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Towards the global monitoring of biodiversity change

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Governments have set the ambitious target of reducing biodiversity loss by the year 2010. The scientific community now faces the challenge of assessing the progress made towards this target and beyond. Here, we review current monitoring efforts and propose a global biodiversity monitoring network to complement and enhance these efforts. The network would develop a global sampling programme for indicator taxa (we suggest birds and vascular plants) and would integrate regional sampling programmes for taxa that are locally relevant to the monitoring of biodiversity change. The network would also promote the development of comparable maps of global land cover at regular time intervals. The extent and condition of specific habitat types, such as wetlands and coral reefs, would be monitored based on regional programmes. The data would then be integrated with other environmental and socioeconomic indicators to design responses to reduce biodiversity loss.

The need for biodiversity monitoring

The Convention on Biological Diversity (CBD; http://www.biodiv.org) aims 'to achieve by 2010 a significant reduction of 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' [1]. The European Union has set an even more stringent target: to halt biodiversity decline by 2010 (Göteborg European Council, 2001[†]). Examination of current trends [2], as well as the exploration of plausible future scenarios [3], suggests that the CBD 2010 target is unlikely to be achieved unless an unprecedented effort is made, both at the policy and institutional levels, to improve current conservation efforts and to develop new strategies. This would include the implementation of measures targeted at biodiversity conservation inside and outside protected areas [4–6] and at limiting the causes of biodiversity loss in all economic sectors, from energy production to agriculture [7].

To determine how current conservation efforts can be improved and to guide new strategies, it is crucial that our progress towards the CBD 2010 target and beyond is monitored. How this should be done is now the subject of much debate. Most of the discussion has been directed at what indicators should be used based on existing data [8–10]. Recently, Balmford and colleagues [11] suggested that monitoring should be focused on trends in the abundance and distribution of populations and habitat extent, and reviewed the data available for these measures. Here, we go one step further by proposing a global monitoring network of biodiversity to gather new data for these measures and to integrate current monitoring initiatives.

A global monitoring network for biodiversity

Biodiversity is defined in the CBD as the 'the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems' [12]. This is a broad concept with many dimensions. For the purposes of biodiversity monitoring, we focus on two scales: regional and global, and two levels: species and ecosystems. These levels of biodiversity have particular implications at each scale for the delivery of ecosystem services (Box 1).

Current biodiversity monitoring programmes suffer from three main constraints [2,9,13]: incomplete taxonomic and spatial coverage; lack of compatibility between data sets owing to different collection methodologies; and insufficient integration at different scales. We propose a pragmatic approach to the global monitoring of biodiversity to tackle these issues, with global- and regional-scale programmes at the species and ecosystem levels (Figure 1). Whereas the ecosystem-level component will provide information about land cover, the species component will provide information about aspects of ecosystem condition. The global-scale programmes would follow a top-down approach, with an emphasis on central coordination, whereas the regional-scale programmes would follow a bottom-up approach, with an emphasis on regional needs and capabilities. The scientific community would have a major role in designing and implementing the network, including: a monitoring programme for the regular global sampling of indicator taxa of terrestrial biodiversity; a global network of regional programmes monitoring indicator populations for terrestrial, freshwater and

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Box 1. Ecosystem services

Ecosystem services are the benefits that people obtain from ecosystems, and can be divided into four groups (Figure I): provisioning services, regulating services, cultural services and supporting services. We generally only recognize services that have a market value, such as provisioning services and some cultural services, but we benefit from other cultural services (including the existence values that people place on conserving wild biodiversity) and regulating services, and, indirectly, from supporting services.

Each type of ecosystem service depends on particular components of biodiversity. The population abundance of species at the local level is important for ensuring the delivery of regional ecosystem services, such as forest foods and pest control, and is also important for recreational services, such as bird watching. Some studies suggest that supporting and regulating services depend not only on population abundances, but also on species richness and composition (e.g. primary productivity) [38–41]. Global species diversity delivers an important cultural service because of existence values; for example, people place a high value in conserving charismatic species, such as the California condor *Gymnogyps californianus* and the Iberian lynx *Lynx pardinus*. The extent of particular habitats, such as wetlands, forests or coral reefs, is also important for ecosystem services at the local and global scales. For instance, run-off regulation and firewood production are delivered at a regional scale, whereas carbon sequestration is delivered at the global scale. Finally, the diversity of ecosystems is important both in terms of scenic D.W. D.W. beauty (a regional cultural service) and existence values (a global cultural service).

The recently concluded Millennium Ecosystem Assessment [42] provides the most comprehensive assessment to date of the status and trends of ecosystem services. The Assessment finds that most ecosystem services are in decline. However, whereas some ecosystem services (e.g. food and some other provisioning services) are routinely monitored, most ecosystem services are monitored only sporadically. Enhanced efforts to monitor the state of ecosystem services themselves would be needed to complement the global biodiversity-monitoring programme proposed here.

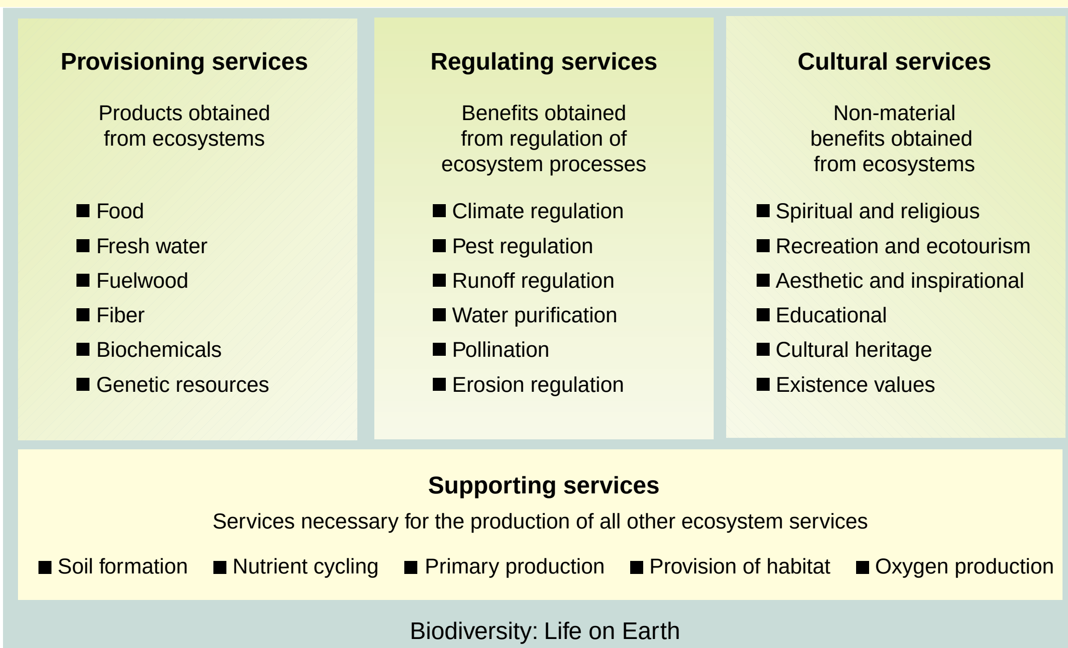

Figure I. A classification of ecosystem services. Modified with permission from [40].

marine biodiversity; the production of regular and comparable global land-cover maps based on remote sensing; a global network of regional programmes monitoring habitats that are best monitored, or have particular relevance, at the regional level.

Species level monitoring

The taxonomic coverage of current species-monitoring programmes is incomplete [14]. Although this is a limitation, it was not until recently that we had global distribution maps of species of one of the most well known groups, terrestrial vertebrates. These maps are now being produced in the context of Global Assessments for amphibians, reptiles, birds and mammals [15,16], conducted by IUCN (http://www.iucn.org), Conservation International (http://www.conservation.org), BirdLife International (http://www.birdlife.net), and other institutions. By contrast, there are few data on global plant distribution. This is a major deficiency given the ecological importance of plants and perhaps also a surprising one, because plants, as a group, are relatively well described [17].

A single snapshot of a species distribution is often insufficient to assess its vulnerability fully. Therefore, the Global Assessments are also compiling information about population trends based on information from experts and available data sets. Similarly, the Living Planet Index (LPI, [18,19]) developed by WWF International (http://www.panda.org) and UNEP-WCMC (http://www.unep-wcmc.org) to measure biodiversity change in the world, compiles 3000 population trends for <1100 vertebrate species, including freshwater, terrestrial and marine species. However, the selection of populations was constrained by data availability. For instance, most species are from temperate regions and, even within each species, the data are not spatially representative of

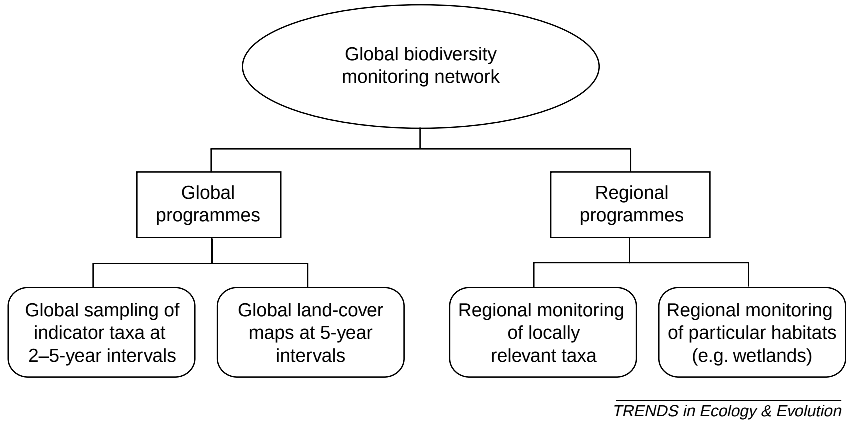

Figure 1. Hierarchical organization of the global biodiversity-monitoring network. The network would integrate global top-down programmes and regional programs. Both types of programmes would monitor two components of biodiversity: species and ecosystems.

what is happening within the distribution range of the species. Another problem comes from temporal discontinuities in the data.

One limitation of the LPI calculation method is that all decreases in population size, regardless of whether they bring a population close to extinction, are equally accounted for. An alternative is the Red List Index (http://www.redlist.org/info/programme.html), which compares the current classification of vulnerability of each species with the previous Red List assessment [20,21]. Vulnerability ranks can be assigned extinction probabilities, which gives a particular weight to species that are on the edge of extinction.

The LPI and the Global Assessments (which are the basis for the Red List Index) both emphasize data compilation, but are not as focused on designing or integrating monitoring programmes for data collection. The best examples of monitoring programmes come from regular regional surveys of taxa, often based on the work of hundreds of amateurs. For instance, the Patuxent Wildlife Research Center in collaboration with the Canadian Wildlife Service coordinate the Breeding Bird Survey, a monitoring programme of North American bird populations that was initiated in 1966 (http://www.pwrc.usgs.gov/bbs). The sampling is coordinated by professionals and uses a common protocol. Over 2500 volunteers participate in the annual sampling of 4100 survey routes located across continental USA and Canada. Similar efforts are the American Christmas Bird Count (http://www.audubon.org/bird/cbc) and the UK Breeding Bird Survey (http://www.rspb.org.uk/science/birdweb). In Europe, a Pan-European Common Bird Monitoring initiative (http://www.ebcc.info) has recently been developed [22], and an associated index (Farmland Bird Index) has been included in the list of Structural Indicators of the European Union (http://epp.eurostat.cec.eu.int).

Distribution atlases can also give important information about trends in geographical ranges, provided that they are sampled by using similar methods over time. For instance, Thomas *et al.* [23] used two UK butterfly atlases (1984 and 2001), two bird atlases (1976 and 1993) and two flora atlases (1962 and 2002) to document an overall decrease in species geographical ranges, based on samplings of 10 km x 10 km grid squares. In the absence of historical atlas data, herbarium samples and natural history museum samples can also be used to generate retrospective assessments of the trends in distribution of species [17,24].

Towards global species monitoring

Currently, there are no global equivalents of the Breeding Bird Survey for any taxa. To fill that gap, we propose that a global sampling programme targeted to indicator taxa should be developed. These indicator taxa should respond over short timescales to anthropogenic perturbations and should correlate well with the responses of other taxa. They should also have key roles in delivering ecosystem services globally. For reasons of feasibility, taxa for which the monitoring capacity already exists should be chosen. To enhance the value of the results in communicating to the general public and to policy makers, widely understood and appreciated groups should be selected. Finally, instead of a ‘monitor as many species as possible approach’, there should be a parsimonious approach in selecting taxa. Arguments could be advanced for a range of taxa that would satisfy these criteria, and a broader scale debate would be needed before investing in the development of a global species-monitoring programme. To encourage such a debate, we set out in Box 2 some reasons in favour of a global monitoring programme for birds and vascular plants.

The global sampling scheme should be designed by a coordinating team, but we suggest that it should involve nested spatial resolutions (e.g. from 20 km x 20 km in populated areas to 200 km$\times$200 km in isolated areas). Given that the land surface of the Earth is $\sim$134 million km^2 (excluding ice-covered Antarctica and Greenland), at the coarsest scale, $\sim$3500 sampling units would have to be studied. Units in areas where many skilled volunteers exist could be sampled every other year, whereas the most-isolated units could be sampled less regularly (e.g. every five years). The sampling design should maximize compatibility with ongoing surveys and should aim at estimating the abundance of each species in each unit. The observers could be a mix of volunteers already

Box 2. Which taxa should be monitored at the global level?

We propose that vascular plants and birds would be suitable and complementary indicators for global monitoring.

Vascular plants

The reasons for choosing plants are [17]: (i) vascular plants are the main primary producers in terrestrial ecosystems and, thus, are fundamental to ecosystem functioning; (ii) the diversity of plants is one of the best available predictors of diversity of other taxa [3] and has been used as such in the designation of biodiversity 'hotspots' [43]; and (iii) several organizations are already committed to a better understanding of plant diversity as part of the Global Strategy for Plant Conservation (http://www.biodiv.org/programmes/cross-cutting/plant). The biggest caveat of choosing plants is likely to be that it is a very large group, with 220 000–422 000 species (the difference hinging on the extent of synonymy) and ∼10–20% undescribed species [17]. The initial work would therefore have to focus on particular species subsets.

Birds

The reasons for choosing birds are: (i) they are easy to census, with many species being relatively conspicuous and/or highly vocal [44]; (ii) it is a feasible group to monitor, with ∼10 000 species, many ongoing monitoring programmes to build on [45] and many volunteers ready to contribute [44]; (ii) it is a group in which international cooperation is imperative, given the large percentage of species that are migrants. One problem with using birds is that they are the least endangered group among vertebrates [16], which suggests that they are less sensitive to anthropogenic change than are other vertebrate taxa. Still, a few studies have shown that the responses of birds to anthropogenic changes are correlated with the responses of other taxa [46].

participating in current surveys, and hired professionals to sample the most isolated units.

The global sampling of birds and plants would be complemented with a global network that integrates existing and new national, regional or global sampling programmes. This network would sample the taxa that are most relevant nationally or regionally as indicators of biodiversity change in selected sites (e.g. sites that are undergoing rapid land use change). In addition, because the new global sampling programme that we propose is directed primarily towards terrestrial biodiversity, existing programmes to monitor freshwater and marine taxa (e.g. fishes) would also have to be enhanced. We propose that the network is organized by biogeographical realms: Palearctic, Nearctic, Neotropic, Afrotropic, Indo-Malay, Australasia and Oceania [25]. Countries in each realm would propose a list of taxa and sites that they intend to monitor for each major terrestrial (e.g. forest, cropland, etc.), freshwater (e.g. rivers, lakes, etc.) and marine biome (e.g. coral reefs, estuaries and oceans). Taxa and distribution of sites would be harmonized for each biome within each realm and, if possible, across realms.

Ecosystem-level monitoring

Monitoring of ecosystem cover can be done using remote-sensing data [26,27]. One could expect that it would be easier to find global data on ecosystem change than on species change. Surprisingly, there are no directly comparable sets of global land-cover data for two different dates. For instance, the Global Land Cover for the year 2000 (GLC 2000) based on SPOT VEGETATION (Figure 2; http://www-gvm.jrc.it/glc2000) is not directly comparable with the International Geosphere–Biosphere Programme (IGBP) Land Cover (1992–1993, http://edcdaac.usgs.gov/glcc/globdoc2_0.asp) based on the National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer (NOAA-AVHRR). The difficulties arise from the use of different sensors, different land-cover classification systems (including different definitions of forest) and different classification methods. There is currently an ongoing programme to produce a global land-cover map for the year 2005, using the same classification as the GLC 2000. This is the GLOBCOVER project (http://www.gofc-gold.uni-jena.de/sites/globcover.html), an initiative of the European Space Agency. However, it will be based on data from a different sensor (ENVISAT-MERIS) and at a different resolution from GLC 2000, so it remains to be seen how comparable the two products will be. The difficulty of classifying remote-sensing data should not be underestimated. GLC 2000 involved 30 teams producing classifications for 19 regions of the world, which were later translated to a global legend. Still, for a cost of just Euro2.5 million a standard global data set was obtained [28].

In the absence of comparable global land-cover maps, other approaches have been attempted to measure global forest cover change [29,30] and, more recently, global land-cover change [31]. This last study used a combination of global and regional remote-sensing data sets, regional censuses, together with expert opinion, to derive a global map of rapid land-cover change for 1981–2000.

An example of a regional approach to monitor ecosystem change is the European Corine Land Cover (CLC) project (http://terrestrial.eionet.eu.int/CLC2000). The CLC provides data for two different years (1990 and 2000), using 44 land-cover classes. One of the advantages of developing regional maps is the possibility of using regionally tailored land-cover classes. Unfortunately, the land-cover classes of CLC are not the most appropriate to monitor biodiversity [9]. For instance, currently the CLC has only three classes for forest (broad-leaved, coniferous and mixed); therefore, an observed increase in broad-leaved forest area could be due to an increase in plantation area of an exotic species, such as *Eucalyptus globulus*, or an increase in native broad-leaved forest, two phenomena with different implications for biodiversity. Similar problems occur with the even more general classes of global land-cover maps. The classification system adopted by the GLC 2000, the Land Cover Classification System (LCCS, [32]) potentially separates plantation forest from natural forest, but this separation was not fully implemented in the GLC 2000.

Regional assessments combining satellite remote sensing with on-the-ground monitoring and aerial photography can be particularly important in studying habitats that are best monitored at small scales, such as wetlands [33] and coral reefs [34].

Towards the global monitoring of ecosystem change

We are close to having the data for a global monitoring of ecosystem change. We need the efforts of GLOBCOVER to receive the financial and institutional support that will

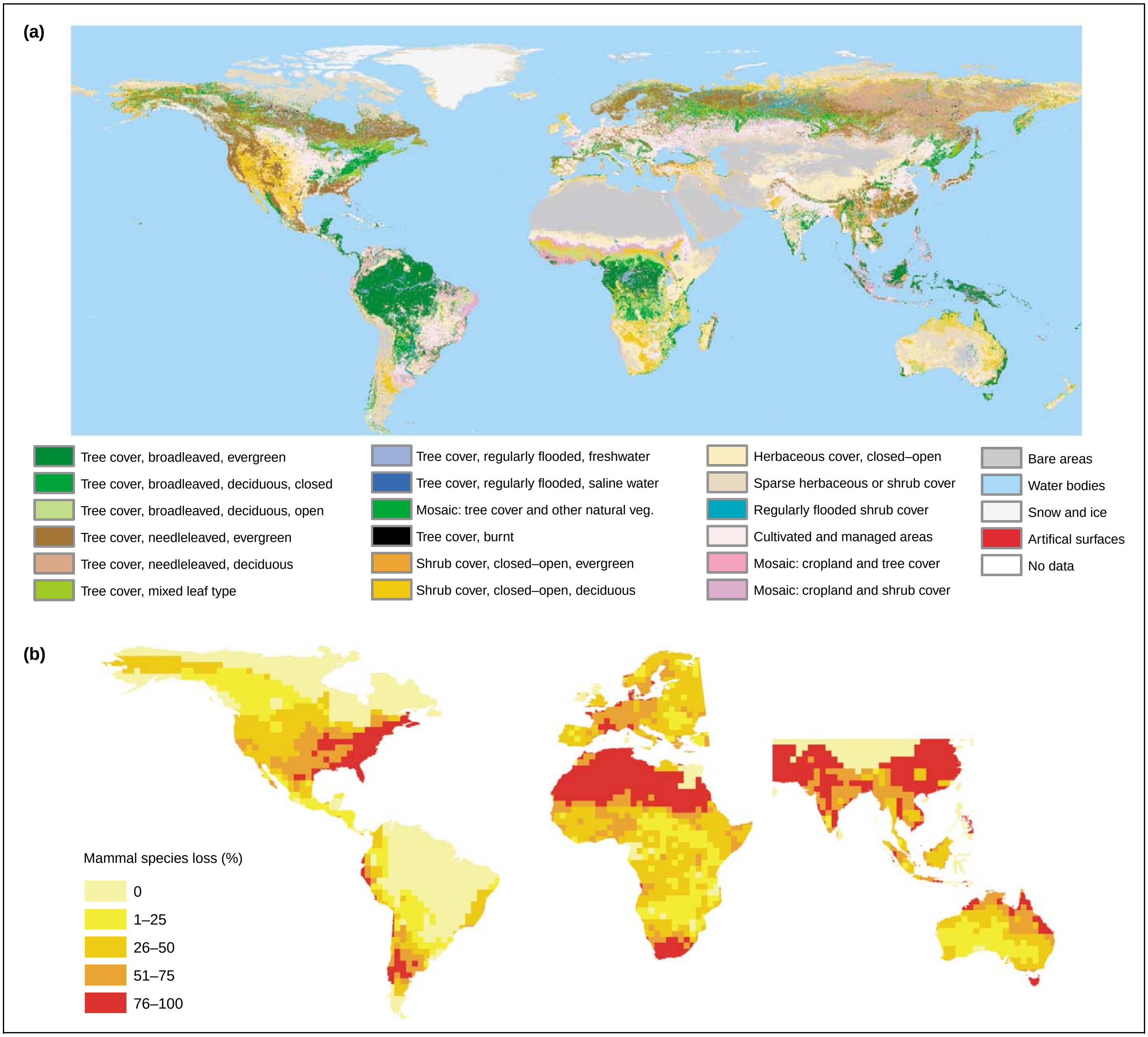

Figure 2. The global land-cover map for the year 2000 **(a)** and a map of mammal species range contractions **(b)**. The mammal map represents the percentage of species that have disappeared from each 2° quadrat over the past century, based on a set of species with shrinking ranges in North America (18 spp.), South America (17 spp.), Europe (15 spp.), Southeast Asia (13 spp.), Africa (52 spp.) and Australia (58 spp.). Both maps provide information about biodiversity change. (a) shows which areas have been converted to human-dominated habitats, whereas (b) shows where local species extinctions have occurred. Some of the areas in Europe, Southeast Asia and the Americas that have been converted to human-dominated habitats have also suffered mammal species loss. In Africa, hunting and competition with domestic animals, and in Australia, the introduction of exotics, appear to have had a bigger role in recent mammal range contractions. The monitoring programme that we propose would produce similar species maps for indicator taxa, but with a higher temporal resolution and estimates of population abundance (instead of occurrence). Furthermore, these maps could be compared with the dynamics of land-cover change (by comparing land-cover maps for different years). Data in (a) taken from [49]; (b) reproduced with permission from [50].

enable the timely production of the global land-cover map for 2005, and the planned global land-cover map for 2010. The recent agreement at the Third Earth Observations Summit to establish a Global Earth Observation System of Systems (GEOSS, http://www.epa.gov/geoss) could facilitate and contribute to this, thereby ensuring that GEOSS fully embraces not only the physical and chemical aspects of earth observations, but also the biological and ecological dimensions. We also need the conservation biology community to participate in this effort, and to begin working on which indicators of ecosystem change should be developed based on GLOBCOVER. There is also a window of opportunity for the scientific community to improve the comparability of existent land-cover data sets, to develop classification systems differentiating natural forest from industrial tree plantations, and to develop global remote-sensing data sets for dryland degradation [31].

A complementary approach to deriving global land-cover maps would be to track specific ecosystems or habitat types that might not be monitored well using the resolution of a Global Land Cover Map (e.g. 300 m in GLOBCOVER, 1 km in GLC 2000). For instance, wetlands and coral reefs should be monitored by national or

Box 3. Integrating monitoring information into composite indexes

Composite indices that integrate information about species change (e.g. change in the abundance or distribution of populations) and ecosystem changes (e.g. changes in extent of particular biomes) could be important in communicating information about overall trends in biodiversity, and further efforts need to be applied to their development. Such composite indices should be kept simple so that the significance of changes in the index can be understood intuitively.

There are now a few proposals for how such a composite index should be produced. The Natural Capital Index, developed by the National Institute of Public Health and the Environment in The Netherlands (http://www.rivm.nl/en/), is a weighted sum of the product of the extent of each ecosystem (relative to a baseline) with the condition of the ecosystem, where the condition is measured as the population size of a group of indicator species relative to a baseline [47]. The Biodiversity Intactness Index is similar conceptually, but with the different ecosystems being weighted by their species richness and the population sizes being estimated for each land-use class in each ecosystem [48].

regional projects, but aiming at regional to global integration through meta-analysis [34]. To facilitate integration, the monitoring of these ecosystems should follow a common scheme.

Implementing the network

A global network for monitoring biodiversity change such as the one proposed here would not be cheap. We estimate that the annual costs of running the global biodiversity network could be of the order of US$10 million, including funds for the coordination of regional and global programmes, and funds to support the costs of global species and ecosystem monitoring. This money would also support some of the regional monitoring programmes, particularly those in developing countries and where skilled volunteers are lacking. This amount is modest when compared with the estimated annual needs for the Global Climate Observing System of some US$600 million (http://www.wmo.ch/web/gcos/gcoshome.html), or the estimated US$5 billion over a period of 10–20 years needed to describe every species on the planet [35].

It is important that the funds are secured from budgets for science and monitoring and not diverted from the budgets for the conservation and sustainable use of biodiversity, or from existing capacity building activities in developing countries. GEOSS, as well as existing organizations such as the United Nations Environmental Programme (UNEP), could have a key role in raising the necessary funds. The network could be developed under the auspices of the CBD, by organizations such as UNEP, the International Council for Science (http://www.icsu.org), IUCN and Diversitas (http://www.diversitas-international.org) working with other relevant UN agencies, scientific societies (such as the Society for Conservation Biology) and conservation NGOs (such as Birdlife International).

The biggest logistical challenge is likely to be organizing for the first time the global sampling of populations of indicator taxa. This is no easy task, and will involve the participation of the scientific community in the survey design and in the major capacity-building effort required. Another challenge will be the analysis of the data collected by the network and the integration with other data sets (including data sets on ecosystem services and climate change, and socioeconomic data sets). A crucial issue is the use of composite indexes to integrate data from species-monitoring and ecosystem-monitoring programmes (Box 3). These kinds of composite indexes could have the same role in environmental policy that GDP has in economic policy [8], enhancing the communication of trends in biodiversity to decision makers and the general public.

Concluding remarks

The global biodiversity-monitoring network could enhance the provision of data for several of the indicators adopted by the CBD to assess progress towards the 2010 target [36]. It would also complement the 'biodiversity indicator space' [37] covered by existing indicators, by providing higher comprehensiveness of ecological levels (species and ecosystems), high spatial comprehensiveness (global coverage) and high spatial and temporal resolution. But our proposal goes beyond the 2010 target and assumes a long-term effort on understanding biodiversity change. It will be this understanding that will enable us to best respond to the drivers causing biodiversity loss. Whereas a variety of stakeholders, including the private sector, governments and the public, will have a key role in this effort, its success will depend on the commitment of the scientific community as a whole.

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References

1 UNEP (2002) *Report of the Sixth Meeting of the Conference of the Parties to the Convention on Biological Diversity* (UNEP/CBD/COP/6/20). Decision VI/26, UNEP (http://www.biodiv.org/decisions/?m=cop-06)
2 Mace, G.M. *et al.* Biodiversity. In *Ecosystems and Human Well-Being: Current State and Trends* (Scholes, B. and Hassan, R., eds), Island Press and Millennium Ecosystem Assessment (in press)
3 Sala, O.E. *et al.* Biodiversity across scenarios. In *Ecosystems and Human Well-Being: Scenarios* (Carpenter, S. and Pingali, P., eds), Island Press and Millennium Ecosystem Assessment (in press)
4 Rodrigues, A.S.L. *et al*. (2004) Global gap analysis: priority regions for expanding the global protected-area network. *Bioscience* 54, 1092–1100
5 Bruner, A.G. *et al*. (2001) Effectiveness of parks in protecting tropical biodiversity. *Science* 291, 125–128
6 Daily, G.C. *et al*. (2003) Countryside biogeography of Neotropical mammals: conservation opportunities in agricultural landscapes of Costa Rica. *Conserv. Biol.* 17, 1814–1826
7 Duraiappah, A. *et al.* (2005) *Synthesis Report for the Convention on Biological Diversity*, Millennium Ecosystem Assessment (http://www.maweb.org/proxy/document.354.aspx)
8 Balmford, A. *et al*. (2005) The convention on biological diversity's 2010 target. *Science* 307, 212–213
9 Mace, G. *et al.* (2005) *A User's Guide to Biodiversity Indicators*, European Academy of Sciences Advisory Council (http://www.easac.org/EASACBioindicator.pdf)

10 Balmford, A. *et al*. (2005) The 2010 challenge: data availability, information needs and extraterrestrial insights. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 360, 221–228
11 Balmford, A. *et al*. (2003) Measuring the changing state of nature. *Trends Ecol. Evol.* 18, 326–330
12 CBD (1992) *Convention on Biological Diversity. Article 2*, CBD (http://www.biodiv.org/convention/articles.asp)
13 Pereira, H.M. *et al.* Condition and trends of ecosystem services and biodiversity. In *Ecosystems and Human Well-Being: Multi–scale Assessments* (Samper, C. and Capristano, D., eds), Island Press and Millennium Ecosystem Assessment (in press)
14 Mace, G.M. (2005) Biodiversity – an index of intactness. *Nature* 434, 32–33
15 Brooks, T.M. *et al*. (2004) Coverage provided by the global protected-area system: is it enough? *Bioscience* 54, 1081–1091
16 Baillie, J.E.M. *et al.* (2004) 2004 *IUCN Red List of Threatened Species. A Global Species Assessment*, IUCN (http://www.iucn.org/themes/ssc/red_list_2004/GSA_book/Red_List_2004_book.pdf)
17 Nic Lughadha, E. *et al*. (2005) Measuring the fate of plant diversity: towards a foundation for future monitoring and opportunities for urgent action. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 360, 359–372
18 Loh, J. *et al*. (2005) The Living Planet Index: using species population time series to track trends in biodiversity. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 360, 289–295
19 Loh, J. and Wackernagel, M. (2004) *Living Planet Report 2004*, World Wide Fund for Nature (http://www.panda.org/downloads/general/lpr2004.pdf)
20 Butchart, S.H.M. *et al.* (2004) Measuring global trends in the status of biodiversity: Red List Indices for birds. *PLoS Biol.* DOI: 10.1371/journal.pbio.0020383
21 Butchart, S.H.M. *et al*. (2005) Using Red List Indices to measure progress towards the 2010 target and beyond. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 360, 255–268
22 Gregory, R.D. and Vorisek, P. (2003) Report on the Pan- European Common Bird Monitoring Workshop. *Bird Census News* 16, 2–13
23 Thomas, J.A. *et al*. (2004) Comparative losses of British butterflies, birds, and plants and the global extinction crisis. *Science* 303, 1879–1881
24 Shaffer, H.B. *et al*. (1998) The role of natural history collections in documenting species declines. *Trends Ecol. Evol.* 13, 27–30
25 Olson, D.M. *et al*. (2001) Terrestrial ecoregions of the world: a new map of life on Earth. *Bioscience* 51, 933–938
26 Turner, W. *et al*. (2003) Remote sensing for biodiversity science and conservation. *Trends Ecol. Evol.* 18, 306–314
27 Pettorelli, N. *et al.* (2005) Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends Ecol. Evol.* DOI: 10.1016/tree.20050.05.011
28 Bartholomé, E. (2004) The GLC 2000 Land-cover map and beyond: lessons learnt, strengths, weaknesses, possible improvements. In *Proceedings of the VEGETATION 2004 Conference, Antwerp, Belgium, 24–26 March 2004* (Veroustraete, F. *et al.*, eds), Office for official publications of the European Communities (http://www-gvm.jrc.it/tem/PDF_publis/PDF_publis/2004/Bartholome_VGT2004_full%20text.pdf)
29 Achard, F. *et al*. (2002) Determination of deforestation rates of the world's humid tropical forests. *Science* 297, 999–1002
30 FAO (2001) *Global Forest Resources Assessment 2000: Main Report*, FAO (http://www.fao.org/ docrep/004/y1997e/y1997e00.htm)
31 Lepers, E. *et al*. (2005) A synthesis of information on rapid land-cover change for the period 1981–2000. *Bioscience* 55, 115–124
32 Di Gregorio, A. and Jansen, L.J.M. (2000) *Land Cover Classification System (LCCS): Classification Concepts and User Manual*, FAO (http://www.fao.org/docrep/003/x0596e/x0596e00.htm)
33 Shuman, C.S. and Ambrose, R.F. (2003) A comparison of remote sensing and ground-based methods for monitoring wetland restoration success. *Rest. Ecol.* 11, 325–333
34 Gardner, T.A. *et al*. (2003) Long-term region-wide declines in Caribbean corals. *Science* 301, 958–960
35 Wilson, E.O. (2000) A Global Biodiversity Map. *Science* 289, 2279
36 UNEP (2004) *Report of the Seventh Meeting of the Conference of the Parties to the Convention on Biological Diversity (UNEP/CBD/COP/6/20)*. Decision VII/30, UNEP (http://www.biodiv.org/decisions/?m=COP-07)
37 Brooks, T.M. and Kennedy, E.T. (2004) Biodiversity barometers. *Nature* 431, 1046–1047
38 Tilman, D. *et al*. (2001) Diversity and productivity in a long-term grassland experiment. *Science* 294, 843–845
39 Hector, A. *et al.* (1999) Plant diversity and productivity experiments in European grasslands. *Science* 286, 1123–7
40 Zavaleta, E.S. and Hulvey, K.B. (2004) Realistic species losses disproportionately reduce grassland resistance to biological invaders. *Science* 306, 1175–1177
41 Chapin, F.S. *et al*. (1998) Ecosystem consequences of changing biodiversity: experimental evidence and a research agenda for the future. *Bioscience* 48, 45–52
42 Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-Being: Synthesis*, Island Press
43 Myers, N. *et al*. (2000) Biodiversity hotspots for conservation priorities. *Nature* 403, 853–858
44 Gibbons, D.W. *et al*. (1996) Birds. In *Ecological Census Techniques* (Sutherland, W.J., ed.), pp. 227–259, Cambridge University Press
45 Elzinga, C. *et al*. (2001) *Monitoring Plant and Animal Populations*, Blackwell Science
46 Gregory, R.D. *et al*. (2005) Developing indicators for European birds. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 360, 269–288
47 ten Brink, B. (2002) *Biodiversity: How Much is Left? The Natural Capital Index Framework (NCI)*, Netherlands National Institute of Public Health and the Environment (http://www.rivm.nl/bibliotheek/digitaaldepot/NCIflyer.pdf)
48 Scholes, R.J. and Biggs, R. (2005) A biodiversity intactness index. *Nature* 434, 45–49
49 ECJRC (2003) *The Global Land Cover Map for the Year 2000, GLC2000 Database*, European Commission Joint Research Centre (http://www-gvm.jrc.it/glc2000)
50 Ceballos, G. and Ehrlich, P.R. (2002) Mammal population losses and the extinction crisis. *Science* 296, 904–907