Conservation Biology

Essay

The Why, What, and How of Global Biodiversity Indicators Beyond the 2010 Target

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Abstract: *The 2010 biodiversity target agreed by signatories to the Convention on Biological Diversity directed the attention of conservation professionals toward the development of indicators with which to measure changes in biological diversity at the global scale. We considered why global biodiversity indicators are needed, what characteristics successful global indicators have, and how existing indicators perform. Because monitoring could absorb a large proportion of funds available for conservation, we believe indicators should be linked explicitly to monitoring objectives and decisions about which monitoring schemes deserve funding should be informed by predictions of the value of such schemes to decision making. We suggest that raising awareness among the public and policy makers, auditing management actions, and informing policy choices are the most important global monitoring objectives. Using four well-developed indicators of biological diversity (extent of forests, coverage of protected areas, Living Planet Index, Red List Index) as examples, we analyzed the characteristics needed for indicators to meet these objectives. We recommend that conservation professionals improve on existing indicators by eliminating spatial biases in data availability, fill gaps in information about ecosystems other than forests, and improve understanding of the way indicators respond to policy changes. Monitoring is not an end in itself, and we believe it is vital that the ultimate objectives of global monitoring of biological diversity inform development of new indicators.*

Keywords: CBD, Living Planet Index, monitoring, Red List Index, targets

El Porqué, Qué y Cómo de los Indicadores Globales de Biodiversidad Más Allá de la Meta 2010

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Paper submitted December 15, 2009; revised manuscript accepted September 8, 2010.

Conservation Biology, Volume **, No. **, ***–***

DOI: 10.1111/j.1523-1739.2010.01605.x

Resumen: *La meta 2010 de biodiversidad acordada por los signatarios de la Convención de Diversidad Biológica atrajo la atención de los profesionales de la conservación hacia el desarrollo de indicadores para medir los cambios en la diversidad biológica a escala global. Consideramos porqué se requieren indicadores globales de biodiversidad, qué características tienen los indicadores globales y cómo funcionan los indicadores existentes. Debido a que el monitoreo podría absorber una gran proporción de fondos disponibles para la conservación, consideramos que los indicadores deberían estar ligados explícitamente con los objetivos de monitoreo y que las decisiones sobre los planes de monitoreo merecedores de financiamiento deberían estar informadas por predicciones de tales planes para la toma de decisiones. Sugerimos que el incremento de la percepción del público y los tomadores de decisiones, la auditoría a las acciones de manejo y la notificación de las opciones de políticas son los objetivos más importantes del monitoreo global. Utilizando 4 indicadores de la diversidad biológica bien desarrollados (extensión de bosques, cobertura de áreas protegidas, Índice de la Lista Roja, Índice del Planeta Vivo) como ejemplos, analizamos las características que requieren los indicadores para cumplir con estos objetivos. Recomendamos que los profesionales de la conservación mejoren los indicadores existentes eliminando sesgos espaciales en la disponibilidad de datos, llenen huecos en la información sobre ecosistemas distintos a bosques y mejoren el conocimiento de la manera en que los indicadores responden a los cambios en las políticas. El monitoreo no es un fin en sí, y consideramos que es vital que los objetivos finales del monitoreo global de la biodiversidad biológica propicien el desarrollo de indicadores nuevos.*

Palabras Clave: CDB, Índice de la Lista Roja, Índice del Planeta Vivo, metas, monitoreo

Introduction

In 2002 the 193 signatory parties to the Convention on Biological Diversity (CBD) agreed to "significantly reduce the rate of biodiversity loss by 2010." This commitment has become known as the 2010 biodiversity target. European ministers of the environment agreed to the more ambitious target of halting biodiversity loss by 2010. These agreements stimulated considerable effort in developing indicators to monitor progress in meeting this objective (Mace & Baillie 2007; Butchart et al. 2010). The CBD defines *biodiversity* as "the variety of life on Earth and the natural patterns it forms" (CBD 2000). Monitoring of biodiversity, as it is defined by the CBD, cannot be based on a single measure (Gaston 1996); therefore, the CBD adopted a suite of indicators. Nevertheless, less than half of the CBD indicators can be considered well developed (with established methods and a global time series) (Walpole et al. 2009).

Recent evidence suggests the 2010 biodiversity target has not been met (Butchart et al. 2010). The development of post-2010 targets is now underway, which raises the question of which indicators should be used to monitor biodiversity in the future (Walpole et al. 2009; Mace et al. 2010). Many authors have voiced concerns about the limitations of existing biodiversity-monitoring protocols at all extents and resolutions. They note that not enough attention is paid to the objectives of the monitoring, to what is being monitored, and to the design of indicators (Yoccoz et al. 2001; Balmford et al. 2005; Legg & Nagy 2005; Katzner et al. 2007). Yoccoz et al. (2001) call these the why, what, and how of biodiversity monitoring. We believe now is the time to consider why global biodiversity indicators are needed, what characteristics such indicators should have, and how four CBD indicators (extent of forests, protected-area coverage, Living Planet Index, and Red List Index) perform with respect to those characteristics and to identify priorities for development of post-2010 indicators.

Objectives of Monitoring

Monitoring is commonly defined as the process of gathering information about state variables at different points in time for the purpose of drawing inferences about changes in state (Yoccoz et al. 2001), whereas an *indicator* is defined as a metric that represents that state. Biodiversity indicators can be straightforward metrics, such as relative abundance of species, or they can be composite metrics that combine data from a number of different monitoring programs (Collen et al. 2009). Because monitoring biodiversity change at a global scales involves collating relevant data from available sources (Butchart et al. 2010), we define *monitoring* in the context of global biodiversity indicators as a process that includes collection of primary biodiversity data, synthesis of data into an indicator, and public dissemination of trends in the indicator.

Understanding why an aspect of biological diversity should be monitored is an essential prerequisite for ensuring that a monitoring program is efficient and fit for the purpose. Many monitoring programs lack explicit objectives (Yoccoz et al. 2001; Lindenmayer & Likens 2009) and are not tied closely to decision making (Nichols & Williams 2006). There have been recent advances in optimal monitoring theory, which involves defining explicit objectives for monitoring taking into consideration resource constraints and the additional value of the information generated with respect to management decisions

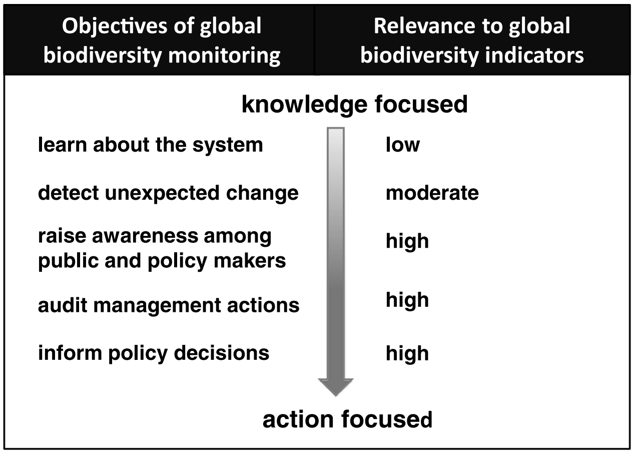

Figure 1. Possible objectives for biodiversity monitoring and their relevance to global biodiversity indicators.

(Field et al. 2004; Gerber et al. 2005; Joseph 2008). Optimizing monitoring is important because resources available for conservation are limited, but it requires an explicit understanding of the objectives of monitoring.

We suggest that objectives for monitoring biodiversity range from those that are knowledge focused (information collected has no direct link to management actions) to those that are action focused (information collected can be applied directly to management action) (Fig. 1). Joseph (2008) presents five reasons for monitoring biodiversity: to learn about the system, detect unexpected change in the system, raise awareness of the public and policy makers, audit management actions, and inform policy decisions. We considered the degree to which these reasons are relevant to monitoring of biodiversity at a global scale.

Learn about the System

We believe acquisition of knowledge is an important justification for monitoring and may well lead to subsequent policy action. For example, monitoring of stratospheric ozone levels in the Antarctic (Farman et al. 1985) resulted in the international agreement in 1989 to phase out use of chlorofluorocarbons. Well-designed monitoring of global biodiversity may improve understanding of ecological processes because data from multiple regions and ecosystems are more likely to shed light on general mechanisms or processes than data that are more geographically restricted. For many ecological processes, however, global monitoring may not be the most cost-effective way of learning because targeted experiments and directed studies across carefully selected sites are more efficient. We argue that learning about the system is unlikely to be one of the most important objectives of global biodiversity monitoring.

Detect Unexpected Change in the System

Long-term biodiversity monitoring has been useful in ways that were not foreseen. For example, much of what is known about the impact of pesticides on North American raptors was derived from monitoring designed to measure avian responses to other threats (Michener et al. 2009). Nevertheless, it would be difficult to justify a global biodiversity monitoring program with the primary objective of detecting unexpected trends, unless it was inexpensive.

Raise Awareness among the Public and Policy Makers

Monitoring data can inform the general public and raise the profile of conservation issues. For example, each year surveys carried out in the United Kingdom by the British Trust for Ornithology generate significant media coverage and increase general awareness of biodiversity trends. Public engagement affects whether decision makers ratify international treaties and pass and enforce national legislation (Dunlap 1995). National public opinion responds most strongly to indicators at the national or regional level. Nevertheless, the drivers of both conservation responses (e.g., financial donations) and biodiversity losses often originate in regions far from where losses are taking place. We believe monitoring of global indicators of biodiversity loss is therefore important for increasing public awareness internationally.

Audit Management Actions

Monitoring to evaluate whether a conservation action has been effective informs decision making (Sutherland et al. 2004) and motivates those in power to work toward meeting agreed targets (Bird et al. 2005). Although many conservation-relevant decisions are made at the national level, action or inaction may have international effects. For example, regional land-use decisions may cause the extinction of an endemic species. National governments have coordinated policies with objectives of meeting global targets for biodiversity conservation, and nongovernmental conservation organizations with an international mission donate substantial funds to conservation efforts (Brooks et al. 2006). We believe monitoring of global indicators is therefore needed to audit national and international decisions that may have global effects and to measure the effectiveness of international conservation organizations.

Inform Policy Decisions

Monitoring data can inform decisions among competing policy options. For example, the U.S. Fish and Wildlife Service decided between possible sets of harvest regulations for Mallards (*Anas playrhynchos*) on the basis of data on duck abundance and wetland cover (Nichols & Williams 2006). Their decisions depended on the outcome of competing mechanistic models that linked a given policy with duck abundance or wetland cover. As data accumulated over time, models with more support were given more consideration. The principle that monitoring should be part of the management process is well established, but such adaptive management is still not widely applied (Walters 2007; Lindenmayer & Likens 2009).

Desirable Characteristics of Global Biodiversity Indicators

To meet the objectives of global monitoring of biological diversity highlighted above, we suggest that global biodiversity indicators need to be cost-effective; provide information about diverse taxonomic groups; provide reliable information on the status and trends of underlying biodiversity components; be informative at multiple extents and resolutions; allow frequent reporting; be meaningful to the public; and respond predictably to major policy changes.

Monitoring is costly and spending on monitoring may reduce spending on conservation interventions (Field et al. 2004). Cost-effectiveness is unlikely to be linearly related to the amount spent. Too little data and the indicator may not yield the desired information and the investment is wasted, whereas beyond a particular cost threshold the indicator may not provide any further useful information regardless of how much is invested. There may be substantial time delays in realization of the benefits of an investment in conservation monitoring, and there may be costs associated with delaying decisions while waiting for monitoring results. Cost considerations must therefore be central to the choice and design of indicators. Ideally, the cost of monitoring any indicator would be compared with the expected value of the information the measure provides, yet few indicators are routinely evaluated in this way.

Existing data on the status of species are heavily biased toward vertebrates, charismatic, and commercially important species (Nee 2004). Basing indicators on a taxonomically biased subset of species has been criticized (Dobson 2005), although the extent to which this is a problem depends on the monitoring objectives. The objective of raising awareness may best be met by monitoring charismatic species, yet this may produce results that are not sufficiently representative for auditing management decisions or informing policy choices. Taxonomic coverage in any monitoring program will always be incomplete, and we suggest careful consideration be given to the costs and benefits of addressing specific biases.

The empirical relation between a biodiversity indicator and the trend in the state variables it provides information on may change if efforts are made to control the indicator directly (Goodhart 1975). In education, for example, the emphasis on the results of exam scores as indicators of learning has been blamed for the focus on teaching the contents of tests and has resulted in exam scores becoming a less reliable indicator (Klein et al. 2000). In conservation, the abundance of a cavity-nesting species as an indicator of old-growth forest condition would not be reliable if artificial nest boxes for the species were being supplied. A composite indicator constructed from a number of different data sets and species tends to be more difficult to manipulate and thus may ensure the indicator reliably reflects trends in the underlying biodiversity component of interest.

To meet the monitoring objective of informing policy choices, global indicators should provide information at global, national, and subnational levels. As an analogy, the economic indicator gross domestic product can be presented as a single global figure, but is commonly calculated for a region or nation. An indicator of trends at the national level is more likely to inform national policy than an indicator of trends at the continental or global level. Nevertheless, a global indicator can only be disaggregated to finer spatial levels if sufficient data are available. Currently, coverage of biodiversity data is heavily biased toward countries with high gross domestic product (Pereira & Cooper 2006).

Ideally it should be possible to report indicator values relatively frequently (e.g., annually). There is a particular need for frequent reporting when indicators are used to audit management actions because such actions need to be held accountable on a reasonable time frame if indicators are to affect decision making. In practice, the frequency of reporting that is possible for a given indicator depends on the cost of gathering data (some indicators derived from remotely sensed data are relatively easily updated) and the temporal scale and resolution of the ecosystem processes being measured.

If the aim of monitoring is to engage the public and thus inform policy makers, indicators should attract public interest. This does not mean the public must understand how an indicator is calculated. For example, the technical details of many macroeconomic indicators (e.g., the consumer price index or the Dow Jones index) are poorly understood by most members of the public, yet they are widely referenced.

If the purpose of an indicator is to inform policy choices, the likely response of the indicator to policy changes should be known at least qualitatively. Characterizing this response requires an understanding of the mechanisms that link policy change to changes in biodiversity, the effect of these changes on the indicator, and the role of other drivers of biodiversity change. For example, the CITES Monitoring Illegal Killing of Elephants program aims to determine whether changes in CITES policy affect the level of elephant poaching, but differentiating the effect of global trade restrictions from the effects of other drivers of elephant poaching (e.g., civil strife, global economic trends) is a formidable statistical challenge (Burn 2007). Predicting the effect of policy actions on indicators is not new. Economic policy makers depend heavily on models of the effects of specific policies on economic indicators (e.g., gross domestic product, inflation, unemployment rate). To meet the objective of informing conservation policy, models are needed that predict trends in biodiversity indicators in response to likely changes in policy. This explicit connection between global biodiversity indicators and policy decisions has yet to be explored.

Performance of Existing Global Indicators

There will never be a perfect global biodiversity indicator. An indicator may perform well with respect to one desirable characteristic and not as well with respect to another. We believe our list of desirable characteristics of an indicator provides a useful framework within which to consider the strengths and weaknesses of existing and future indicators. We investigated the performance of the four well-developed global indicators of biodiversity status and trends approved by the CBD: extent of forest (derived from data of the Food and Agriculture Organization [FAO]); protected-area coverage (calculated by U.N. Environment Program-World Conservation Monitoring Centre from data in the World Database of Protected Areas); the Living Planet Index (calculated by WWF and the Zoological Society of London from time series of vertebrate species abundance); and the Red List Index (developed by BirdLife International, the Zoological Society of London, and IUCN from trends in extinction probability of birds, amphibians, mammals, and corals estimated on the basis of the IUCN Red List).

Cost-Effective

The extent of forests indicator is based on the FAO's Forest Resources Assessment, which relies on a combination of national reporting of forest extent and remote sensing. The most recent 5-year assessment of forest extent cost approximately $25 million (M. Løyche Wilkie, personal communication). As the resolution and availability of remote sensing of global land cover improves, the cost of producing this indicator will decrease. The World Database of Protected Areas has been in development for 26 years, and $3 million was spent recently to update the database and improve the quality of the data. The database now costs approximately $1 million/year to maintain (C. Besançon, personal communication). The information content of the indicator would be improved if data on protected-area effectiveness (in terms of biodiversity representation and management effectiveness) were collected (Chape et al. 2005), which would add to the cost. From internal budgets, we estimated that the initial cost of the Living Planet Index in 2000 and annual operating costs are $160,000 and $250,000, respectively. We estimated the cost of delivering the Red List Index is approximately $1.6 million annually. The Red List Index could be improved by expanding its taxonomic coverage, which would be costly. Whether the cost of maintaining existing biodiversity indicators is warranted depends on the value of the biodiversity that is conserved on the basis of decisions informed by trends observed in the indicators. Such explicit evaluation of the performance of an indicator has not been attempted.

Provide Information about Diverse Taxonomic Groups

The four indicators we examined provide information on different elements of biodiversity. As a set, they are biased toward terrestrial systems. The Living Planet and the Red List Index are biased toward birds and mammals, but the taxonomic diversity included in both is expanding (Collen et al. 2009). To improve the taxonomic coverage of the Red List Index (Fig. 2), representative samples of species in selected taxonomic groups are being assessed (Baillie et al. 2008). Although forests are well represented in the current indicator set, many other ecosystems are not. We believe future developments in these indices should increase coverage strategically to maximize their value for decision making.

Reliably Inform on the Status and Trends of Biodiversity Components

Use of multiple indicators means that together the CBD indicators are relatively robust to distortion by actions targeting each indicator rather than the underlying biodiversity trend the indicators represent. Differences in the definition of *forest* and in monitoring methods among nations have limited the usefulness of the extent of forest indicator (Mayaux et al. 2005), but we think an increased reliance on remote sensing will make the indicator more robust. Until information on management effectiveness is included, protected-area coverage could be inflated by the creation of paper parks. The Living Planet Index and the Red List Index are relatively robust due to the broad range of data incorporated (on many species and from many different monitoring programs); although at finer spatial scales, values of both indices may be influenced by changes in the abundance or status of just a few species.

Informative at Multiple Levels

Measures of forest extent and protected-area coverage are available at the national level. The Living Planet Index has been calculated at the national level for several countries, and the Red List Index has been calculated for China (Xu et al. 2009), but it only makes sense to calculate these two indicators at smaller spatial levels if species coverage is adequate.

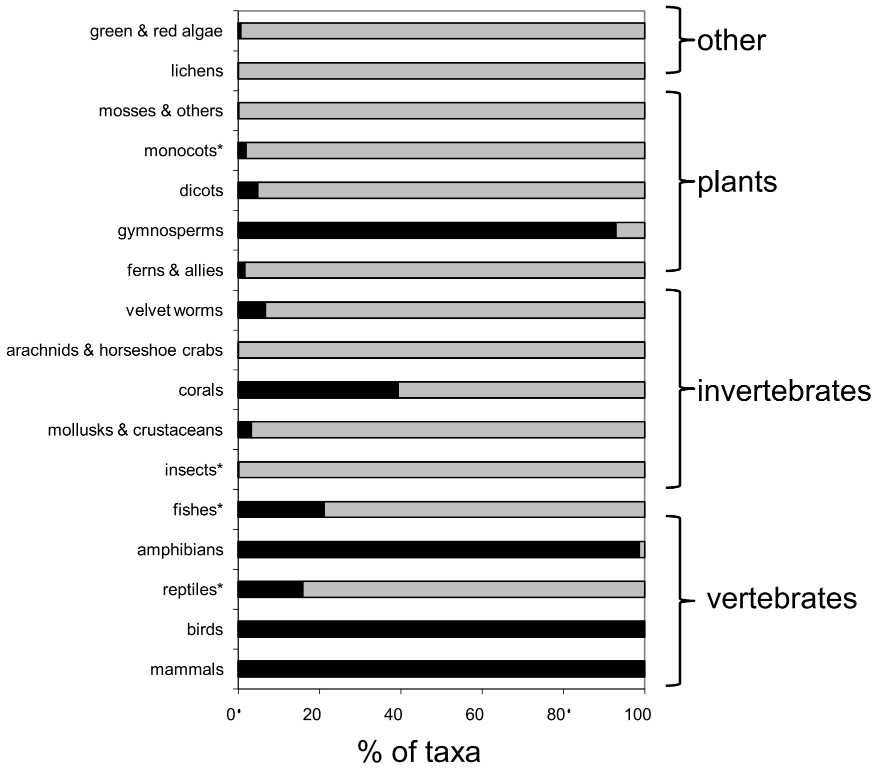

Figure 2. Taxonomic representation of species considered in International Union for Conservation of Nature Red List assessments (black, assessed species; gray, unassessed species; ∗, 1500 species within the taxonomic groups chosen at random to create a representative sample (Baillie et al. 2008) (data from IUCN 2010).

Possible to Report Frequently

The FAO assesses forest extent at 5-year intervals (Grainger 2008). Protected-area coverage and the Living Planet Index are reported annually. The IUCN Red List is annually updated for the subset of species for which new assessments have been carried out, but the Red List Index is only updated every 4 years. It may be possible to update some indicators more frequently (e.g., forest extent could theoretically be reported annually at relatively low cost), but the Red List Index probably cannot be updated more frequently because of the high cost of data collection and the fact that, because it is a relatively coarse measure, this indicator would not be expected to change rapidly.

Meaningful to the Public

Extent of forest cover is easily understood by the public. Nevertheless, the indicator is not currently the focus of regular media coverage. Coverage of protected areas may be helpful to policy makers because they can compare their country's progress with progress in other countries. For example, there was substantial publicity when the president of Madagascar announced that the country would triple its protected-area coverage (Norris 2006). As a measure of the abundance of wild species, Living Planet Index resonates with the public. Its website regularly receives over 100,000 hits on the day it is updated each year. The IUCN Red List on which the Red List Index is based also attracts widespread attention. Worldwide, the number of television, radio, and print stories rose from 980 in 2007 to 2300 in 2008 (data collated by IUCN).

Respond Predictably to Policy Changes

Scenario modeling can help assess the effects of different policies on global biodiversity (Balmford et al. 2008). Previous scenario-modeling exercises, however, have used metrics such as the number of extinctions avoided in particular taxonomic groups (Venter et al. 2009) rather than CBD indicators. If global biodiversity indicators are to inform policy makers faced with a range of options, then models that predict the effects of policies on these indicators need to be improved. Scenario modeling could, for example, be used to explore how each of the four indicators we examined are likely to respond to financial incentives to reduce carbon emissions from deforestation and degradation (REDD). Presumably, extent of forests would respond relatively quickly and reliably to a reduction in the rate of forest loss. The effect of such financial incentives for forest conservation on protected-area coverage depends on the outcome of the ongoing debate about the remit and definitions of REDD+ (Clements et al. 2010). We expect the Red List Index would respond relatively slowly as the status of forest-reliant species improved. How the Living Planet Index would respond depends on the extent to which forest-dependent species are represented in the index.

Priorities for Post-2010 Indicator Development

Beyond the 2010 CBD target, there will be an increasing focus on the need to improve global biodiversity indicators (Walpole et al. 2009; Butchart et al. 2010). Calls for a global biodiversity monitoring program have increased (Pereira & Cooper 2006). One such program is being developed under the auspices of the Group on Earth Observation (GEO), a voluntary partnership of governments and international organizations. The GEO-Biodiversity Observation Network (Scholes et al. 2008) aims at integrating existing regional programs of biodiversity monitoring, developing new monitoring programs where gaps exist, and exploring the integration of remote sensing with *in situ* monitoring. To make the best of these exciting developments, we believe that future global monitoring efforts should be allocated strategically.

Constant reinvention of indicators is costly in terms of time, cost, and public engagement. Although there are gaps in the existing indicator set, the well-developed CBD indicators are relatively broad and robust and we believe they should be maintained and improved. Indicator robustness could be improved by collecting data in a way that reduces existing biases, particularly spatial biases in data availability and quality. Conservation scientists and practitioners from academic, government, and nongovernmental sectors can contribute to improving the value of these indicators by supplying data.

It is beyond the scope of this paper to carry out a full gap analysis in the existing indicator set, but we suggest that more investment is needed in making the best use of new technologies so that extent and quality of ecosystems other than forests can be measured. Development of indicators of change in the extent of coral reefs, sea grasses, and mangroves on the basis of remote sensing data is in progress (Walpole et al. 2009). If remote-sensing techniques can be developed that robustly classify land cover and quantify land-cover change, then global information could be gathered at relatively low cost.

For indicators to fulfill their potential to both audit management actions and inform policy choices, a better understanding of the way indicators respond to policy changes is needed. Scenario analysis that explicitly considers the effects of policy on biodiversity indicators would help global biodiversity indicators fulfill their potential for informing policy.

It is not necessarily the case that to be useful global biodiversity indicators must comprehensively represent all elements of biodiversity, from all regions of the world, equally well. This is not a justification, however, for focusing indicators exclusively on relatively well-known species in well studied places; rather, indicators need to be devised that can perform their central function well for a realistic cost. Development of new indicators will be needed, but it is crucial not to lose sight of why indicators are needed in the first place.

Acknowledgments

This paper was developed from discussions at a workshop funded by the Natural Environment Research Council Centre for Population Biology. We acknowledge the support of the Leverhulme Trust (J.P.G.J., M.S., E.J.M.-G.), a Royal Society Wolfson Research Merit award (E.J.M.-G.), and the Rufford Maurice Laing Foundation (B.C.). P.B. and H.P.P. acknowledge the support of the Australian Research Council and the Commonwealth Environmental Research Facilities program. We also thank C. Besançon, J. Blanchard, R. W. Burn, S. Butchart, K. Carpenter, B. Costelloe, R. Ewers, S. Fritz, C. Hilton-Taylor, M. Hoffman, V. Katariya, S. Livingstone, M. Løyche-Wilkie, L. McCrae, G. Mace, J. Ragle, L. Russo, S. Stuart, K. Sullivan, D. Tyre, F. M. Underwood, N. Yoccoz, and two anonymous reviewers.

Literature Cited

Baillie, J. E. M., et al. 2008. Toward monitoring global biodiversity. Conservation Letters **1:**8–26.

Balmford, A., P. Crane, A. Dobson, R. E. Green, and G. M. Mace. 2005. The 2010 challenge: data availability, information needs and extraterrestrial insights. Philosophical Transactions of the Royal Society B-Biological Sciences **360:**221–228.

Balmford, A., A. S. L. Rodrigues, M. Walpole, P. ten Brink, M. Kettunen, L. Braat, and L. de Groot. 2008. Review on the economics of biodiversity loss: scoping the science. Report (contract ENV/070307/2007/486089/ETU/B2). European Commission, Cambridge, United Kingdom.

Bird, S. M., D. Cox, V. T. Farewell, H. Goldstein, T. Holt, and P. C. Smith. 2005. Performance indicators: good, bad, and ugly. Journal of the Royal Statistical Society Series a—Statistics in Society **168:** 1–27.

Brooks, T. M., R. A. Mittermeier, G. A. B. da Fonseca, J. Gerlach, M. Hoffmann, J. F. Lamoreux, C. G. Mittermeier, J. D. Pilgrim, and A. S. L. Rodrigues. 2006. Global biodiversity conservation priorities. Science **313:**58–61.

Burn, R.W. 2007. Elephants and ivory. Significance **4:** 118–122.

Butchart, S. H., et al. 2010. Global biodiversity: indicators of recent declines. Science **328:**1164–1168.

Convention on Biological Diversity. 2000. Sustaining life on Earth: how the convention on biological diversity promotes nature and human well-being. Secretariat of the Convention on Biological Diversity, Montreal.

Chape, S., J. Harrison, M. Spalding, and I. Lysenko. 2005. Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Philosophical Transactions of the Royal Society B-Biological Sciences **360:**443–455.

Clements, T. 2010. Reduced expectations: the political and institutional challenges of REDD+. Oryx **44:**309–310.

Collen, B., J. Loh, S. Whitmee, L. McRae, R. Amin, and J. E. M. Baillie. 2009. Monitoring change in vertebrate abundance: the Living Planet Index. Conservation Biology **23:**317–327.

Dobson, A. 2005. Monitoring global rates of biodiversity change: challenges that arise in meeting the Convention on Biological Diversity (CBD) 2010 goals. Philosophical Transactions of the Royal Society B-Biological Sciences **360:**229–241.

Dunlap, R. E. 1995. Public opinion and environmental policy. Pages 63–114 in J. P. Lester, editor. Environmental politics and policy: theories and evidence. Duke University Press, Durham, North Carolina.

Farman, J. C., B. G. Gardiner, and J. D. Shanklin. 1985. Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction. Nature **315:**207–210.

Field, S. A., A. J. Tyre, N. Jonzen, J. R. Rhodes, and H. P. Possingham. 2004. Minimizing the cost of environmental decisions by optimizing statistical thresholds. Ecology Letters **7:**669–675.

Gaston, K. 1996. Biodiversity: abiology of numbers and difference. Blackwell Science, Oxford, United Kingdom.

Gerber, L. R., M. Beger, M. A. McCarthy, and H. P. Possingham. 2005. A theory for optimal monitoring of marine reserves. Ecology Letters **8:**829–837.

Goodhart, C. 1975. Monetary relationships: a view from Threadneedle Street. Papers in monetary economics. Reserve Bank of Australia, Sydney.

Grainger, A. 2008. Difficulties in tracking the long-term global trend in tropical forest area. Proceedings of the National Academy of Sciences of the United States of America **105:**818–823.

Joseph, L. N. 2008. Theory to guide management of species for conservation. PhD thesis. University of Queensland, Brisbane.

Katzner, T., E. J. Milner-Gulland, and E. Bragin. 2007. Using modelling to improve monitoring of structured populations: are we collecting the right data? Conservation Biology **21:**241–252.

Klein, S. P., L. S. Hamilton, D. F. McCaffrey, and B. M. Stecher. 2000. What do test scores in Texas tell us? Education Policy Analysis Archives **8:**1–22.

Legg, C. J., and L. Nagy. 2005. Why most conservation monitoring is, but need not be, a waste of time. Journal of Environmental Management **78:**194–199.

Lindenmayer, D. B., and G. E. Likens. 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. Trends in Ecology & Evolution **24:**482–486.

Mace, G. M., and J. E. M. Baillie. 2007. The 2010 biodiversity indicators: challenges for science and policy. Conservation Biology **21:**1406–1413.

Mace G.M., et al. 2010. Biodiversity targets after 2010. Current Opinion in Environmental Sustainability **2:**1–6.

Mayaux, P., P. Holmgren, F. Achard, H. Eva, H. Stibig, and A. Branthomme. 2005. Tropical forest cover change in the 1990s and options for future monitoring. Philosophical Transactions of the Royal Society B-Biological Sciences **360:**373–384.

Michener, W. K., K. L. Bildstein, A. McKee, R. R. Parmenter, W. W. Hargrove, D. McClearn, and M. Stromberg. 2009. Biological field stations: research legacies and sites for serendipity. Bioscience **59:**300–310.

Nee, S. 2004 More than meets the eye—earth's real biodiversity is invisible, whether we like it or not. Nature **429:**804–805.

Nichols, J. D., and B. K. Williams. 2006. Monitoring for conservation. Trends in Ecology & Evolution **21:**668–673.

Norris, S. 2006. Madagascar defiant. BioScience **56:**960–965.

Pereira, H. M., and H. D. Cooper. 2006. Towards the global monitoring of biodiversity change. Trends in Ecology & Evolution **21:**123–129.

Scholes, R. J., G. M. Mace, W. Turner, G. N. Geller, N. Jurgens, A. Larigauderie, D. Muchoney, B. A. Walther, and H. A. Mooney. 2008. Ecology – toward a global biodiversity observing system. Science **321:**1044–1045.

Sutherland, W. J., A. S. Pullin, P. M. Dolman, and T. M. Knight. 2004. The need for evidence-based conservation. Trends in Ecology & Evolution **19:**305–308.

Venter, O., W. F. Laurance, T. Iwamura, K. A. Wilson, R. A. Fuller, and H. P. Possingham. 2009. Harnessing carbon payments to protect biodiversity. Science **326:**1368–1368.

Walpole, M., et al. 2009. Tracking progress toward the 2010 biodiversity target and beyond. Science **325:**1503–1504.

Walters, C. J. 2007. Is adaptive management helping to solve fisheries problems? Ambio **36:**304–307.

Xu, H. G., et al. 2009. China's progress toward the significant reduction of the rate of biodiversity loss. BioScience **59:**843–852.

Yoccoz, N. G., J. D. Nichols, and T. Boulinier. 2001. Monitoring of biological diversity in space and time. Trends in Ecology & Evolution **16:**446–453.