A Global Indicator for Biological Invasion

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Abstract: *"Trends in invasive alien species" is one of only two indicators of threat to biodiversity that form part of the Convention on Biological Diversity's (CBD) framework for monitoring progress toward its "2010 target" (i.e., the commitment to achieve by 2010 a significant reduction in the current rate of biodiversity loss). To date, however, there is no fully developed indicator for invasive alien species (IAS) that combines trends, derived from a standard set of methods, across species groups, ecosystems, and regions. Here we provide a rationale for the form and characteristics of an indicator of trends in IAS that will meet the 2010 framework goal and targets for this indicator. We suggest single and composite indicators that include problem-status and management-status measures that are designed to be flexible, readily disaggregated, and as far as possible draw on existing data. The single indicators at national and global scales are number of IAS and numbers of operational management plans for IAS. Global trends in IAS are measured as the progress of nations toward the targets of stabilizing IAS numbers and the implementation of IAS management plans. The proposed global indicator thus represents a minimum information set that most directly addresses the indicator objective and simultaneously aims to maximize national participation. This global indicator now requires testing to assess its accuracy, sensitivity, and tractability. Although it may not be possible to achieve the desired objective for a global indicator of biological invasion by 2010 as comprehensively as desired, it seems possible to obtain trend estimates for a component of the taxa, ecosystems, and regions involved. Importantly, current indicator development initiatives will also contribute to developing the mechanisms necessary for monitoring global trends in IAS beyond 2010.*

Keywords: biodiversity indicators, biodiversity monitoring, convention on biological diversity, invasive alien species, species management

Un Indicador Global para la Invasión Biológica

Resumen: *Las "tendencias de las especies no nativas invasoras" es uno de sólo dos indicadores de amenaza a la biodiversidad que forman parte del marco de referencia de la Convención de Diversidad Biológica para monitorear su progreso hacia el "objetivo 2010," (i.e., el compromiso de lograr en 2010 una reducción significativa de la tasa actual de pérdida de biodiversidad). Sin embargo, a la fecha no hay un indicador completamente desarrollado para especies no nativas invasoras que combine tendencias, derivadas de un conjunto estándar de métodos, en grupos de especies, ecosistemas y regiones. Aquí proporcionamos un fundamento para la forma y las características de un indicador de tendencias en especies no nativas invasoras que cumplirá las metas y objetivos de este indicador en el marco de referencia de 2010. Sugerimos indicadores individuales y compuestos que incluyen el estatus del problema y las medidas de gestión y que están diseñados para ser flexibles, fácilmente desagregados y utilizar los datos existentes hasta donde sea posible. Los indicadores individuales a escala nacional y regional son el número de especies no nativas invasoras (ENNI) y el número de programas operativos de gestión para las ENNI. Las tendencias globales de ENNI son medidas como el progreso de las naciones hacia el objetivo de estabilizar el número de ENNI y la implementación de planes de manejo de ENNI. Por lo tanto, el indicador global propuesto representa un conjunto de información mínima que aborda el objetivo del indicador directamente y al mismo tiempo trata de maximizar la participación nacional. Este*

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indicador global ahora requiere ser probado para evaluar su precisión, sensibilidad y maleabilidad. Aunque puede que no sea posible alcanzar el objetivo deseado de un indicador global de invasión biológica para 2010, parece que es posible obtener estimaciones de tendencias para un componente de los taxa, ecosistemas y regiones involucradas. Es importante destacar que las iniciativas actuales para el desarrollo de indicadores también contribuirán al desarrollo de mecanismos necesarios para el monitoreo de tendencias globales de especies no nativas invasoras más allá de 2010.

Palabras Clave: convención de diversidad biológica, especies no nativas invasoras, gestión de especies, indicadores de biodiversidad, monitoreo de biodiversidad

Introduction

Biological invasion is a key threat to biodiversity (Mooney & Hobbs 2000) and causes major economic losses (Pimental et al. 2005). This threat is the rationale for the inclusion of alien invasions under "Threats to Biodiversity" in the Convention on Biological Diversity's (CBD's) framework for monitoring progress toward the "2010 target" (i.e., "the commitment 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"; BIP 2006). This target was adopted by over 180 nations at a meeting of the CBD in 2001 and endorsed by the World Summit on Sustainable Development in 2002 (BIP 2006).

Implicit in the 2010 target is a detailed understanding of past and current levels of threat to biodiversity and rates of biodiversity change (UNEP 2003*a*). Options for achieving such understanding within the time frame are limited (Mace et al. 2005) and must necessarily rely heavily on both historical information and on the use of particular taxa or measures (i.e., biodiversity indicators as representative of whole-scale biodiversity and the threats to it). To this end, the CBD's Subsidiary Body on Scientific Technical and Technological Advice has adopted 22 "Headline Indicators," across seven focal areas, to measure progress toward the 2010 target (BIP 2006). Although some of these headline indicators are well developed, globally recognized, and have a history of assessment and application (e.g., the Living Planet Index [Loh et al. 2005]), others have received comparatively little attention and have not been developed fully or adopted broadly (Mace et al. 2005). Furthermore, the best method by which progress toward the 2010 target is to be monitored remains a matter of active debate (Balmford et al. 2005; Pereira & Cooper 2006).

"Trends in invasive alien species" is one such headline indicator that is not yet ready to be implemented and that requires further development (Mace et al. 2005; but see UNEP 2005). For example, an evaluation of this indicator is not included in the special issue of *Philosophical Transactions of the Royal Society of London B* (2005, volume 360) that addresses several other of the CBD headline indicators and general principles relevant to all of them. Nonetheless, the CBD has proposed "numbers and cost of alien invasions" as a possible measure under this headline indicator (UNEP 2004*a*). The relevant CBD framework goal is to "control threats from invasive alien species" and the two targets are to (1) "control pathways for major potential alien invasive species" and to (2) "have management plans in place for major alien species that threaten ecosystems, habitats or species" (UNEP 2004*a,* 2004*b*, 2005). An indicator of trends in invasive alien species (IAS) is currently being designed by an expert group under the initiative Implementing European Biodiversity Indicators 2010 (Mace et al. 2005). Given the immediacy of the challenge to meet the 2010 target, broad discussion of the CBD headline indicator "trends in invasive alien species" and an evaluation of the scientific criteria underlying it are crucial.

We used the CBD 2010 target and headline indicator framework (UNEP 2005; CBD 2006) to develop a rationale for the form and characteristics of an indicator of trends in IAS that will meet the 2010 framework goal and targets for this indicator. We elaborate on the objectives of an indicator to monitor the global status of alien species invasion and discuss the form, structure, and desirable characteristics of an indicator that would meet these objectives (from both scientific and policy perspectives). This paper is thus a contribution to the design phase of indicator development (sensu UNEP 2003*a*) and to the debate on the development of global standards for invasive species monitoring.

An Indicator of the Status of Alien Species Invasion

In the context of the CBD 2010 target the primary reason for using an IAS (see Table 1 for definitions) indicator is to indicate the status of alien species invasion and to monitor change in its status (Table 2). This reasoning is based on the now well-supported assertion that some alien species pose a threat to biodiversity (MA 2005; Mooney et al. 2005). Two possible approaches exist to reduce the IAS threat: limit potential introduction and range expansion pathways and control or manage those populations that have already established (Byers et al. 2002; Simberloff et al. 2005; Table 2). To assess progress toward reduc-

Table 1. Definitions in invasion biology relevant to the invasive alien species (IAS) indicator.[a]

Species status (invasion status category)[b]	Definition
Alien (I)	species that are present as a result of intentional or accidental introduction as a result of human activity but do not form self-replacing populations
Naturalized (II)	alien species that reproduce consistently and sustain populations over several generations without direct intervention by humans (or in spite of human intervention) but do not necessarily invade natural, seminatural, or human-made ecosystems
Invasive (III)	naturalized species that produce reproductive offspring in very large numbers and are able to spread over a considerable area
Transformer (IV)	subset of invasive species that change the character, condition, form, or nature of ecosystems over a substantial area relative to the extent of that ecosystem

[a] *Based on definitions and scheme in Richardson et al. (2000).*
[b] *Categories I–IV indicate increasing invasion status. Species in categories I and II are potential invasive alien species, whereas species in III and IV qualify as invasive alien species.*

tion of the threat to biodiversity from IAS, information is needed on the number and invasion status of alien species (problem-status indicators) and on actions underway to reduce the number and status of IAS (management-status indicators) (Table 3). Because management actions are aimed at reducing number and status of IAS, such actions should reduce over time, or at least stabilize, the values of problem-status indicators (Carlton & Ruiz 2005; Wittenberg & Cock 2005). Together, the problem- and management-status indicators provide information necessary to assess the status of invasion by alien species and the status of management action and to monitor trends therein (i.e., fulfilling the objective of the IAS indicator, Table 2).

Several indicators of IAS have previously been proposed, developed, and applied at different, usually national or finer, scales (e.g., percentage of land surface area covered by alien plant species [The Heinz Center 2002]; area and density of weeds under active management [Natural Heritage Trust 2006]; distribution and abundance of selected alien species; number and extent of exotic species in park ecosystems [Parks Canada 2005]; rate of increase in aquaculture-related introduced species in the marine environment in European Seas [EEA 2003]; total number of invasive species as a percentage of particular groups [UNEP 2003*a*]). The only regional indicator developed to date is the "cumulative number of alien species in Europe since 1900," and this is also the first data set (containing data for five countries) to contribute to the development of a general indicator of trends in IAS for Europe (ECCHM 2005). No fully developed indicator exists that combines trends, derived from a standard set of methods, across species groups, ecosystems, and regions, and includes both species-status and management information. In other words a global indicator of IAS that addresses the relevant headline indicator framework goal and targets has to date not been developed.

We suggest component measures (or single indicators [UNEP 2003*b*]) and a composite indicator of the status and trends in IAS. We selected these measures on the basis of two widely accepted principles for effective indicators (1) that measures should directly and simply address the conservation and indicator objectives and (2) that measures used should be those most readily and broadly available to achieve geographic and taxonomic coverage by the indicator in the short to medium term (McGeoch 2002; UNEP 2003*a*). The proposed indicator therefore represents a minimum information set, and more detailed and sophisticated components and indicators are possible in those instances in which the additional data are already

Table 2. Rationale for the development of an indicator of trends in the status of invasive alien species (IAS).

Rationale	IAS context
Conservation goal	reduce the threat to biodiversity from IAS
Mechanisms to achieve conservation goal	reduce and control introduction pathways of potential IAS and control or manage existing populations of IAS
Objective of indicator*	indicate the status of alien species invasion and monitor change (trends) in this status
Policy relevance	Convention on Biological Diversity calls on its parties to "prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats, or species" (UNEP 2004*a*)

**This indicator does not directly assess the impact of invasive alien species on biodiversity. Rather, it is a measure of the extent of the threat (a so-called pressure indicator) (UNEP 2003a).*

Table 3. Components in the development of an invasive alien species indicator.

Developmental component	*Symbols and calculation*	*Description of indicator*
Single indicators (or measures)		problem-status indicator
	N	number and status of IAS
		management-status indicators
	E	number of IAS with operational management plans for existing populations of invasive alien species
	P	number of IAS introduction pathways covered by operational management plans
National indicator		$N : E : P$, where
	$N = N_{\text{III}} + N_{\text{IV}}$	N is the number of species in invasion status categories III and IV (Table 1); E is as defined earlier considering all species in status categories III and IV (Table 1); P is as defined earlier and lies between 0 and 5 on the basis of the number of the following introduction pathways for which management plans are in operation: air, sea, road, postal, intraboundary translocation
Semiaggregated form of single indicators	$E_{\%} = (E/N_{\text{III+IV}}) \times 100$	$E_{\%}$ is the percentage of IAS with operational national management plans
Global indicator		single indicators
	calculated across contributing nations[a]	mean $N_{\text{III+IV}}$; mean E; median P
		composite indicator
		relative positions of nations with respect to the IAS problem- and management-status target, i.e., few IAS and extensive management of introduction pathways and existing populations of IAS (Fig. 2)
Trends in IAS		national
		single indicators
		trend: change in N, and where possible also E and P over time (Fig. 1a & 1b)
		target: decrease, asymptote, or decline in the rate of increase of N and increases in E and P (Fig. 1a & 1b)
		composite indicator
	$T = \sum(\Delta E - \Delta N)$	trend: progress toward IAS target measured as T (i.e., change in E minus change in N from t_1).[a] T may be plotted as a time series to assess the trend
		target: increase in value of T over time and attaining a P of 5 (equivalent to decreasing distance from IAS target, Fig. 2)[b]
		global
		single indicators
		trend: changes in mean $N_{\text{III+IV}}$,[c] and where data are available also mean E and median P (Fig. 1c)
		target: a decrease, asymptote, or decline in the rate of increase in mean $N_{\text{III+IV}}$, and increases in mean E and median P (Fig. 1c)
		composite indicator
	$T_G = \sum (T)/n$	trend: progress toward IAS target measured as T_G (i.e., mean of T from t_1, across all contributing nations [n])
		target: increasing T_G and median P over time (equivalent to decreasing mean distance to IAS target, Fig. 2)

[a] *The* t_1 *is time step 1.*
[b] *Rate of progress (rate of increase in* T*) is expected to decline as* T *approaches the IAS target (Fig. 2), especially after* $E = 100\%$ *and* $P = 5$ *have been attained, and may fluctuate around an equilibrium level thereafter.*
[c] *Single indicators may be weighted by, for example, land area or gross domestic product to accommodate variation in the size and economic capacity of nations.*

available or readily obtainable. Inevitably a compromise must be reached between maximizing the number of nations that are able to provide data on the indicator (to ensure global representivity of the trends established) and using an indicator that is sufficiently information-rich to provide an accurate and sensitive estimate of progress toward the 2010 target.

Component Measures

PROBLEM-STATUS INDICATOR

The number of IAS is perhaps the most direct and simple measure for indicating the status of alien species invasion at national and global scales and for monitoring trends therein. A reduction in the number of IAS implies a decline in the potential threat to biodiversity (but see discussion below). High rates of increase in this number (bearing in mind potentially confounding factors, Costello & Solow 2003; Wonham & Pachepsky 2006) suggest that introduction pathways are numerous or wide open (Carlton & Ruiz 2005), whereas a decline or stabilization in this number suggests that control and management actions are effective. A comparison of relative numbers of IAS across nations also provides information on the global extent of the problem. Furthermore, implicit in this measure is the identity of IAS, which is information that is gathered automatically in the process of listing and counting numbers of IAS at any scale (de Poorter et al. 2005). Number of IAS thus provides information that is highly relevant to meeting both the conservation and indicator objectives for this headline indicator (Table 2).

The number of alien species is on its own an insufficient indicator of biodiversity threat because threat is distributed very unevenly across alien species (Andow 2005; Rejmánek et al. 2005). A small proportion of alien species tend to have a disproportionately large impact on biodiversity (Williamson 1996). Therefore, some measure of the relative distribution and abundance of individual species is necessary to indicate the status of alien species invasion. The extent to which the threat to biodiversity from alien species is reduced thus depends not only on a decline in the number of invasive and potentially invasive species but, most importantly, on a decline in the number of transformers of natural and seminatural habitats (Table 1; Richardson et al. 2000). It is, however, equally important to evaluate the number of species at earlier stages of a potential invasion (category II, Table 1, de Poorter et al. 2005) so that the rates of establishment and potential future threat can be assessed and the species can be prioritized for control. For example, the number of naturalized species may be a reliable predictor of the number of invasive species (Rejmánek & Randall 2004). The likely success of control measures is also higher earlier on in the invasion process (Simberloff et al. 2005). Nevertheless, information on transformer and invasive species (Table 1) are likely to be more readily available than data on alien and naturalized species and is also more immediately relevant to the indicator objective (Table 2).

Therefore, although data on alien and naturalized species are valuable at a national scale for evaluating potential future threat (and may be incorporated into the IAS indictor), numbers of invasive and transformer species are the minimum information necessary for a global IAS indicator. The numbers of species in categories of increasing invasion status (Table 1) thus provide the simplest possible measure for evaluating the relative threat to biodiversity posed by alien species. An assessment of the relative numbers of alien species in each of the four categories of invasion status (Table 1) thus provides information necessary to prioritize and monitor the success of IAS management systems (via the two means of achieving the conservation objective listed in Table 2).

Not only is this measure highly relevant to indicating the status of alien species invasion, but information on numbers of IAS is widely available for several nations, groups of taxa, and habitats (UNEP 2004*c*). In addition, several countries already have ongoing, systematic monitoring programs for one or more IAS (CBD 2000*a*) and would thus be in a position to categorize alien species as either naturalized, invasive, or transformer species (de Poorter et al. 2005). Four major electronic metadatabases have links to over 120 databases that list IAS and contain some, but rarely comprehensive information on them (Table 4).

For example, The Global Invasive Species Database is a continuously updated online information source on IAS containing species profiles and management and related information (de Poorter et al. 2005, Table 4). The database DAISIE is a regional network of IAS information for Europe that aims to both inventory and provide information on the prevention, control, and impacts of IAS (Table 4). Clearly a global information system for invasive species is necessary (Ricciardi et al. 2000), and to this end the GISIN is currently under development (Table 4). This information system will collate and standardize the presentation of available information, prioritize the information required to support national and global-scale indicators of IAS, and identify major information gaps (Table 4).

In addition to numbers of IAS, the cost of alien invasions has been proposed as an indicator of trends in alien species invasion (UNEP 2004*a*). The cost of IAS to society includes the (1) cost to national and global economies as

Table 4. Major electronic sources of information on invasive alien species.

Metadatabases and databases	*Internet address*
List of Global and International Invasive Alien Species Online Information	http://invasivespecies.nbii.gov/documents/databases/globaldbs.htm
North European and Baltic Network on Invasive Alien Species (NOBANIS)	http://www.artportalen.se/nobanis/Search.asp
U.S. Government	http://www.invasivespeciesinfo.gov
Delivering Alien Invasive Inventories for Europe (DAISIE)	http://www.europe-aliens.org
Global Invasive Species Database (GISD) of the Invasive Species Specialist Group (ISSG)	http://www.issg.org/database
Global Invasive Species Information Network (GISIN)	http://www.gisinetwork.org

a consequence of, for example, loss of pasture, increased fire frequency, changes in water regimes; (2) cost of the control and management of IAS; (3) cost in terms of biodiversity loss (Pimentel et al. 2000; Pimentel 2001). Although biodiversity loss as a cost of IAS is certainly directly related to the 2010 target, it is inherently difficult to measure and inadequately represented by direct economic damage and IAS control costs (Pimental et al. 2005). Although economic damage and control cost data are attainable (Pimental et al. 2000; Born et al. 2005), placing a direct monetary value on biodiversity loss remains problematic (Pimental et al. 2005). Furthermore, although data on the economic cost of IAS control are available in some instances, time-series information on costs is not (Born et al. 2005). Control costs vary across nations not only as a result of differences in gross domestic product and investment in IAS control but also as a consequence of differences in local economies (e.g., labor, equipment, and implementation costs) (UNEP 2004*a*; Born et al. 2005). Therefore, at present, cost does not comply with the principles of simplicity and data availability widely accepted for effective indication. For these reasons we do not further consider the cost of IAS, although we acknowledge that financial indicators are highly policy relevant and strong indicators of political will and capacity to facilitate change.

MANAGEMENT-STATUS INDICATORS

Propagule pressure (introduction effort or the size and frequency of release events of alien individuals) is considered the single best explanatory variable of a particular species becoming invasive and is also the primary mechanism linking different stages of the invasion process (Lockwood et al. 2005; Rejmánek et al. 2005; Colautti et al. 2006). Consequently, the most effective means of reducing the threat of IAS is to prevent the introduction of alien species propagules via routes of entry (see framework for integrated vector management, Carlton & Ruiz 2005). A measure of the number of introduction pathways (routes and vectors, sensu Carlton & Ruiz 2005) covered by operational management plans to prevent or minimize the introduction of propagules will thus provide information on actions being taken to reduce the future potential status of IAS.

Five major introduction pathways, facilitated largely by trade and human movement (Chown et al. 1998; McKinney 2001; Perrings et al. 2005), are recognized: air, sea, road, postal, and intraboundary translocation (Ruiz et al. 2000; Carlton & Ruiz 2005). It is widely recognized that there are gaps in both international and national regulatory frameworks for identifying and controlling introduction pathways (Carlton & Ruiz 2005). For example, the purchase of products over the Internet and subsequent dispersal via postal services is considered a major source of introduction and spread of invasive green macroalgae in the United States (Walters et al. 2006). Intraboundary translocation (i.e., the movement of alien and limited-range indigenous species within national borders and across neighboring ones) is also often poorly regulated (Shine et al. 2005; but see, e.g., U.S. Fish & Wildlife Service 2006). Focus on this management objective (i.e., vector management) as a component of the indicator is thus highly relevant because a reduction in the introduction of alien species propagules is the single most direct and potentially effective means of reducing the threat to biodiversity from IAS (Table 2). Management plans for IAS introduction pathways should thus aim to achieve a reduction in both the number and size of introduction pathways (i.e., to reduce the range of possible entry routes and to reduce the propagule entry rate via those routes that cannot be eliminated).

Preventing future invasion by alien species by controlling introduction pathways is, however, in itself insufficient to reduce the threat to biodiversity from IAS because of the current and immediate threat from several highly IAS already well established in natural and seminatural areas (Mack et al. 2000). Without active management of these species, their threat to biodiversity is likely to increase (Van Wilgen 2004; Wittenberg & Cock 2005). Integrated management plans for existing IAS should aim to reduce the number of populations of each species, and where this is not possible to reduce the density, recruitment rates, and propagule generation of populations (i.e., to simultaneously reduce the range and abundance of IAS) (Kinlan & Hastings 2005; Wittenberg & Cock 2005). Finally, these management-status indicators will facilitate the development of coherent policies for IAS management, as has been advocated to compliment the current, widely adopted species-by-species approach to IAS management (Wittenberg & Cock 2005; Simberloff et al. 2005).

National Indicator

Because more than a single measure is necessary to indicate and monitor the status of alien species invasion, the proposed IAS indicator may be composite (i.e., contain information that is aggregated across the three single indicators) to evaluate national and global progress toward the 2010 target (UNEP 2003*b*; Buckland et al. 2005; Nardo et al. 2005). A composite indicator is most useful in policy analysis and communication and in benchmarking country performance (although the single indicators remain most directly and reliably interpretable) (Nardo et al. 2005). The challenge with composite indicators is nonetheless to keep them simple so that they are readily understood and disaggregated (Pereira & Cooper 2006). In this case aggregation of information will be necessary across single indicators and across taxa, habitats, ecosystems, and nations (see also de Heer et al. 2005). The indicator should be representative of the taxonomic and

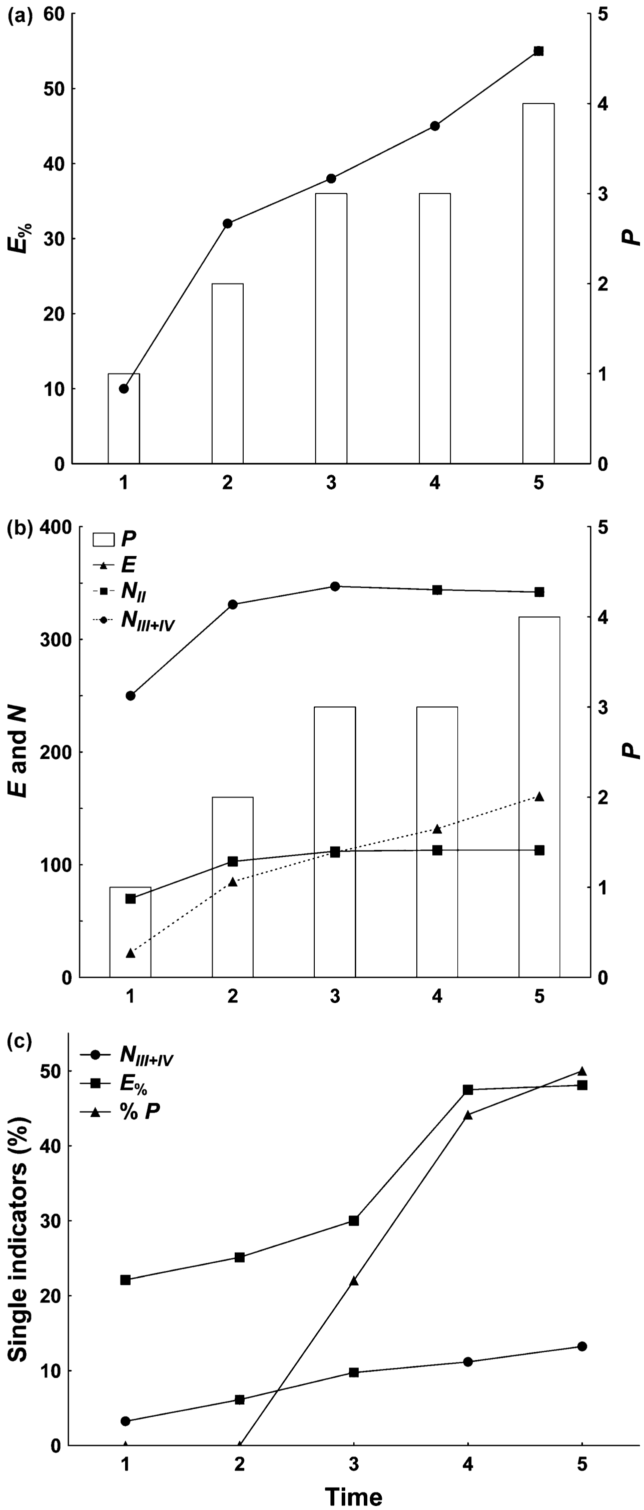

Figure 1. Single indicators of trends in invasive alien species (IAS) at a national scale (a) based on the semiaggregated single indicator ($E_{\%}$*, percentage of IAS with management plans) and* P *(number of introduction pathways with management plans) and (b) based on the single indicators (*N_{III+IV}*, numbers of species in invasive and transformer categories;* E*, numbers of species with management plans; and* P*) and additional available information on alien species status (*N_{II}*, number of naturalized species), and (c) at a global scale based on aggregation by averaging across nations (with number of IAS,* N_{III+IV}*, presented here per unit land area [x10*^{2}*]). See Table 3 for further details of single indicators.*

geographic diversity of IAS (although the groups for inclusion will have to be standardized to ensure comparability across nations). Recommended categories to ensure taxonomic representivity include vertebrates, invertebrates, plants, and microorganisms. The IAS indicator should also be representative of the range of global ecosystems (including marine, freshwater, and terrestrial habitats).

At a national scale, therefore, the number of species in two or more of the invasion status categories (at a minimum N_{III} and N_{IV}, Tables 1 & 2) may simply be the sum of the number of vertebrate, invertebrate, plant species, and microorganisms in marine, freshwater, and terrestrial habitats. This approach readily facilitates disaggregation of the information for more specific, detailed analyses of invasion status by habitat or taxon. In addition, where nations do not have adequate data for all taxa or habitats, partial, qualified indicators may be constructed that exclude particular taxa or habitats. At a national scale, therefore, the indicator may simply take the form of the values: N_{III}, N_{IV}, E, and P (where available, N_{II} may also be incorporated as an indicator of incipient threat) encompassing taxonomic groups and habitats (Table 3). These single indicators may, however, be further aggregated to a lesser or greater degree as desired (as in Table 3 and Fig. 1a-b). Moreover, appropriate weighting for area (Stark et al. 2006) or productive energy availability (Chown et al. 2005) could be applied to N to facilitate comparison.

Finally the indicator needs to be used to establish trends in IAS. Trends may be monitored at the national scale by plotting either $E_{\%}$ and P (Fig. 1a) or N_{II}, N_{III+IV}, E, and P (Fig. 1b) for every temporal record thereof that is available. At national scales, progress toward reducing the threat to biodiversity from IAS, and thus the 2010 target, is measured as a positive trend in $E_{\%}$, P, and E, and a negative trend or no change in the values of N (Fig. 1a-b). Trends in IAS at a national scale may also be determined with a composite indicator (Table 3). The relative positions of nations with respect to the IAS target (low numbers of IAS and comprehensive management plans in operation to reduce introduction risk and manage existing IAS populations) provides a composite global indicator of IAS problem and management status (Fig. 2). Here the trend for any particular nation may be established by plotting its progress toward the IAS target (T) over time, with a positive trend in T signaling achievement of the 2010 target (Table 3). This composite indicator is scalable in the sense that it may be applied at regional, continental, or

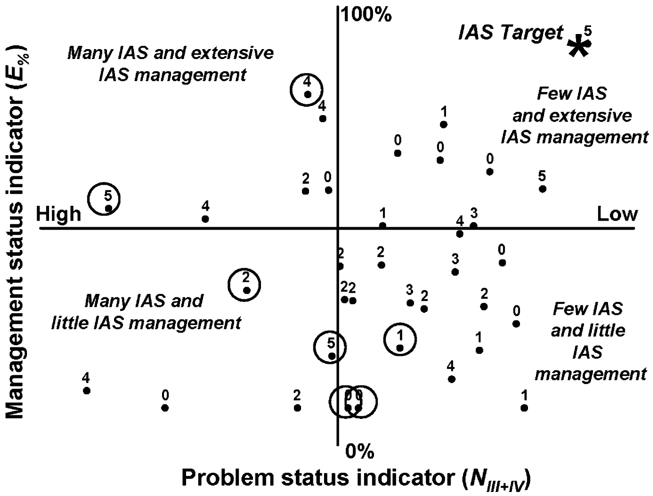

Figure 2. Composite indicator of global trends in invasive alien species (IAS) showing relative positions of nations (points) with respect to the IAS target, based on their problem- and management-status indicators. The P *is presented numerically (0–5) alongside each nation on the cross-plot. Points include data for seven countries (circled, from left to right: Australia, South Africa, New Zealand, Canada, Swaziland, Namibia, and the United Kingdom [the list of data sources used is available from http://www.sun.ac.za/cib]) and simulated country data (uncircled points) for illustration of a range of other possible combinations of the single indicators. Data on the abscissa are $\log_{10}$ transformed, centered (mean = zero), and scaling is from high (left) to low (right). Both axes may be normalized to facilitate unit progress comparisons (because they have different measurement units, see Nardo et al. 2005). For comparisons between nations, the problem-status indicator may be further weighted, for example, by land area or productive energy availability, and the management-status indicator may be further weighted by gross domestic product. Progress toward the target (*T *and* T_G*, see Table 3) over time (*t*) provides both national and global composite indicators of trends in IAS.*

global scales, as well as to one or more taxonomic groups or ecosystems.

To achieve the 2010 target, regular sampling of the selected indicator is required, and at least three data points are necessary for each component of the indicator (Dobson (2005). National-scale trends may be obtained fairly readily with the indicator we propose, particularly if historical data are available for the single indicators. Several countries have ongoing systematic monitoring programs for one or more IAS (CBD 2000*a*). However, without a view to beyond 2010 (see also Pereira & Cooper 2006), this exercise would be pointless for the numerous nations where fewer than three time-series points are available and where this situation is unlikely to change by 2010. Although the 2010 target is an important policy milestone, it would be shortsighted to invest in the development of these indicators were they not intended for longer term, widespread adoption. Therefore, current data shortcomings and the consequent inability to contribute to the information requirements for the 2010 target should not be a disincentive to nations to adopt standard, comparable indicators to contribute to more critical medium- to long-term conservation goals.

Global Indicator

Ultimately, as required by the 2010 target framework (UNEP 2003*a*), national-scale data must be aggregated to provide a global indicator, and this indicator used to establish global trends in IAS. Again, where limited data are available, trends in one or more of the single indicators (mean N_{III+IV} and where data are available also mean E and median P; Table 3) may be used. Nevertheless, where the necessary data are available, it is more informative to present the single indicators N_{III+IV}, E, and P graphically in composite form (Fig. 2). Because of inherent differences in land surface area, productive energy availability and economic well-being (e.g., assessed as gross domestic product), movement by nations toward (or away from) the target (Fig. 2), rather than absolute distance from the target, is a more realistic indicator of global trends in IAS. If desired, relative performance of nations may be compared by, for example, controlling for land surface area and gross domestic product (e.g., Fig. 1c). In addition, for comparability across nations with large differences in indigenous species richness, the number of IAS could be expressed as a percentage of IAS per indigenous species in the group (UNEP 2003*a*). This presupposes, however, the availability of accurate, indigenous species richness information, and inadequate taxonomic information (Gaston & May 1992) will introduce unnecessary error into the IAS indicator.

In addition to the use of across-nation averages for the global indicator (Table 3), the distribution of national T values may be examined to identify possible common factors contributing to either poor or good progress toward achieving the target. An alternative form of global indicator could be the use of existing databases to compile global lists of invasive species and their global status across categories III–IV (Table 1). Global management-status indicators in this case may include international conventions, policies, and risk-related tariffs to limit introduction pathways and control existing populations of IAS (e.g., the Cartagena Protocol on Biosafety [CBD 2000*b*] and the General Agreement on Tariffs and Trade [WTO 1994]) (Perrings et al. 2005; Shine et al. 2005). The feasibility of this approach is, however, highly dependent on the quality and comprehensiveness of global databases such as GISD and GISIN (de Poorter et al. 2005) (Table 4).

Critical Assessment

To ensure the effective development of an IAS indicator, the indicator should be evaluated against several general principles and characteristics of successful indicators (e.g., UNEP 2003*b*, 2004*c*; Balmford et al. 2005; de Heer et al. 2005; Gregory et al. 2005). The process of testing any indicator once it has been developed is critical to validate and demonstrate the sensitivity and accuracy of the indicator (McGeoch 1998, 2002; Dobson 2005). This must include an understanding of the formal relationship between single indicators and may require multivariate, sensitivity, and uncertainty analyses (Nardo et al. 2005; McGeoch 2006). The indicator we propose here therefore remains to be tested and refined or modified on the basis of the outcome of this process (Gregory et al. 2005). For example, by testing an indicator on a simple bird species data set, Buckland et al. (2005) showed that the properties of the geometric mean were superior to the arithmetic mean for aggregating relative abundance data across populations. Characteristics that require testing for the IAS indicator include, for example, its accuracy, precision, practicality, tractability, and responsiveness.

It is already apparent for the global IAS indicator that we propose that progress against the management-status indicator is likely to be achieved more rapidly than progress against the problem-status indicator and that the latter is thus less responsive than the former (Fig. 2). Moreover, the addition or exclusion of nations from the calculation of the global indicator beyond t_1 (Table 3) could influence the trend estimate. Finally, the sensitivity of the global IAS indicator we propose is likely to decline when the majority of nations achieve high values of management-status indicators. At this point it may be necessary to revise the indicator to encompass measures of, for example, decline in IAS population size and distribution. At present it is not feasible to consider using such measures because the availability of species abundance and distribution data are more limited than the measures we have proposed. Inevitably characteristics of accuracy, precision, and responsiveness to change are offset by practicality, expense, speed of implementation, and ease of interpretation. Nonetheless, the performance of the IAS indicator must be evaluated against all of these criteria and refined on the basis of the outcome of such testing.

The confidence with which this indicator may be used depends on (1) the accuracy and comprehensiveness of the information forming the single indicators, (2) the global national and taxonomic coverage achieved, and (3) the way in which the indicator translates into a realized threat to biodiversity. First, therefore, a summary of data availability across countries and over times is required (Nardo et al. 2005). The accuracy of tallies of numbers of species and the category or state of invasion in which they fall depends directly on taxonomic information and survey effort (Richardson et al. 2000). Because of their negative impact, the identity and number of invasive and transformer species are likely to be more accurate than the lists of alien and naturalized species.

Furthermore, at a national scale the downgrading of the status category of individual species is conceivable. Nevertheless, the existence and implementation of management plans to control populations of invasive species or introduction pathways do not necessarily translate into successful control or management. Ineffectual management programs may thus result in an increase in the *E* and *P* components (or maintenance of high values of these components) of the IAS indicator, with no concomitant decline or stabilization in the values of *N*. This provides a strong argument for the use of this indicator in disaggregated form in addition to its composite form (see also Nardo et al. 2005). Although measures of the number of IAS with operational management plans, or the number of management plans for introduction pathways, are less pertinent to the objective than the efficacy of such plans, the former information is more immediately and readily quantifiable than the latter. Furthermore, environmental management plans routinely incorporate systems for monitoring their own efficacy and are thus self-regulatory (ISO 2002). Therefore, information on the existence and implementation of such plans should be sufficient as a measure of the management status of introduction pathways for IAS. Guidelines for minimum criteria of what constitutes an operational management plan in this context will also be necessary.

Obstacles to Development and Implementation of a Global IAS Indicator

The process followed in the attempt to develop a global IAS indicator, as outlined above, highlights several challenges that will have to be overcome if such an indicator is to be implemented. Foremost among these is the absence of a stable definition for invasive species and large differences in the way invasive species are categorized in IAS species checklists (Richardson et al. 2000; Pyšek et al. 2004). Nonetheless, constructive solutions to this problem exist (e.g., Pyšek et al. 2004) and include definitions derived from natural biogeographical processes (rather than human values) associated with species population growth, dispersal, migration, and range expansion (such as those of Richardson et al. [2000] used here).

Second, although lists of alien species are available for several nations, collated and comparable information on species management and the management of introduction pathways is far less-readily accessible. Therefore, as acknowledged by the CBD (UNEP 2004*c*), additional data will have to be collected and existing data collated if a global IAS indicator is to be implemented (de Poorter et al. 2005).

Finally, and relevant to all indicators, including the one we propose, a comprehensive understanding and appreciation of the limitations of single and composite indicators is critical. In its absence biases may be compounded and misinterpretation is likely (particularly in a policy context) (McGeoch 2006). Therefore, the challenge is clearly to develop an IAS indicator that is as robust as possible, that minimizes opportunity for misinterpretation, and that is sufficiently flexible to accommodate advances in scientific understanding.

Conclusion

A minimum indicator at both national and global scales for establishing trends in IAS is thus the problem-status indicator, number of alien species in status categories III and IV (i.e., invasive and transformer species). Nonetheless, the inclusion of management-status indicators is necessary to achieve the CBD management goal and targets for IAS. Global trends in IAS may be quantified as the progress of nations toward the IAS target of a decline (or stabilization) in the number of IAS and implementation of comprehensive IAS management plans. Although it may not be possible to achieve the desired objective for a global indicator of biological invasion by 2010 as effectively or comprehensively as desired, it certainly appears possible to obtain trend estimates for a component of the taxa, ecosystems, and regions involved. The indicator development process will also establish the mechanisms necessary for ongoing monitoring of global trends in IAS (McNeely et al. 2005). The indicators we propose form a component of the foundation of strategic responses identified by the CBD to address the global problem of biological invasion. They represent a subset of the potential indicators of biological invasion, and opinions on their utility will differ. Nevertheless, that the need for such indicators is urgent has been broadly agreed. Therefore, the sooner detailed discussions thereof commence the better the conservation outcomes will be.

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