequency at which levels of invasion are assessed.

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species 6. Extent of alien species 7. Abundance of alien species 8. Impact of alien species 9. Alien species richness 10. Relative invasive abundance	12. Quality of regulatory framework 13. Money spent 14. Planning coverage	14. Planning coverage 19. Effectiveness of species treatments 20. Effectiveness of site treatments B. Number of invasive species that have major impacts C. Extent of area that suffers major impacts from invasions D. Level of success in managing invasions

Additional information and comments

The choice of what to measure in terms of the impact of invasions will be influential and the importance of different impacts will be context dependent. A “minor” reduction in biodiversity in a biodiversity hotspot might be much more important that a “massive” reduction elsewhere; similarly providing the cost of an invasion in absolute terms might hide major and profound societal inequities.

12. QUALITY OF REGULATORY FRAMEWORK

Use and interpretation

This is an input indicator that helps address three key questions:

- What regulatory framework is in place to manage biological invasions?
- What is the level of completeness of this regulatory framework? and
- What mechanisms are in place to enable its implementation, update, review and appeal?

At a country level, this indicator provides an assessment of the degree to which authorities are able to regulate the cultivation or use of alien species, their transport or trade, and to what extent citizens are required to take steps to control problematic invasive alien species. Voluntary agreements should also be considered as relevant here.

Potential for aggregation

This indicator would assess the quality of the regulatory framework at a national level, and there would be no need for aggregation. Can be evaluated at lower spatial administrative levels.

Possible reasons for upward or downward trends

The indicator would change if new regulations are enacted or agreements reached.

Implications for biodiversity management of change in the indicator

Increases or decreases in the quality of the regulatory framework would affect the ability of managers to address the negative effects of invasive alien species.

Units in which it is expressed (from basic to advanced)

12.1	Factor with four levels at a national level: • *None* (there are no regulations (or voluntary agreements) on biological invasions) • *Partial* (regulations are enacted and have clear mechanisms for implementation and enforcement, but only cover some of the aspects of the problem) • *Substantial* (regulations are enacted dealing with most aspects of the problem and/or responsibilities are mostly clearly assigned/most mechanisms for implementation, update, review and appeal are clear) • *Complete* (comprehensive legislation governs biological invasions in a holistic way, with responsibilities clearly assigned and clear mechanisms for implementation, update, review and appeal).
12.2	As for 12.1 but for a range of different administrative entities, and incorporating an evaluation of inter-agency co-operation

Description of Source Data

Gazetted legislation applicable to biological invasions; and published codes of conduct.

Calculation Procedure

12.1	Assessments by experts on the quality of legislation based on completeness (covers all aspects of pathways, species and sites); mechanisms for implementation; update; and review and appeal processes
12.2	As for 12.1 at different administrative levels and incorporating an evaluation of inter-agency co-operation

Guide for applying confidence levels

12.1	High	Assessment of regulation quality provided by an independent team of experts that includes both invasion scientists and members of the legal profession
	Medium	Assessment of regulation quality provided by either an independent or semi-independent team. The team includes invasion scientists or members of the legal profession but not both
	Low	Assessment provided by a team who either come from the institution responsible for developing or enforcing the regulations and/or do not contain assessors qualified in invasion science or law
12.2	High	As for 12.1
	Medium	As for 12.1
	Low	As for 12.1

Most effective forms of presentation

12.1	Table providing a breakdown of coverage of the regulatory framework across all aspects of the problem, on which the assignment to one of the levels is based
12.2	As for 12.1

Table S4.5 (Indicator 12.1)—A table proposed for assessing the quality of regulations pertaining to biological invasions.

	Aspect of biological invasions

Aspect of regulations	Pathways (incl. subcategories)	Species (incl. all taxa)	Sites (incl. different spatial scales and ownership)
Is there a mandate for management interventions?	Detailed /Partial/None		
Is there provision for enforcement of non-compliance?			
Is there a requirement for regular assessment of performance, and review?			

Limits to usefulness and accuracy

Politically sensitive indicator, might be slow to change in response to pressures.

Updating the indicator

Will be updated in response to the legislative process (e.g. amendments or new regulations).

Closely related indicators

Depends upon	Links with	Required for
1. Introduction pathway prominence 2. Introduction rates 3. Within-country pathway prominence 4. Within-country dispersal rates 5. Number and status of alien species 6. Extent of alien species 7. Abundance of alien species	8. Impact of alien species 11. Impact of invasions 13. Money spent	14. Planning coverage 15. Pathways treated 16. Species treated 17. Area treated 18. Effectiveness of pathway treatments 19. Effectiveness of species treatments 20. Effectiveness of site treatments D. Level of success in managing invasions

9. Alien species richness		

Additional information and comments

Can be a long process to change or amend regulations involving public consultations and changes have to be gazetted to take effect.

13. MONEY SPENT

Use and interpretation

Indicator that measures the monetary inputs into the management of biological invasions. It provides a basis on which to estimate one of the main indicators of the outcome of management interventions, namely return on investment.

Potential for aggregation

This indicator can be aggregated across any spatial scale for all of the management interventions at that scale.

Possible reasons for upward or downward trends

Changes in political or economic conditions, resulting in changes to the budget allocated to biological invasions.

Implications for biodiversity management of change in the indicator

Increased allocation can lead to an increased amount of resources to undertake interventions and decreased allocation can lead to a decrease in the number of interventions implemented. Decreases will also lead to the need for prioritisation, and for conservation triage, so that sufficient resources can be allocated to priority sites to achieve the goals of management.

Units in which it is expressed (from basic to advanced)

13.1	Annual government expenditure at a national scale
13.2	Annual government expenditure separated into expenditure on the relevant components of pathways, species and sites
13.3	As for 13.2 including expenditure by private individuals/organisations, and detailed accounts of the sources of funding

Description of source data

Records of expenditure from various government departments. Reports of money spent by private individuals/organisations.

Calculation procedure

13.1	Addition of expenditure from different sources to obtain a total. When compared over multiple years, it would be useful to inflate annual totals to net present values in the current year. This would facilitate meaningful comparisons, especially in countries that experience relatively high levels of inflation.
13.2	As above, split into different units.

13.3	As above, split into different units.

Guide for applying confidence levels

13.1	High	Records of expenditure on biological invasions are available from all participating agencies
	Medium	Records of expenditure from all participating agencies do not differentiate clearly between expenditure on biological invasions and other activities, leading to the need for assumptions
	Low	Records of expenditure are available for some, but not all participating agencies, and/or records do not differentiate clearly between expenditure on biological invasions and other activities
13.2	High	Records of expenditure are available from all participating agencies, with clear breakdowns of expenditure into projects that can be assigned easily to relevant components of pathways, species and sites
	Medium	Records of expenditure are available from all participating agencies, but they do not differentiate clearly between expenditure on biological invasions and other activities, and/or they do not differentiate between expenditure on pathways, species and sites, leading to the need for assumptions
	Low	Records of expenditure are available for some, but not all participating agencies, and/or it is very difficult to ascribe known expenditure to different aspects of biological invasions
13.3	High	as for 13.2, but with the additional requirement that records are available for money spent by private individuals/companies
	Medium	as for 13.2, but with the additional requirement that records are available for money spent by private individuals/companies
	Low	as for 13.2, but with the additional requirement that records are available for money spent by private individuals/companies

Most effective forms of presentation

13.1	Graphic presentation of annual expenditure over time

13.2	Tables of expenditure per component; with graphical summary of how this has changed over time
13.3	As for 13.2

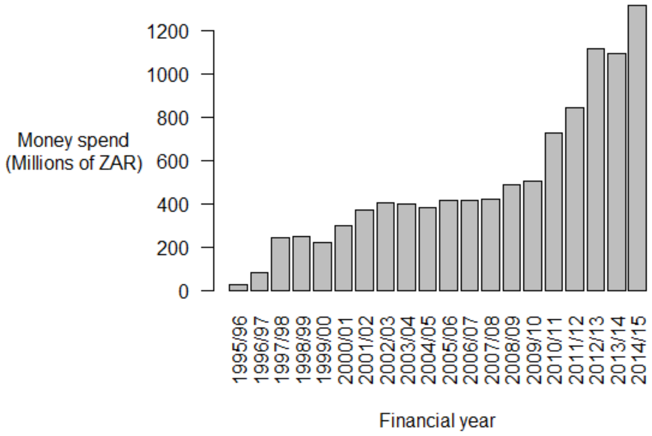


Figure S4.11 (Indicator 13.1)—Annual expenditure by South Africa's Working for Water Programme, the main programme for government control of biological invasions (does not include spending on agricultural pests and animal and human pests or diseases). Data from WfW planning site (https://sites.google.com/site/wfwplanning/), downloaded July 2017. Values are as reported per year, and not adjusted for inflation to give a net present value.

Limits to usefulness and accuracy

Government expenditure data will be hard to collate as expenditure will be in multiple departments some of which will not view the costs as relevant to invasions or separate these from other costs (human health in particular). Contributions from the private sector, and private landowners are unlikely to be readily available, are difficult to estimate, but could be substantial. The indicator is therefore likely to be an underestimate of inputs.

Updating the indicator

This indicator could be updated annually

Closely related indicators

Depends upon	Links with	Required for
None (though ultimately of course all aspects of pathways, species, and sites could come into the calculation) e.g. 5. Number and status of alien species; 6. Extent of alien species and 7. Abundance of alien species	8. Impact of alien species 12.Impact of invasions 12. Quality of regulatory framework 14. Planning coverage 15. Pathways treated	18. Effectiveness of pathway treatments 19. Effectiveness of species treatments 21. Effectiveness of site treatments

	16. Species treated 18. Areas treated	B. Number of invasive species that have major impacts D. Level of success in managing invasions

Additional information and comments

None

14. PLANNING COVERAGE

Use and interpretation

Adequate levels of planning are an essential input into the management of biological invasions. This indicator gauges the level of planning input, which should include the setting of goals, and monitoring and assessment of progress towards those goals. The degree to which management interventions are covered by adequate planning provides a basis for explaining the degree to which outputs and outcomes are achieved.

Potential for aggregation

Plans are drawn up for individual pathways, species and sites, and can be aggregated across the components that require management. For example, ballast water management plans for individual harbours, or passenger, luggage and cargo monitoring plans for individual airports.

Possible reasons for upward or downward trends

Increases in planning coverage would come about as a result of improvements in management plans or by allocating additional resources to that activity to allow for a greater scope of planning. Decreases could come about as a result of funding cuts.

Changes in regulatory requirements can affect the planning coverage.

Implications for biodiversity management of change in the indicator

A lack of planning, or inadequate planning, could lead to major inefficiencies in management, as a result of uncertainty relating to the goals of management, the allocation of funding to various activities, as well as a lack of clarity regarding progress towards goals.

Units in which it is expressed (from basic to advanced)

14.1	The proportion of each component (pathways, species, and sites) that have a regulatory requirement for a management plan and that have a management plan in place.
14.2	As for 14.1, but including an assessment of the quality of plans as gauged against a minimum set of criteria for adequate plans.
14.3	The presence and quality of management plans for each component (pathways, species, and sites) that have been ranked in terms of their priorities

Description of source data

Management plans developed by authorities responsible for the management of various aspects of biological invasions.

Calculation procedure

14.1	The number of pathways, species, and sites requiring management is taken to be pre-determined by any existing regulatory framework. Each component is then assessed as to whether a plan is in place. From this an overall percentage is determined (average of % in place for pathways, species, and sites).
14.2	For the advanced indicator, each plan needs to be assessed with respect to the degree to which the plan meets a minimum set of criteria (e.g., Department of Environmental Affairs, 2015). Each plan should be placed into one of three categories, as follows: • Adequate: Information required in terms of all of the criteria is included, and is of excellent standard; • Partially adequate: Information for most required criteria (>50%) is included, and is of an adequate to good standard; and • Inadequate: Information required in terms of the criteria is almost entirely lacking from the control plan.
14.3	First a risk assessment is conducted for each component of pathways, alien species, and sites to determine where management is needed (regardless of resource constraints). Second for those components where management is needed, the proportion that have plans in place is determined. Finally, plans that are in place are assessed in terms of their quality.

Guide for applying confidence levels

14.1	High	Plans are explicit as to their coverage with details such that gaps can be identified. Comparison across plans is easy as plans are curated in transferable formats. Guidelines meet international best-practice standards and reviewed externally and cover all relevant situations.
	Medium	The coverage and gaps in the plans can be inferred from details of what is covered, and/or the comparison across plans is made difficult by a variety of formats.
	Low	Coverage based on expert opinion
14.2	High	Plans are produced in enough detail to allow assessment of their quality and the assessment is conducted by someone experienced in project management of biological invasions
	Medium	Plans are produced in enough detail to allow assessment of their quality or the assessment is conducted by someone experienced in project management or biological invasions (not both)

	Low	Quality of plans difficult to assess and assessor not suitably experienced
14.3	High	As for 14.2 with some assessment of the confidence in the risk assessments conducted
	Medium	As for 14.2 with some assessment of the confidence in the risk assessments conducted
	Low	As for 14.2 with some assessment of the confidence in the risk assessments conducted

Most effective forms of presentation

14.1	Bar diagrams showing the proportion of pathways, species or sites for which management plans have been prepared. Numbers above the bars indicate the number of pathways or species being managed, and the site being managed.
14.2	Bar charts or tables
14.3	Bar charts or tables

No example presented here.

Limits to usefulness and accuracy

This indicator does not measure whether, or how well or comprehensively, the plans are actually implemented. This could limit usefulness, as effective implementation is an important output. There might also be implementation without plans in place.

At a basic level assumes that the regulatory requirements are an appropriate indication of actual need. At a more advanced level does not take into account the fact that the planning might be appropriate given the resource constraints, i.e. prioritised things are well covered.

Updating the indicator

Potentially annually, linking to annual plans of operation.

Closely related indicators

Depends upon	Links with	Required for
1. Introduction pathway prominence 2. Introduction rates 3. Within-country pathway prominence	12. Impacts of invasions 13. Money spent	15. Pathways treated 16. Species treated 17. Area treated 18. Effectiveness of pathway treatments

4. Within-country dispersal rates 5. Number and status of alien species 6. Extent of alien species 7. Abundance of alien species 8. Impact of alien species 9. Alien species richness 10. Relative invasive abundance 11. Impact of invasions 12. Quality of regulatory framework		19. Effectiveness of species treatments 20. Effectiveness of site treatments D. Level of success in managing invasions

Additional information and comments

Might need to weight the planning coverage by how important it is to have a plan in place, i.e. that given financial constraints, priority pathways, species, or sites should be covered by plans in preference to other components.

15. PATHWAYS TREATED

Use and interpretation

This indicator concerns the management of pathways that could facilitate the introduction of new alien species to a country or the dispersal of alien species within the country after introduction. The indicator is concerned with the outputs of pathway-focused control measures and provides an indication of the degree to which pathways are being managed (including aspects like regulation, inspection, and enforcement).

Potential for aggregation

This indicator was developed for use at a national level, however, as the national level data can be aggregated, the indicator can also be used at larger spatial scales (e.g. regions or continents). For example, information on the total amount of goods or vessels entering different countries or moving within countries, and the amount subjected to a management intervention, could be used to get an indication of the proportion of the goods or vessels for different pathways that are subjected to management at a regional or continental scale. As data could be available at larger (e.g. regions or continents) spatial scales, the indicator can be used at these scales.

Possible reasons for upward or downward trends

Upward or downward trends could be caused by political (e.g. changes to trade agreements), environmental and socio-economic changes (like consumer trends), as well as changes to the biosecurity (e.g. change to resources such as funds or personnel) or policies (e.g. phytosanitary policies) of the importing nation.

An upward trend in this indicator demonstrates that there has been an increase in the proportion of pathways or goods and vessels that are subjected to a management intervention.

A downward trend in this indicator demonstrates that there has been a decrease in the proportion of pathways or goods and vessels that are subjected to a management intervention.

Downward trends are not necessarily undesirable, and might reflect the reallocation of resources to more high priority pathways. Similarly, upward trends could reflect the allocation of resources to many low priority pathways rather than a small number of high priority pathways.

Implications for biodiversity management of change in the indicator

Upward or downward trends could lead to changes in the allocation of resources for biosecurity (money and personnel), and the pathways to which these resources are allocated (e.g. increase allocation to high priority pathways).

Units in which it is expressed (from basic to advanced)

15.1	Factor with five categories based on the degree to which the pathway sub-categories are subjected to a management intervention.

	• Not known • None • Partial • Substantial • Complete
15.2	Proportion of vectors that are subjected to a management intervention per pathway sub-category.
15.3	As for 15.2, with an assessment of the quality of the interventions.

Description of source data

Global or national databases containing trade data run by national governments, intergovernmental or global organisations and companies. Yearly data are often available, however, often not for the most recent years. Data can also be obtained from peer-reviewed journal articles and from the websites and reports of national governments, intergovernmental or global organisations and companies.

Detailed data on management interventions will need to be obtained from the relevant government departments.

Calculation procedure

15.1	For each pathway sub-category determine if management interventions are needed (as per indicator 14) and are in place, then categorise as follows: • Not known • None (pathway sub-category is not managed) • Partial (< 75% of the pathway sub-category has some management) • Substantial (>75% of the pathway sub-category has some management) • Complete (100% of pathway sub-category is managed)
15.2	For each pathway sub-category, calculate the proportion of the goods or vessels that are subjected to a management intervention using information on the amount of goods or vessels and the amount that are subjected to regulation or inspections.
15.3	As above, with the interventions assessed against set standard operating criteria: • Not known; • Inadequate (less than half the criteria addressed); • Partially adequate (more the half the criteria addressed) • Adequate (all criteria met).

Guide for applying confidence levels

15.1	High	Detailed data on all of the interventions in place and the pathways to which they are relevant
	Medium	Inferred from the types of introductions and/or the vectors that are managed or interpreted from other data sources
	Low	Qualitative estimate or based on expert opinion
15.2	High	Detailed data on the total number of imports or vessels per pathway and the number that have been subjected to a management intervention
	Medium	Inferred from the types of introductions and/or the vectors that are managed or interpreted from other data sources
	Low	Qualitative estimate or based on expert opinion
15.3	High	Detailed data on the proportion of imports or vessels that are managed per pathway with enough information to assess the quality of interventions, and assessment of interventions carried out by a relevant expert
	Medium	Inferred from the types of introductions and/or the vectors that are managed and some information on how interventions are carried out
	Low	Qualitative estimates or based on expert opinion

Most effective forms of presentation

15.1	A table or bar chart showing the proportion of pathways treated
15.2	A table or bar chart showing the proportion of pathways treated
15.3	A figure demonstrating the proportion treated to different levels

No examples presented here.

Limits to usefulness and accuracy

Reliant on data provided by governments and found in national and global databases. Data quality might not be known and may vary between countries, leading to more accurate assessments for some countries than others. Databases that are infrequently updated might cause difficulties when estimating upward or downward trends, or will not be useful if updated less frequently than the indicator is updated. Data that is only available at regional or larger scales, will be unsuitable for national scale assessments. Useful measures of the amount of goods and vessels might not be available for all pathways, particularly for less specific pathways such as ‘other escape from confinement’. For some pathways there may be various types of data available, and this could lead to differing estimates.

Updating the indicator

The indicator could be updated yearly or at coarser, but regular time intervals. At the least, the indicator should be updated as often as is required for reporting on the status of biological invasions.

Closely related indicators

Depends upon	Links with	Required for
1. Introduction pathway prominence 2. Introduction rates 3. Within-country pathway prominence 4. Within-country dispersal rates 5. Number and status of alien species 6. Extent of alien species (required for within-country dispersal rates) 12. Quality of regulatory framework (needed for planning coverage) 15: Planning coverage	14 Money spent 16. Species treated 18. Areas treated	18. Effectiveness of pathway treatments A. Rate of introduction of new unregulated species D. Level of success in managing invasions

Additional information and comments

The level of treatment required should be proportionate to the rate of introduction and thus should not be consistent across pathways. For some pathways it might be difficult to access data. For example, some transport data are owned by companies and to gain access to the data or databases a fee is often required.

Some pathways might not need treatment (see indicator 14).

16. SPECIES TREATED

Use and interpretation

Output indicator that provides an indication of the degree to which alien species that need to be managed are being managed.

Potential for aggregation

Can be aggregated across taxonomic groups.

Possible reasons for upward or downward trends

The proportion of known alien species that are being subjected to management could increase if available funds are increased, but could also increase if the funding remains unchanged, but is spread across more species. Decreases could signal either a decrease in funding, or a decision to focus available funds on fewer species. Changes could also be the result of changes in the total number of alien species.

Implications for biodiversity management of change in the indicator

Managing a higher proportion of alien species could be interpreted as advantageous, but it could also signal a dilution of scarce funds, leading to less effective management per species, an undesirable output. At advanced levels of this indicator, it would therefore be necessary to examine whether the level of funding is adequate to make a difference. Changes then will more closely correspond to changes in desired levels.

Units in which it is expressed (from basic to advanced)

16.1	Proportion of regulated species that are being subjected to a management intervention
16.2	Five categories for the degree to which populations of an alien species identified as requiring management are actually being managed • Not known • None • Partial • Substantial • Complete
16.3	As for 16.1 with each intervention (per population or relevant site) assessed as • Not known • Inadequate • Partially adequate • Adequate

Description of source data

Species-specific management plans, including funds allocated per species; estimates of the amount of funding needed to achieve control, usually from research projects.

Calculation procedure

16.1	The number of alien species requiring management is obtained from indicator 14. The indicator is the proportion of these where management is being implemented.
16.2	As for 16.1 with an assessment of the degree to which populations of an alien species are being managed as: • Not known • None (no populations are managed) • Partial (< 75% of populations have some management) • Substantial (>75% of populations have some management) • Complete (100% of populations have some management)
16.3	As for 16.1, with the quality of the implementation assessed against standard criteria (e.g. all individuals/stages addressed, and best practice followed) as: • Not known (there is no monitoring and reporting in place) • Inadequate (none of the criteria are adequately fulfilled) • Partially adequate (not all of the criteria are adequately fulfilled) • Adequate (all criteria fulfilled)

Guide for applying confidence levels

16.1	High	Management plans readily available, up-to-date, with progress reports that are less than two years old. List of invasive species known with high confidence.
	Medium	Not clear if all management plans obtained, and/or the majority of management plans are not up-to-date. Progress report available but somewhat out of date (e.g. 2–5 years old). Alternatively, the list of invasive species known with medium confidence.
	Low	Over 50% of management plans are out of date, with the last progress report greater than 5 years ago, with no indication that the plan has been wrapped up. Alternatively, the list of invasive species known with low confidence.
16.2	High	As for 16.1, in addition with detailed reporting on populations treated and not treated (e.g. >90%)
	Medium	As for 16.1, in addition with some direct data indicating coverage

	Low	As for 16.1, in addition with the level of coverage extrapolated from some data
16.3	High	As for 16.1, in addition there has been a reliable (e.g. peer-reviewed) assessment of the adequacy of the treatments for almost all (>90%) species
	Medium	As for 16.1, in addition there has been a reliable (e.g. peer-reviewed) assessment of the adequacy of the treatments for most (50–90%) species
	Low	As for 16.1, in addition there has been a reliable (e.g. peer-reviewed) assessment of the adequacy of the treatments for less than half of high priority species

Most effective forms of presentation

16.1	Proportion for different taxonomic groups
16.2	Bar chart
16.3	Bar chart

No examples presented here.

Limits to usefulness and accuracy

This output indicator simply measures the number of species that are being managed, unless the indicator is at an advanced level that includes an assessment of the quality of the control measures. At this advanced level, accuracy will depend on an understanding of what represents appropriate standards of control.

Updating the indicator

Can potentially be linked to annual reports, but will likely only be done as part of national reporting cycles (e.g. 3 years for South Africa).

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species 6. Extent of alien species 7. Abundance of alien species 9. Alien species richness	8. Impact of alien species 13. Money spent 16 Pathways treated 17. Area treated	19. Effectiveness of species treatments B. Number of invasive species that have major impacts D. Level of success in managing invasions

12. Quality of regulatory framework 14. Planning coverage		

Additional information and comments

The species that need to be treated might include species that are not introduced yet (i.e. pre-border). In general the treatments should be with the goal of either prevention, eradication, containment, and impact reduction.

17. AREA TREATED

Use and interpretation

Output indicator that provides an indication of the area over which alien species control operations took place.

Potential for aggregation

Can be aggregated from sites with management plans to larger spatial scales.

Possible reasons for upward or downward trends

The invaded area that is subjected to management could increase if available funds increase, but it could also increase if the funding remains unchanged, but if management is shifted from densely-invaded areas to less densely invaded areas. Decreases could signal either a decrease in funding, or a decision to focus available funds on more densely invaded areas. The area that can be treated also depends on the number of times an area needs to be treated before the management can move to new areas. Some areas require numerous follow-up treatments (for example to remove seedlings after felling mature plants), and this will slow the rate at which new areas can be treated.

Implications for biodiversity management of change in the indicator

Area treated is an output indicator that can be used to gauge the proportion of the problem that is being addressed. This, in turn, provides an idea of whether or not the invasion can be reduced to an acceptable level within a reasonable timeframe. However, area treated is not an indicator of success, as the outcome of treatment is not assessed.

Units in which it is expressed (from basic to advanced)

17.1	The proportion of sites that need to be managed that are being managed
17.2	As for 17.1, with the quality of the implementation of each management plan assessed as: • Not known • Inadequate • Partially adequate • Adequate

Description of source data

Management plans from government institutions, non-governmental organisations and private landowners

Calculation procedure

17.1	The sites requiring management is calculated (as per indicator 14), and then the proportion where management plans are being implemented is assessed.
17.2	As for 17.1, with the quality of the implementation of each management plan assessed against standard criteria (e.g. funding sufficient to reach goal of effective control; all sites addressed; introduction and dispersal pathways considered; and best practice followed) as: • No plan in place; • Inadequate (none of the criteria are adequately fulfilled); • Partially adequate (not all of the criteria are adequately fulfilled); • Complete (all criteria fulfilled);

Guide for applying confidence levels

17.1	High	Management plans readily available, up-to-date, with progress reports that are less than two years old. Areas requiring management known with high confidence.
	Medium	Not clear if all management plans obtained, and/or the majority of management plans are not up-to-date. Progress report available but somewhat out of date (e.g. 2–5 years old). Alternatively, the area requiring management is known with medium confidence.
	Low	Over 50% of management plans are out of date, with the last progress report greater than 5 years ago, with no indication that the plan has been wrapped up. Alternatively, the area requiring management is known with low confidence.
17.2	High	As for 17.1, and assessment based on clear goals in management plans, and on regular and verifiable monitoring of progress
	Medium	As for 17.1, and assessment based on irregular monitoring of progress
	Low	As for 17.1, and assessment based on expert local knowledge

Most effective forms of presentation

17.1	Maps of different sites, displayed according to appropriate administrative or biogeographical units.
17.2	Bar chart

No examples presented here.

Limits to usefulness and accuracy

Relies on the availability of reports on monitoring and evaluation of control operation.

Updating the indicator

Annually, in line with annual project reporting.

Closely related indicators

Depends upon	Links with	Required for
6. Extent of alien species 7.Abundance of alien species 12. Quality of regulatory framework 14. Planning coverage	13. Money spent 15. Pathways treated 16. Species treated	20. Effectiveness of site treatments C. Extent of area that suffers major impacts from invasions D. Level of success in managing invasions

Additional information and comments

It does not examine whether these treatments were effective.

18. EFFECTIVENESS OF PATHWAY TREATMENTS

Use and interpretation

This indicator concerns the effectiveness of managing pathways that facilitate the introduction of alien species to a country from another region, and the dispersal of alien species within a country after introduction. The indicator is concerned with the outcomes of pathway-focused control measures and in particular, the degree to which pathway treatments are reducing the rate of introduction and within-country dispersal of alien species. Depending on the available data, the indicator can be used to answer two questions:

- What proportion of pathways that require management are effectively managed?;
- What is the return on investment for pathway-focused control measures?

Potential for aggregation

Although this indicator was developed for use at a national level it can be used at a wide range of spatial scales, depending on the scale at which data are available (e.g. regions or continents).

Possible reasons for upward or downward trends

Upward or downward trends could be caused by changes to the rate at which alien species are being introduced to the country or dispersing within the country. Additionally, changes to the policies of the country or the resources available for biosecurity (funds and personnel), and how these resources are allocated, could cause upward or downward trends.

An upward trend indicates that the effectiveness of pathway-focused control measures has increased, while a downward trend indicates a decrease in the effectiveness of control measures.

Implications for biodiversity management of change in the indicator

Upward or downward trends could lead to changes in the resources allocated to pathway-focused control measures, and could influence the pathways that are managed.

Units in which it is expressed (from basic to advanced)

18.1	Number of pathways in six categories of control effectiveness • Not known • Counter-productive. Intervention has exacerbated the problem. • Ineffective. There has been an intervention, but it is ineffective. • Partial. Somewhat effective intervention • Effective. The treatment has reduced the problem to below a desired management threshold. On-going control is required.

	• Permanent. The problem has been reduced to a sustainably low level (or zero), and so no on-going management is required. AND An assessment of any negative impacts of control.
18.2	Quantitative measure of impact on introduction pathway prominence, introduction rates, within-country pathway prominence, and within-country dispersal rates AND A formal environmental and social assessment of non-target effects of the interventions
18.3	Return on investment expressed as a ratio of the amount spent on control to the value of avoided cost of impact. AND Include non-target impacts as costs

Description of source data

Reports on monitoring and evaluation of control interventions obtained from the relevant government departments. Information on the rate at which alien species are being introduced to the country and dispersing within the country obtained from assessments of the status of the introduction pathways and within-country dispersal pathways and data from interventions (e.g. interception data).

For more advanced metric, economic costings and back-casts from the relevant government departments, as well as estimates of avoided costs from models.

Calculation procedure

18.1	Data on control effectiveness from published reports, data on rates of introduction or expert opinions are used to categorise the effectiveness of treatment for each pathway as: • Not known • Counter-productive. Evidence that there are more introductions or spread; • Ineffective. There is no discernible change in the rate of introductions or within-country dispersal. • Partial. Rates of introduction and dispersal have decreased • Effective. Rates of introduction and dispersal are below an explicitly defined management threshold, management is continuing. • Permanent. Active management is no longer required, as there are no more introductions or dispersal AND Expert assessment informed by data collected on any collateral damage (e.g. details of legal claims and reports of direct non-target

	damage to native species and damage to ecological infra-structure, with such data ideally collected in the region of interest).
18.2	A counter-factual model is produced that is used to project values with and without control interventions. Using this a percentage change in relevant indicators (e.g. introduction rates) is calculated. AND An impact assessment (both environmental and social) is conducted as per standard guidelines for the relevant country.
18.3	Estimates of the costs of control are calculated for different management scenarios with the models used in the calculation of 18.2 together with quantitative estimates of the impact of the introductions or dispersal combined to give a ratio. Ratio > 1 where cost of control is less than the value of impacts avoided through effective control or negative; <1 where control costs exceed the value of impacts avoided through effective control. AND The costs of non-target impacts are included in costs of control.

Guide for applying confidence levels

18.1	High	There has been a published peer-reviewed quantitative assessment of the degree of control achieved.
	Medium	There is a report that is based on monitoring data.
	Low	Expert opinion.
18.2	High	As 18.1 in addition, the models used are published in peer-reviewed journals and have been extensively tested in similar situations.
	Medium	As 18.1 in addition, the models used are published in peer-reviewed journals, but only recently or this is one of only a few examples of their implementation.
	Low	As 18.1 in addition, the models used have not been published.
18.3	High	As 18.2
	Medium	As 18.2
	Low	As 18.2

Most effective forms of presentation

18.1	A table with number of pathways in different categories

18.2	A box-plot showing the degree to which different interventions have reduced specific indicators of biological invasions
18.3	A table

No examples presented here.

Limits to usefulness and accuracy

Relies on accurate and up to date data obtained from pathway management plans that are at present only available for a limited number of pathways. Poor data quality (e.g. poor estimates of rate of introduction or cost-benefit ratio) might lead to an inaccurate assessment.

Updating the indicator

The indicator could be updated yearly or at coarser, but regular time intervals. At the least, the indicator should be updated as often as is required for reporting on the status of biological invasions.

Closely related indicators

Depends upon	Links with	Required for
1. Introduction pathway prominence 2. Introduction rates 3. Within-country pathway prominence 4. Within-country dispersal rates 5. Number and status of alien species 6. Extent of alien species 10. Relative invasive abundance 12. Quality of regulatory framework (needed for planning coverage) 13. Money spent 15: Planning coverage 15. Pathways treated	None	A. Rate of introduction of new unregulated species D. Level of success in managing invasions

Additional information and comments

Return on investment is not relevant if there is no control and there should have been, this is dealt with in the quality of the planning framework. Return on investment is only relevant if measured using an indicator that is related to control outcomes (e.g. rate of introductions rather than some metric of how many inspections were carried out).

19. EFFECTIVENESS OF SPECIES TREATMENTS

Use and interpretation

Outcome indicator of the number of alien species that require management brought under different degrees of control, based in part on that developed for assessing the efficacy of classical biological control programmes (Klein, 2011). This indicator could inform the allocation of future management and research resources.

Potential for aggregation

Can be aggregated across different taxonomic groups.

Possible reasons for upward or downward trends

Increases in the number of species brought under effective control could result from the development of improved management techniques, the adoption and implementation of effective best-practice control measures, or increased funding or other resources.

Decreases could be due to reductions in resources for control or changes away from effective treatments, and if more species start to require management.

Implications for biodiversity management of change in the indicator

If the number of species brought under effective control increases, then scare funds could be freed up for controlling additional species.

Units in which it is expressed (from basic to advanced)

19.1	Number of species in six categories of control effectiveness • Not known • Counter-productive. Intervention has exacerbated the problem • Ineffective. There has been an intervention but it is ineffective. • Partial. Somewhat effective intervention • Effective. The treatment has reduced the problem to below a desired management threshold. On-going control is required. • Permanent. The problem has been reduced to a sustainably low level (or zero), and no on-going management is required. AND An assessment of any negative impacts of control.
19.2	Quantitative measure of impact on population size, extent or impact due to control AND A formal impact assessment of the interventions
19.3	Return on investment expressed as a ratio of the amount spent on control to the value of avoided cost of impact.

	AND Non-target impacts as costs

Description of source data

This indicator is determined using data on the number of species management plans obtained from literature, academic and government institutions, and on the success of such management obtained from literature, academic and government institutions.

Calculation procedure

19.1	Data on control effectiveness from published reports and sources or expert opinions are used to categorise the control effectiveness for each species as: • Not known • Counter-productive. There is evidence that control has led to further spread; has caused increases in abundance; and/or has made subsequent treatments more difficult without reducing the invasion; • Ineffective. There is no discernible change to the rate at which the extent of the invasion or the abundance of the species are increasing. • Partial. Rate of increase in extent or abundance has slowed. • Effective. Extent or abundance is decreasing or has ended up below a management threshold, management is continuing. • Permanent. There is no more active management and despite this the population remains below the management threshold. AND Expert assessment informed by data collected on any collateral damage (e.g. details of legal claims and reports of direct non-target damage to native species and damage to ecological infra-structure, with such data ideally collected in the region of interest).
19.2	A counter-factual model is produced that is used to project values with and without control interventions. Using this a percentage change in relevant indicators (e.g. population size after a given time) is calculated. AND An impact assessment is conducted as per standard guidelines for the relevant country.
19.3	Estimates of the costs of control are calculated for different management scenarios with the models used in the calculation of 19.2 together with a quantitative estimate of the impact of the invasions combined to give a ratio. > 1 where cost of control is less than the value of impacts avoided through effective control or negative; < 1 where control costs exceed the value of impacts avoided through

	effective control, or where control is ineffective and delivers little or no benefit AND The costs of non-target impacts are included in costs of control.

Guide for applying confidence levels

19.1	High	There has been a published peer-reviewed quantitative assessment of the degree of control achieved.
	Medium	There is a report that is based on monitoring data.
	Low	Expert opinion.
19.2	High	As for 19.1 in addition, the models used are published in peer-reviewed journals and have been extensively tested in similar situations.
	Medium	As for 19.1 in addition, the models used are published in peer-reviewed journals, but only recently or this is one of only a few examples of their implementation.
	Low	As for 19.1 in addition, the models used have not been published.
19.3	High	As for 19.2
	Medium	As for 19.2
	Low	As for 19.2

Most effective forms of presentation

19.1	A table with the number of species in different categories
19.2	A box-plot showing the degree to which different interventions have reduced specific indicators of biological invasions
19.3	A table

No example presented here.

Limits to usefulness and accuracy

Relies on accurate and to update data obtained from species management and control plans that are at present only available for limited number of species

Updating the indicator

Annually

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species 6. Extent of alien species 7. Abundance of alien species 8. Impact of alien species 9. Alien species richness 10. Relative invasive abundance 12. Quality of regulatory framework (needed for planning coverage) 13. Money spent 15: Planning coverage 16. Species treated	None	D. Level of success in managing invasions

Additional information and comments

None.

20. EFFECTIVENESS OF SITE TREATMENTS

Use and interpretation

Outcome indicator that assesses the effectiveness of site-focused control measures.

Potential for aggregation

Data at smaller spatial scales can be aggregated to larger scales.

Possible reasons for upward or downward trends

Effectiveness would be improved through the development and implementation of more effective treatment technologies, through more strategic application of existing technologies, through increased funding and other resources, or through a decrease in the area requiring treatment (and vice versa for decreases).

Implications for biodiversity management of change in the indicator

Increases imply that management is decreasing the size of future problems. In this instance resources could be directed to other sites.

Units in which it is expressed (from basic to advanced)

20.1	Number of sites in six categories of control effectiveness • Not known; • Counter-productive. Intervention has exacerbated the problem; • Ineffective. There has been an intervention but it is ineffective; • Partial. Somewhat effective intervention; • Effective. The treatment has reduced the problem to below a desired management threshold. On-going control is required; • Permanent. The problem has been reduced to a sustainably low level (or zero), and no on-going management is required. AND An assessment of any negative impacts of control.
20.2	Quantitative measure of control on relative invasive abundance or alien species richness AND Conduct a formal impact assessment of the interventions
20.3	Return on investment expressed as a ratio of the amount spent on control to the value of avoided cost of impact. AND Include non-target impacts as costs

Description of source data

This indicator is determined using data on the number of sites that have species monitoring, control and eradication plans; and species status reports that were obtained from literature, academic and government institutions.

Calculation procedure

20.1	Data on control effectiveness from published reports and sources or expert opinions are used to categorise control effectiveness at sites as: • Not known; • Counter-productive. Evidence that relative invasive abundance is increasing as a result of the intervention; • Ineffective. There is no discernible change in the degree to which relative invasive abundance is increasing; • Partial. The relative invasive abundance has decreased; • Effective. The relative invasive abundance has decreased to below a management threshold, management is continuing; • Permanent. There is no more active management, despite this relative invasive abundance remains below a management threshold. AND Expert assessment informed by data collected on any collateral damage (e.g. details of legal claims and reports of direct non-target damage to native species and damage to ecological infra-structure, with such data ideally collected in the region of interest).
20.2	A counter-factual model is produced that is used to project values with and without control interventions. Using this a percentage change in relevant indicators (e.g. relative invasive abundance) is calculated. AND An impact assessment is conducted as per standard guidelines for the relevant country.
20.3	Estimates of the costs of control are calculated for different management scenarios with the models used in the calculation of 20.2 together with quantitative estimates of the impact of the invasions combined to give a ratio. > 1 where cost of control is less than the value of impacts avoided through effective control or negative; <1 where control costs exceed the value of impacts avoided through effective control, or where control is ineffective and delivers little or no benefit AND The costs of non-target impacts are included in costs of control.

Guide for applying confidence levels

20.1	High	There has been a published peer-reviewed quantitative assessment of the degree of control achieved.
	Medium	There is a report that is based on monitoring data.
	Low	Expert opinion.
20.2	High	As for 20.1 in addition, the models used are published in peer-reviewed journals and have been extensively tested in similar situations.
	Medium	As for 20.1 in addition, the models used are published in peer-reviewed journals, but only recently or this is one of only a few examples of their implementation.
	Low	As for 20.1 in addition, the models used have not been published.
20.3	High	As for 20.2
	Medium	As for 20.2
	Low	As for 20.2

Most effective forms of presentation

20.1	A table with number of sites in different categories
20.2	A box-plot showing the degree to which different interventions have reduced specific indicators of biological invasions
20.3	A table

No examples presented here.

Limits to usefulness and accuracy

Relies on accurate and up to date data obtained from management and control plans for each site. Such data are, at present, only available for limited number of sites.

Updating the indicator

In line with reporting processes.

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species	None	C. Extent of area that suffers major impacts from invasions

6. Extent of alien species 7. Abundance of alien species 8. Impact of alien species 9. Alien species richness 10. Relative invasive abundance 11. Impact of invasions 13. Money spent 12. Quality of regulatory framework 14. Planning coverage 17. Area treated		D. Level of success in managing invasions

Additional information and comments

None.

A. RATE OF INTRODUCTION OF NEW UNREGULATED SPECIES

Use and interpretation

This provides an indication of potential future biological invasions (i.e. species-based invasion debt).

Species which have been introduced following a proper detailed and independently assessed risk analysis are not included.

Potential for aggregation

This is a high-level indicator, already aggregated at a national level.

Possible reasons for upward or downward trends

Upward trends are to be expected as the volume of trade and travel are increasing. Downward trends in the rate of arrival could come about as a result of effective regulation of imports, and better at-border incursion response efforts.

Technically if the country is saturated with alien species then the rate of new introductions will be zero. However, globally there is little evidence of saturation (Seebens et al., 2017) except for very specific and historic pathways (Liebhold et al., 2017).

Implications for biodiversity management of change in the indicator

Unregulated (or poorly regulated) introductions indicate that prevention methods have not succeeded.

Unregulated introductions might manifest in a greater number of invasive species, and ultimately of the area that they occupy. This in turn would increase the magnitude and complexity of management needed to prevent impact.

Units in which it is expressed

A	Number of species introduced per year.

Description of source data

Data would be sourced from ongoing mapping and monitoring projects (such as atlas projects for various taxonomic groups), as well as from periodic surveys and studies.

Calculation procedure

A	Observations of new species are added up. Species which were deliberately introduced are assessed. If a formal detailed risk analysis that was subject to independent expert review was conducted and as a result their introduction was officially sanctioned, these species are not included.

Guide for applying confidence levels

A	High	There is good data and systems in place to detect new introductions, so that the putative time between an introduction and it being detected will always be < 5 years; the risk analysis process is transparent and documented in enough detail to allow proper assessment.
	Medium	The majority of introductions are detected within 10 years of probable date of introduction; and/or the risk analysis process is well laid out, though the process is not entirely clear.
	Low	It is likely there is a substantial delay between introduction and detections (such that the indicator will not be responsive). For example, if a large number of new detections are found without regular and routine monitoring (e.g. by a visiting international taxonomist) then it is likely the increase is not due to new introductions but to sampling effort; and/or the risk analysis process and decisions are not available for scrutiny.

Most effective forms of presentation

Annual trends in the rates of new introduction.

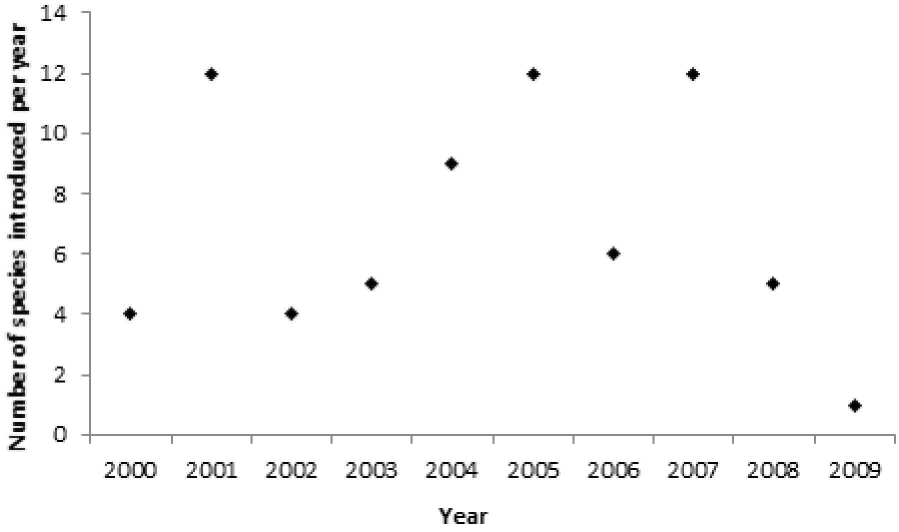


Figure S4.12 (Indicator A.1)—Number of alien taxa introduced to South Africa each year during the last full decade (2000 – 2009). During this period the average rate of introduction of new species was 7 species per year. Data from Chapter 3 of van Wilgen and Wilson (2018).

Limits to usefulness and accuracy

This indicator is sensitive to survey effort and the availability of sufficient taxonomists to confirm identification of species. The indicator is likely to always be an underestimate, given the difficulties of covering a large area, and of detecting less conspicuous species. A change can be an indication of better survey effort.

New introduced species might pose little risk, and so ultimately not be of concern. Likewise, taxa introduced after risk analysis might still cause impacts.

It only looks at new species, but the introduction of new individuals can be problematic for several reasons (e.g. introduction to new sites, introduction of new genetic material).

Updating the indicator

In South Africa it is proposed to update indicators every three years.

Closely related indicators

Depends upon	Links with	Required for
2. Introduction rates 3. Within-country pathway prominence 4. Within-country dispersal rates 5. Number and status of alien species 6. Extent of alien species 7. Abundance of alien species 15. Pathways treated 18. Effectiveness of pathway treatments	1. Introduction pathway prominence D. Level of success in managing invasions	None

Additional information and comments

It includes reintroductions after species have been eradicated or died out from a region.

B. NUMBER OF INVASIVE SPECIES THAT HAVE MAJOR IMPACTS

Use and interpretation

The total number of alien species that have been reported to have a Major (**MR**) or Massive (**MV**) impact under either the EICAT or SEICAT Schemes provides an indication of the current size and complexity of the problem. A growth in the number of species would indicate an increase in consequences and management complexity (as the number of species grows, so too will the range of impacts, and the need for species-specific management solutions).

Potential for aggregation

This is a high-level indicator, already aggregated at a national level.

Possible reasons for upward or downward trends

Species brought under control through biological control or impacts reduced through successful impact reduction or control efforts.

Impacts have increased over time; new invasive species have been introduced, species already present are becoming invasive or are spreading widely.

Better documentation of impacts.

Implications for biodiversity management of change in the indicator

An increase would generally mean there is a greater cost of biological invasions to society. The number of species requiring detailed management plans will change.

Units in which it is expressed

B	Number of species

Description of source data

Published literature on impacts.

Calculation procedure

B	Species are assessed through the EICAT and SEICAT schemes. The number of species that currently have major or massive impacts in any impact mechanism are added together.

Guide for applying confidence levels

B	High	For a particular group at least 90% of known invasive species have been assessed using both EICAT and SEICAT with a medium or high level of confidence (see 8.1) and were not found to be data deficient.

	Medium	For a particular group at least 50–90% of known invasive species have been assessed using both EICAT and SEICAT with a medium or high level of confidence (see 8.1) and were not found to be data deficient; or 90% of the most widely distributed invasive species have been assessed
	Low	25–50% of all known invasive species have been assessed with at least a low level of confidence (see 8.1) or 70–90% of the most widely distributed species have been assessed with at least a medium level of confidence (see 8.1).

Most effective forms of presentation

Trend over time as a line graph. Potentially the turnover in which species are added, or removed from the list.

No examples provided here.

Limits to usefulness and accuracy

This indicator would be dependent on regular and ongoing surveys and documentation of impacts. The indicator is likely to always be an underestimate, given the difficulties of covering a large area, and of detecting less conspicuous species. If repeat work is not conducted it can quickly become out of date.

Updating the indicator

In South Africa it is proposed to update indicators every three years.

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species 6. Extent of alien species 7. Abundance of alien species 8. Impact of alien species 10. Relative invasive abundance 11. Impact of invasions 13. Money spent 16. Species treated 19. Effectiveness of species treatments	C. Extent of area that suffers major impacts from invasions D. Level of success in managing invasions	None

Additional information and comments

A species which has a major impact based on one mechanism will be rated as of more concern than a species which has a moderate impact based on several impact mechanisms.

C. EXTENT OF AREA THAT SUFFERS MAJOR IMPACTS FROM INVASIONS

Use and interpretation

The extent of invaded area that suffers major impacts gives an indication of the overall extent of impacts of biological invasions. Invaded areas are expected to deliver fewer or diminished ecosystem services, and/or to support lower levels of biodiversity.

Potential for aggregation

This is a high-level indicator, already aggregated at a national level.

Possible reasons for upward or downward trends

Upward trends would reflect the growth of populations of invasive species, spread to previously un-invaded areas, and increases in the impacts. Downward trends would result from control measures reducing the cover or population sizes of the most dominant invaders, or reassessments indicating that invasions have otherwise declined or were previously over-estimated.

Implications for biodiversity management of change in the indicator

Increases in the extent of the invaded area that suffers major impacts would indicate increasing pressure on biodiversity and the delivery of ecosystem services. Given that the resources required to manage the problem will almost certainly be insufficient to control all species effectively, areas would need to be prioritised and managed accordingly. Management should focus on those sites that are of high priority, and where invasions have not yet reached severe proportions, as the likelihood of success of control measures would be higher in less severely invaded areas.

Unit in which it is expressed

C	Area or proportion of the country

Description of source data

Assigning values to this indicator requires the assessment of invasion severity at fine scales across the whole country, and aggregation to a national level. Currently in South Africa, this is only possible for alien plants at the scale of quarter-degree grid cells, where species presence and levels of invasion are recorded. Even then, estimates are coarse as severe invasions recorded within grid cells do not necessarily cover the entire grid cell.

Calculation procedure

C	Data on indicator 11. Impact of invasions is used, and the total area with major or massive impacts calculated

Guide for applying confidence levels

C	High	As per indicator 11
	Medium	As per indicator 11
	Low	As per indicator 11

Most effective forms of presentation

A map showing areas that have major or massive impacts; a single figure stating the proportion of the area of the country assessed as having major or massive impacts.

No examples provided here.

Limits to usefulness and accuracy

Currently, for South Africa, this indicator can only be based on plant species. The inclusion of additional taxa would make the indicator more meaningful.

The sites currently experiencing major impacts might not be those that should be prioritised for management as returns on investment might be greater at sites where there are currently low levels of invasion or that are responsible for higher rates of spread (i.e. to prevent future invasions and impacts).

Updating the indicator

In South Africa it is proposed to update indicators every three years**.**

Closely related indicators

Depends upon	Links with	Required for
5. Number and status of alien species 6. Extent of alien species 7. Abundance of alien species 8. Impact of alien species 9. Alien species richness 10. Relative invasive abundance 11. Impact of invasions 17. Area treated 20. Effectiveness of site treatments	B. Number of invasive species that have major impacts D. Level of success in managing invasions	None

Additional information and comments

Will be important to link this indicator to other data on biodiversity and ecosystem functioning.

D. LEVEL OF SUCCESS IN MANAGING INVASIONS

Use and interpretation

The degree of success achieved by control measures will vary from place to place, and this indicator is intended to provide an assessment of overall control effectiveness across all projects. High levels of effectiveness would indicate that control measures are appropriate and that the goals of management are realistic and achievable. Low levels of effectiveness would indicate inefficiencies in management, or unrealistic expectations and goals, or both. It should trigger a thorough examination of the component projects with a view to re-allocating national-level resources to projects where the goals are more likely to be achieved, or to re-defining more-realistic goals.

Potential for aggregation

This is a high-level indicator, already aggregated at a national level.

Possible reasons for upward or downward trends

There would be many reasons for upward or downward trends. These would include the ability of managers to assess the magnitude and complexity of the problem leading to unrealistic goal-setting, the extent to which best-practice control measures are adhered to, unforeseen fluctuations in funding, unforeseen events (fires, floods, droughts), bureaucratic inefficiencies, and a lack of understanding of the ecology of target species (e.g., Shackleton et al., 2016).

Implications for biodiversity management of change in the indicator

Change to management approaches would be required if the indicator suggests high levels of inefficiency. This would be in line with the philosophy of adaptive management, where the methods employed could be improved, or the funding could be moved to new sites or species where success would be more likely, or the goals of management could be changed.

Units in which it is expressed (from basic to advanced)

D	% efficacy

Description of source data

Data would be sourced from regular monitoring of progress towards the goals listed in formal management plans.

Calculation procedure

D	First the proportion of pathways, species, and sites that require management and where a plan is in place is calculated (see indicators 14, 15, 16 and 17).

	Second for pathways, species, or areas treated, treatments are assessed based on their effectiveness (see indicators 18, 19, and 20) and scored as: • *Counter-productive*. -100% • *None / ineffective / not known*. 0% • *Partial*. 20% • *Effective* or *Permanent*. 100% Then the proportion which are treated are multiplied with the proportion that are effective to give an overall percentage success for pathways, species and sites. Finally the percentage efficacy of pathway, species, and site interventions are averaged to give an overall figure.

Guide for applying confidence levels

D	High	All the relevant indicators are assessed with at least medium confidence
	Medium	All the relevant indicators are assessed but some with low confidence
	Low	Some of the relevant indicators are not assessed, so assumptions are made/the analysis is not complete, or all of the relevant indicators are assessed with low confidence.

Most effective forms of presentation

D	% (that at maximum will be 100%, but can be negative if interventions are on balance exacerbating invasions)

No examples provided here.

Limits to usefulness and accuracy

This indicator will be limited to the area for which management plans are available. Currently, South African legislation requires all protected areas develop management plans, and that would provide a useful starting point. Ideally, management plans should also be developed for sites where substantial funding is being expended on control of invasive alien species. The assessment of management effectiveness would be dependent on (1) setting goals for management progress; and (2) regular monitoring of progress towards those goals.

Updating the indicator

In South Africa it is proposed to update indicators every three years.

Closely related indicators

Depends upon	Links with	Required for
1. Introduction pathway prominence 2. Introduction rates 3. Within-country pathway prominence 4. Within-country dispersal rates 5. Number and status of alien species 6. Extent of alien species 7. Abundance of alien species 8. Impact of alien species 9. Alien species richness 10. Relative invasive abundance 11. Impact of invasions 12. Quality of regulatory framework 13. Money spent 14. Planning coverage 15. Pathways treated 16. Species treated 17. Area treated 18. Effectiveness of pathway treatments 19. Effectiveness of species treatments 20. Effectiveness of site treatments	A. Rate of introduction of new unregulated species B. Number of invasive species that have major impacts C. Extent of area that suffers major impacts from invasions	None

Additional information and comments

Impacts which are scored as permanent might need to be removed from the calculation at some point, as those taxa would no longer need to be managed (so wouldn't come in under pathways, species, and sites treated). Ironically, however, this could lead to a decrease in the indicator. This will need to be resolved.

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		Required for																							
		Indicator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	**A**	**B**	**C**	**D**
	Pathways	1												x		x	x			x						x
		2												x		x	x			x			x			x
		3												x		x	x			x			x			x
		4												x		x	x			x			x			x
	Species	5		x		x		x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x
		6				x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		7				?	x			x	x	x	x	x	x	x		x	x		x	x	x	x	x	x
		8											x			x		x			x	x		x	x	X
	Sites	9											x	x		x		x			x	x			x	X
		10								x			x			x					x	x			x	x
		11								x			x			x				x	x	x		x	x	x
Interventions	Inputs	12														x					x	x		x	x	x
		13														x	x	x	x	x	x	x				x
		14																		x	x	x		x		x
	Outputs	15																		x			x			x
		16																			x			x		x
		17																				x			x	x
	Outcomes	18																					x			x
		19																						x		x
		20																							x	x

Figure S4.13 A link analysis of the indicators showing how the indicators (in the columns) depend on other indicators (in the rows) for their calculation.

Supplementary Material 5—Pathway classification scheme as adopted by the CBD (Scalera et al., 2016)

Pathway	Pathway subcategory
Release in nature	Biological control
	Erosion control/dune stabilisation
	Fisheries
	Hunting
	Landscape/flora/fauna ‘improvement’
	Conservation purposes or wildlife management’
	Release in nature for use other than above
	Other intentional release
Escape from confinement	Agriculture
	Aquaculture/mariculture
	Botanical garden/zoo/aquaria
	Pet/aquarium/terrarium species
	Farmed animals
	Forestry
	Fur farms
	Horticulture
	Ornamental purpose other than horticulture
	Research and ex-situ breeding
	Live food and live baits
	Other escape from confinement
Transport-contaminant	Contaminant nursery material
	Contaminated bait
	Food contaminant
	Contaminant on animals
	Parasites on animals
	Contaminant on plants
	Parasite on plants
	Seed contaminant
	Timber trade
	Transport of habitat material
Transport - stowaway	Angling/fishing equipment
	Container/bulk
	Hitchhikers on airplane
	Hitchhikers on ship/boat
	Machinery/equipment
	People and their luggage/equipment
	Organic packing material
	Ship/boat ballast water
	Ship/boat hull fouling
	Vehicles
	Other means of transport
Corridor	Interconnected waterways/basins/seas
	Tunnels and land bridges
Unaided	Natural dispersal across borders of invasive species that have been introduced through the above pathways

Scalera, R., Genovesi, P., Booy, O., Essl, F., Jeschke, J., Hulme, P., McGeoch, M., Pagad, S., Roy, H., Saul, W., -C. & Wilson, J. (2016) Technical Report: Progress toward pathways prioritization in compliance to Aichi Target 9. Information documented presented at SBSTTA 20 UNEP/CBD/SBSTTA/20/INF/5, the twentieth meeting of the CBD’s Subsidiary Body on Scientific, Technical and Technological Advice, Montreal, Canada, 25–30 April 2016.

Supplementary Material 6—Guidance regarding the use of the confidence rating

These are as per Hawkins et al. (2015), modified from the EPPO pest risk assessment decision support scheme (Alan MacLeod 09/03/2011; revised 28/04/2011; copied from CAPRA, version 2.74; 2).

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

Hawkins, C. L., Bacher, S., Essl, F., Hulme, P. E., Jeschke, J. M., Kühn, I., . . . Blackburn, T. M. (2015) Framework and guidelines for implementing the proposed IUCN Environmental Impact Classification for Alien Taxa (EICAT). *Diversity and Distributions,* **21,** 1360-1363.