LETTER

# Toward monitoring global biodiversity

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## Abstract

The world's governments have identified reducing the rate of biodiversity loss as a global priority. However, we lack robust measures of progress toward this target. Developing indicators that are generally representative of trends in global biodiversity has presented the scientific community with a significant challenge. Here we discuss the development and implementation of the IUCN Red List Index with a new sampled approach, permitting the assessment of the conservation status and trends of large, speciose taxonomic groups. This approach is based on the IUCN Red List and measures trends in extinction risk through time. The challenges in developing this new approach are addressed, including determining the species groups to be included in the index, identifying the minimum adequate samples size, and aggregating and weighting the index. Implementing this approach will greatly increase understanding of the status of the world's biodiversity by 2010, enabling the first assessment of a number of key groups.

## Introduction

Biodiversity loss is of increasing concern to society, scientists, and policymakers. People care about loss of species for intrinsic reasons, but there is accumulating evidence that loss of biodiversity will also have major impacts for ecosystem functions and services, and hence for human well-being (Millennium Ecosystem Assessment 2005; Diaz *et al.* 2006). At the same time, other environmental changes, such as climate change, invasive species, or disease will interact with biodiversity loss in ways that could increase the negative impact (Millennium Ecosystem Assessment 2005). Recognizing the significance of biodiversity loss, the countries that are parties to the Convention on Biological Diversity (CBD) set the ambitious target "to achieve 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 by 2010" (decision VI/26) (Balmford *et al.* 2005a). The scientific community now faces the challenge of measuring progress toward that target, and beyond (Balmford *et al.* 2005b; Buckland *et al.* 2005; Gregory *et al.* 2005; Nic Lughadha *et al.* 2005; Pereira & Cooper 2006; Mace & Baillie 2007). For a range of purposes, therefore, we need measures of the rate and extent of biodiversity loss over time, and ideally these measures should be applicable at global and sub-global scales. In this article we present a new technique to estimate biodiversity loss, based on the rate at which a stratified sample of the world's species move through categories reflecting their risk of global extinction.

There are some major obstacles to developing global biodiversity indices across species, as our knowledge is far from complete (The Royal Society 2003). Less than 10% of the probable total of the world's species have been described (not including microorganisms where the proportion is probably much less), and within the described taxa existing information is strongly biased toward the terrestrial megafauna and megaflora, and to temperate rather than tropical areas (Mace *et al.* 2005). Although it is possible to survey extinction risk status in groups such as the birds (10,000 species) that are more or less fully described, and whose conservation status has been comprehensively assessed several times (most recently: BirdLife International 2004), the situation is different among other groups. For example, of the estimated 320,000 plant species (Groombridge & Jenkins 2002) roughly 85% have been described but of those only 4% have had their conservation status assessed (Baillie *et al.* 2004).

Here we describe a simple method to sample known groups of organisms across major taxa to provide measures of changes in extinction risk status that are broadly representative of global biodiversity. Our method is based on the Red List Index, which draws on data from the IUCN Red List. This is a well-established system that uses quantitative criteria to classify species into categories of extinction risk according to measures of distribution areas and population or habitat fragmentation, population size, and rates of decline (see IUCN 2001 for details). Using the IUCN Red List criteria, species are classified into one of the categories representing increasing levels of extinction risk: Least Concern, Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild, and Extinct (Mace & Lande 1991; IUCN 2001).

The Red List Index (RLI) measures trends in extinction risk based on repeated Red List assessments for sets of species, and enables trends in overall extinction risk to be tracked for entire taxonomic groups, or for sets of species in particular geographic areas, ecosystems, habitats, etc. (Butchart *et al.* 2004, 2005, 2007). Importantly, changes in the index are driven only by species changing Red List category between assessments as a consequence of genuine improvement or deterioration in conservation status (i.e., excluding category changes resulting from improved knowledge or taxonomic revisions (Butchart *et al.* 2004)). The RLI can only be applied to a taxonomic group if all, or close to all, species have been assessed. Groups that have been incompletely assessed are likely to contain a biased subset of species, for example, the best-known species or those perceived to be at highest risk.

Other than for birds, a preliminary RLI is available for amphibians for the period from 1980 to 2004 (Butchart *et al.* 2005). This and the bird RLI show continuous declines since the 1980s (Baillie *et al.* 2004; BirdLife International 2004; Butchart *et al.* 2004, 2005). Although informative, these taxa represent only a small fraction of the world's species. The extent to which the status and trends of these groups are broadly representative of the status and trends of biodiversity is unknown (Lawton *et al.* 1998; Thomas *et al.* 2004; Barlow *et al.* 2007). Here we present a method to combine a sampling approach with the well-established Red List Index method (Butchart *et al.* 2004, 2005, 2007) to develop a sampled Red List Index (SRLI). With the SRLI it is not necessary to census entire taxonomic groups to monitor trends in extinction risk and therefore a much larger range of species groups can be included, resulting in indicators more broadly representative of all biodiversity.

## Developing and testing methods

This SRLI presents a number of challenges: selecting the taxonomic groups to be included in the index, determining the minimum sample size (number of species) necessary to provide robust trends, determining a sampling strategy to ensure sufficient geographic and taxonomic representation, establishing methods for aggregating data and weighting the index, and estimating confidence intervals. Each of these is discussed below.

### Selecting taxonomic groups

There are approximately 1.75 million known species (Heywood & Watson 1995; Groombridge & Jenkins 2002), and 5–30 million or more that likely exist on the planet (Erwin 1982; May 1992; Dirzo & Raven 2003; Mace *et al.* 2005). Ideally an indicator should be based on a set of species that are representative of all taxa. However, it is only possible to monitor the species we know, and of those we can only assess the conservation status of the ones for which we have adequate information to apply the IUCN Red List Categories and Criteria (IUCN 1994; IUCN 2001). Thus, a global indicator tracking trends in the extinction risk of biodiversity is necessarily limited to a subset of better-known species groups. Our goal is to sample the broadest possible set of such taxa.

We excluded microorganisms from further scrutiny as they are generally poorly known and the IUCN Red List criteria were not designed to be applied to them. This leaves vertebrates, invertebrates, plants, fungi, and algae. We began by surveying what was known about major higher taxa in terms of the likely comprehensiveness of their scientific description, the existence of species lists, and of experts interested to undertake conservation assessments. We identified the following criteria to select the species groups for inclusion in the SRLI:

1. There must be a complete or near complete global species list (preferably including all published names and distributional information).
2. The species list must have a person or organization updating the list, and processes / programs in place to continue this into the future.
3. The list must contain over 1,500 species (to be useful for the sampling approach). The list may be slightly smaller if all species on it will be comprehensively assessed.
4. There must be experts capable of conducting Red List assessments.
5. There must be sufficient data available to assess the species for the IUCN Red List and for at least 60% of them not to qualify as data deficient (see below).

These criteria are intended both to minimize taxonomic and geographic biases and increase the likelihood that the selected groups will continue to be assessed regularly. The cutoff for data-deficient species has been set to ensure that most species in any taxonomic group are reasonably well known and to reduce the biases that poorly known species groups could introduce into the index from limited information on just a few well-known species.

A broad group of experts were surveyed to identify the taxa for which the criteria are met, and the results are shown aggregated at three levels in Table 1. The top level is presumed to reflect all species diversity best, and Level 3 represents the lowest taxonomic level at which the criteria for inclusion were met. The Level 3 groups can be aggregated into broader categories in Level 2 (Vertebrates, Plants, Invertebrates, Fungi, and Algae). For vertebrates and plants, where good species lists exist, species in the index will be sampled from all known species in these groups. For invertebrates, fungi, and algae, all of which are patchily known, species are sampled from a small number of better-known taxonomic groups. For example, insects could be represented by species sampled from butterflies, dragonflies, and dung beetles.

## Sampling strategy

### *Minimum sample size*

For the SRLI, the sample size must be large enough to produce accurate and robust trends, both within and between groups, but small enough to be practical, as Red List assessments require time and resources. In addition, the sample should be large enough to permit exploration of patterns in subsets of the data, for example by biogeographic realm and ecosystem, and perhaps also to provide insight into the threat processes driving change, and the conservation measures required to counteract them.

We investigated the minimum required sample size by calculating SRLIs for subsets of the bird and amphibian data sets, and comparing how similar these were to the RLI. We took 50,000 subsamples from the currently available complete data sets for birds (9,917 species, 1988–2004) and amphibians (5,743 species, 1980–2004; see Butchart *et al*. 2005 for full details) without replacement, starting at a sample size of 100 and increasing in increments of 100 up to 1,500. This was done for birds for each of the three periods between comprehensive assessments (1988–1994, 1994–2000, 2000–2004) (Figure 1A–C) and for amphibians for 1980–2004. The SRLI from each subsample was compared to the RLI calculated for the complete group.

Given the policy context, we were particularly interested in testing the probability of a SRLI falsely showing an apparent reduction in the rate of biodiversity loss (i.e., a positive slope to the index: see Butchart *et al*. 2007) when the known trend is negative. The bird indices in Figure 1A–C show that the probability of wrongly identifying a reduction in the rate of biodiversity loss never exceeds 5% and the probability of type I error very rarely even comes close to 5% for a sample size of 900 species or above. For amphibians, even a sample size as small as

**Table 1** Taxonomic groups included in the SRLI 1. The following taxa are those that met all the criteria for inclusion (see text). For the vertebrates and plants, the level three indices represent a sample of all species in the group or clade. For the invertebrates, fungi, and algae the samples will be based on a small number of clades generally numbering over 1,500 species where a complete or near complete species list has been produced

| Level 1 | All species | | | | |
|---|---|---|---|---|---|
| Level 2 | Vertebrates | Plants | Invertebrates | Fungi | Algae |
| Level 3 | Mammals | Gymnosperms | Insects | Mushrooms | Brown algae |
| | Birds | Bryophytes | Crustaceans | Moulds | Red algae |
| | Amphibians | Pteridophytes | Molluscs | Lichens | Green algae |
| | Fishes | Monocotyledon | Arachnids | | |
| | Reptiles | Dicotyledons | Corals | | |

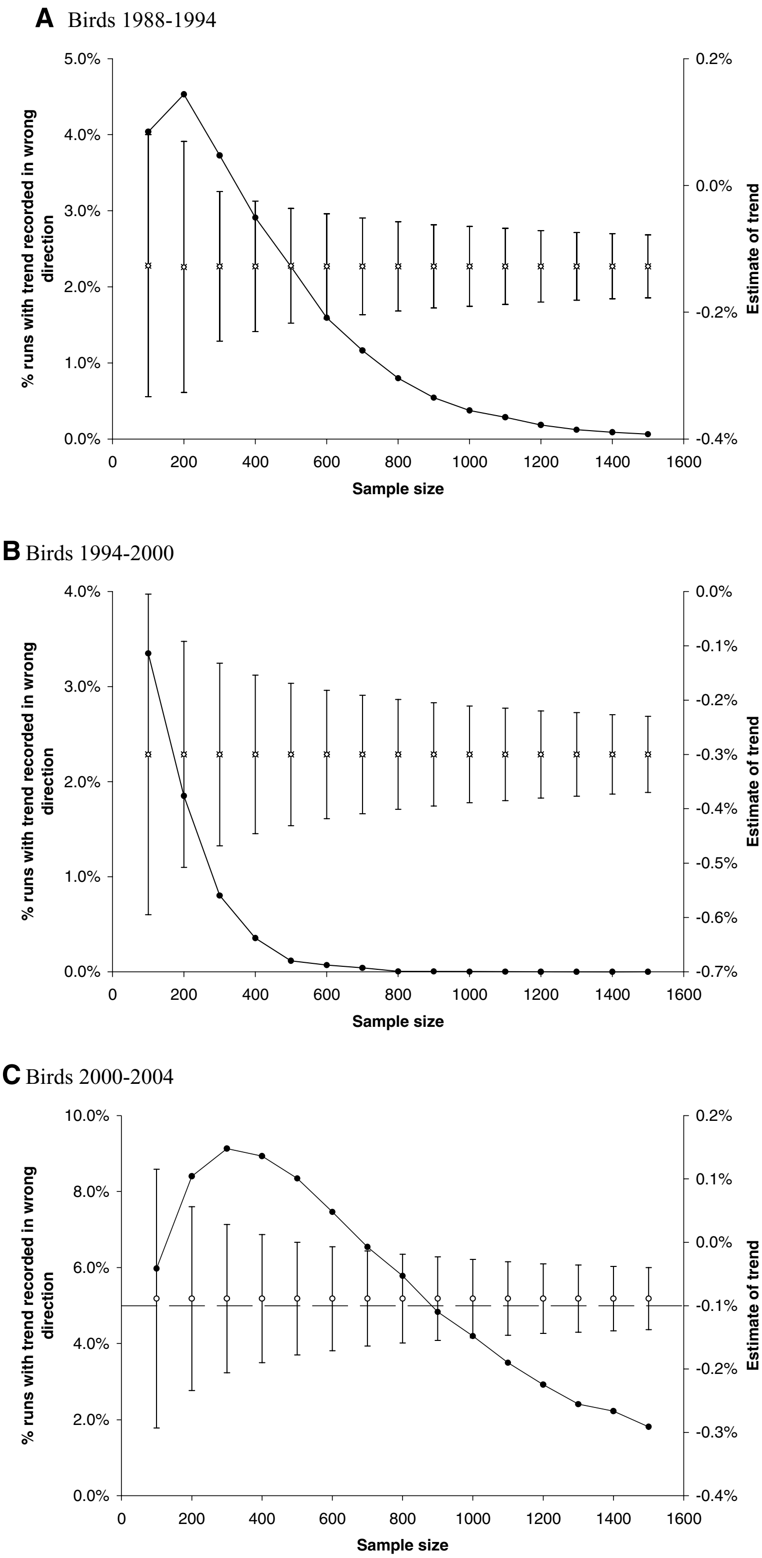


**Figure 1** (A,B,C). Effect of sample size on the accuracy of the direction of RLI trend. Figures A–C demonstrate the effect of sample size on the percentage of 50,000 samples for which the SRLI showed a positive trend when the real RLI trend, based on the complete set of species, showed a negative trend. Figures (A) is for birds from 1988-1994, Figure (B) 1994-2000, and Figure (C) 2000-2004. The dashed line in Figure 1c represents the 5% level. The vertical bars in each figure represent 95% range of the estimated trend values (right hand axis).

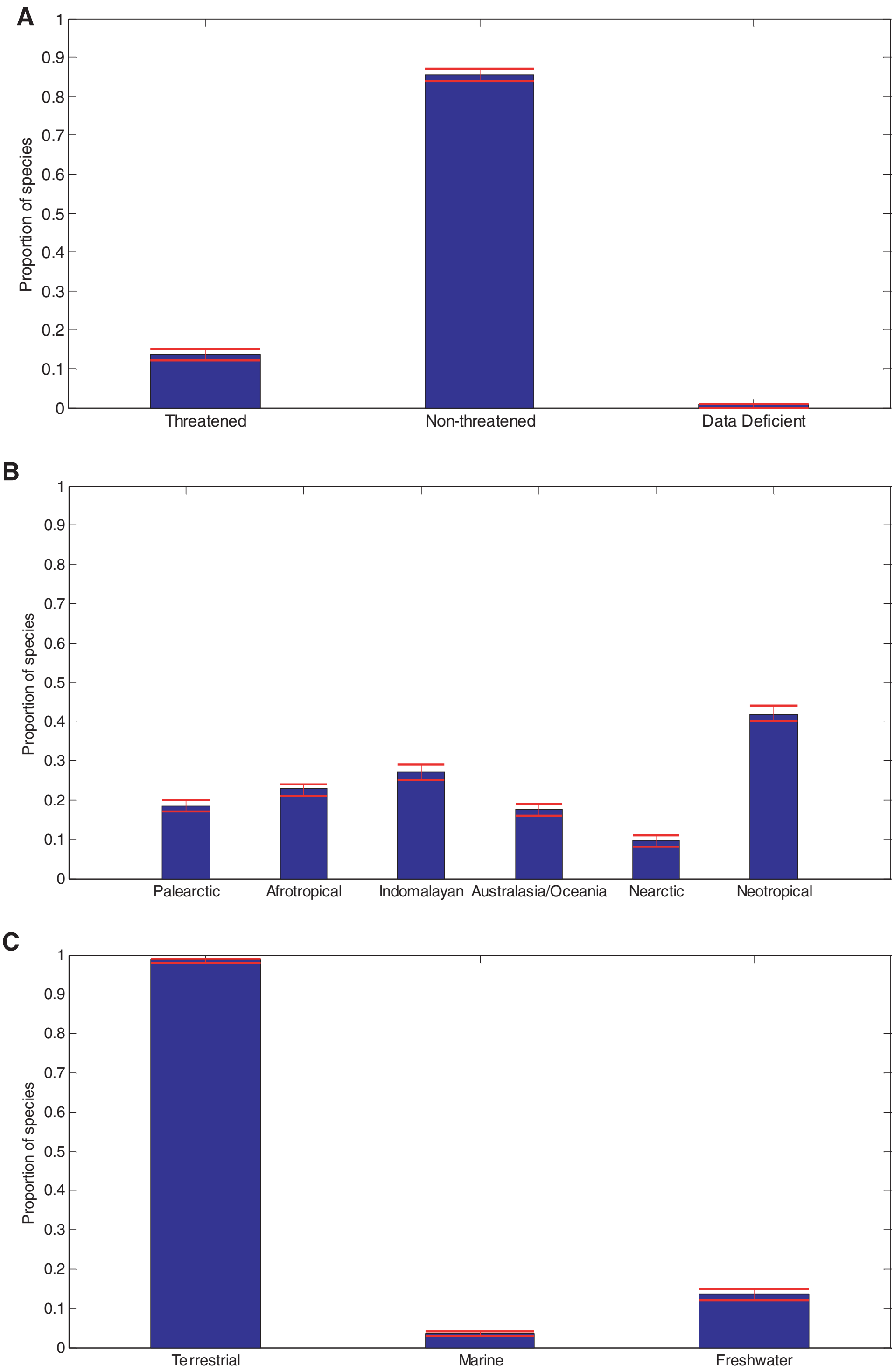


**Figure 2** Representatives of a sample of 900 Birds. Comparison of 50,000 samples of 900 bird species with the complete set of 9,917 bird species in terms of the proportion of species in different (A) threat classes, (B) biogeographic realms and (C) ecosystems (results for taxonomic Orders not presented due to the long list - see Baillie et al., 2007 for details). The bars show the known values for the complete set of species, while the error bars show the 95% distributions for the sample of 900 species.

100 species never produced an RLI with a positive trend (results not presented (see Baillie *et al.* 2007)).

Based on these results we set 900 species as the minimum acceptable sample size to derive the sampled index. In real data sets, especially of poorly known taxa, we expect that a substantial proportion of species selected at random will be so poorly known that only an IUCN Red List assessment of Data Deficient will be possible. This category carries no information about the species' threat status, but simply indicates that more information is needed to assess the species. We therefore recommend that a minimum sample of 1,500 species be used to allow for as much as 40% of the species in the sample to be data deficient (see Baillie *et al.* 2007).

The overall SRLI will have a sample size that is the sum of the number of species in all the indices on which it is based (ultimately more than 21 indices of *c.*1500 species each). Other aggregated indices for higher taxonomic groups (e.g., vertebrates, invertebrates, plants, fungi, algae), biogeographic realms (e.g., Nearctic, Indomalayan), and ecosystems (e.g., freshwater, terrestrial, marine) will also have larger sample sizes. .

### *Sampling for taxonomic and geographic representation*

The SRLI should permit comparisons of extinction rates among higher taxonomic groups, biogeographic realms, and ecosystem types, but for these to be reliable there needs to be a sufficient sample size within key subsets of the data. A number of approaches could be employed to ensure that the 1,500 species selected are a representative sample of a specific group, including stratifying the sample according to key measures. However, options are limited because this would require prior knowledge of attributes of species, including their threat category and geographic distribution that in most cases are not known until the Red List assessments are carried out. Stratification by taxonomic group should be possible since we have this information for the selected groups in Table 1. One possibility would be to require samples to include representatives from all families or all genera within each taxonomic group, but this could create a bias toward smaller taxonomic groups, which in some taxa are known to be at greater risk of extinction (Purvis *et al.* 2000).

We tested whether a randomly selected sample of 1,500 species would on average be representative of the complete taxonomic group when disaggregated in various ways. Our tests were for all mammals (4,853 species), birds (9,917 species), and amphibians (5,743 species; Baillie *et al.* 2004). We randomly selected, without replacement, 1,500 species from each group, 50,000 times. On average, the proportion of species in each threat class (threatened, nonthreatened, data deficient), Order, ecosystem (terrestrial, freshwater, marine) and biogeographic realm, was not significantly different from the overall proportion of species in each class for the three groups with the 95% distributions less than 2.5% from the actual values (Figure 2 shows the results for birds; results not presented for Order; and mammals and amphibians, see Baillie *et al*. 2007). Note that in most taxonomic groups there will be strata with few representatives (e.g., one member of an Order), and these may not be represented in the sample, but this does not mean that the sample is not generally representative of the entire taxonomic group.

## Aggregating and weighting the index

Indices for higher taxonomic groups (Table 1, Level 2: vertebrate, invertebrate, plant, fungi, and algae) will be produced from data from the relevant species groups (Table 1, Level 3). For example, the mammals, birds, reptiles, amphibians, and fish indices will form the vertebrate index. The overall species index will be calculated by aggregating the higher taxonomic group indices (vertebrate, invertebrate, plant, fungi, and algae). There are a number of ways in which the various indices could be weighted to calculate the higher taxonomic group indices and the overall biodiversity index, most obviously by weighting each group by its sample size (number of species) or weighting each group equally.

Because species are unevenly distributed among taxa, and in particular because of the overwhelming number of arthropods, especially insects, compared to other taxa, weighting the overall index by species richness would lead to a measure dominated by the arthropods and would effectively equate to an RLI for the insects. This would not adequately reflect the status of all species, and it would also put most weight on the species about which we know the least. Weighting each group equally would have the effect that less speciose groups contribute disproportionately to the index, and thus the index is effectively a simple average of the groups upon which it is based. For example, within the vertebrates, *c.* 5,500 mammals would contribute as much as *c.* 28,500 fishes. For the global biodiversity index *c.* 58,000 vertebrates would contribute as much as *c.* 1.2 million invertebrates (Hammond 1992, 1995; Groombridge & Jenkins 2002). Although the first approach of weighting by the number of species puts more emphasis on within-group variation, weighting each group equally emphasizes intergroup variation. This is effectively weighting by major radiation, therefore highlighting trends in a broad range of evolutionarily distinct groups. Equal weighting also puts more emphasis on the less speciose, but often better-known groups, which have been assessed with a higher degree of certainty.

Although indices can be calculated using both approaches, we believe that with current data limitations an approach favoring the better-assessed groups and weighting for more equal representation of major groups is likely to be preferred by, and more understandable to, policy- and decisionmakers.

### Aggregating nontaxonomic indices

In order to identify the conservation status and trends for each biogeographic realm or ecosystem, species from different taxonomic groups need to be aggregated. In contrast to the calculation of the overall biodiversity index, different taxonomic groups should not now be given equal weight but instead should be weighted by the number of species of that group present in that realm or ecosystem. This would help to ensure that a subgroup such as reptiles, with only a few marine representatives, does not disproportionately influence the marine ecosystem index.

Therefore, to aggregate and weight taxonomic groups for RLIs of nontaxonomic indices (divisions such as ecosystems and biogeographic realms), the index weight $WT$ for taxonomic group $g$ is calculated as

$$WT_g = \frac{N_{g,d}}{N_g}$$

where $N_g$ is the total number of assessed (excluding data-deficient) species in taxonomic group $g$, and $N_{g,d}$ is the total number of assessed (excluding data-deficient) species in taxonomic group $g$ in the index for the particular division $d$ (e.g., ecosystem type, biogeographic realm, etc) The Red List Index value for the division $RLI_D$, can then be calculated as

$$RLI_D = \frac{\sum_g (WT_g \cdot I_{g,d})}{\sum_g WT_g}$$

where $I_{g,d}$ is the Red List Index for species in taxonomic group $g$ present in division $d$. This formula weights each taxonomic group by its contribution to the specific ecosystem or biogeographic region, for which an index is being produced.

### Calculating confidence intervals

Uncertainty in the form of confidence limits should be presented alongside trends. For the sampled taxonomic groups, the confidence interval due to sampling variability will be obtained by a bootstrap method. Each bootstrap replicate will be calculated by the following procedure. For each group, a sample size equal to the number of assessed non-data-deficient species in the taxonomic group will be selected at random with replacement and the RLI calculated. The bootstrap procedure will be carried out 50,000 times and the bounds of the central 47,500 index values will be taken to represent the 95% confidence interval for the index. Confidence intervals for the higher taxa and non-taxonomic indices will also be obtained using this approach. Bootstrap sample estimates for the relevant subindices will be calculated and aggregated using the appropriate weighting. We tested this approach on the comprehensively assessed bird data from the year 2000. We took 2,000 samples of 1,500 randomly selected species from the data set and calculated the confidence intervals. We found that 93.98% of the confidence intervals overlapped with the actual RLI.

## Discussion

The intervals between assessments being undertaken on major groups will determine the timing of recalculation of the index. Assessments can realistically take place every 4 to 5 years for the vertebrates and some plant groups, and at least every 10 years for all other groups. Thus, the overall biodiversity index will be calculated every 10 years, and the vertebrate and plant subindices every 5 years. This may seem a long period, but it is appropriate for the rate at which the index is expected to change. For example, among birds there were 250 Red List category changes resulting from genuine changes in conservation status between 1988 and 2004. This represents a change in index value of 0.924 in 1988 to 0.919 in 2004. Every effort will be made to ensure that relevant group assessments are carried out at the same time so that biases are not introduced because one group has been assessed many years after another.

A high proportion of data-deficient species could lead to taxonomic or regional biases as they tend to be clumped by species group or geography (Baillie *et al.* 2004). Ensuring that species groups included in the index have less than 40% data-deficient species will help to minimize this bias. There are a number of short-term solutions such as implementing weighting to compensate for under-represented regions or groups. However, the simplest and most effective solution is to make sure that the conservation status of all species in the sample is assessed as soon as possible. In many cases this will require securing additional resources so that the status, distributions, and conservation status of all species in the index can be determined. With 5 to 10 years between assessments, it should be possible to re-evaluate the species initially assessed as data deficient.

A serious potential bias may result if species included in the SRLI are more likely to attract conservation actions.

This would result in the index under-representing negative trends, or even showing an unrepresentative positive trend. Species groups that are currently the focus of most conservation attention such as mammals and birds are likely to be most susceptible to this bias as additional information on their status may trigger conservation actions. However, the well-known vertebrate groups (mammals, birds, and amphibians) will continue to be comprehensively assessed (i.e., all species regularly re-evaluated), thus minimizing this bias. Many of the species from groups such as mosses, arachnids, and crustaceans are unfortunately unlikely to receive additional conservation attention, even if they are listed on the IUCN Red List. In addition, given the total number of species in the SRLI it would require an improbably substantial and focused conservation effort to introduce a major bias.

This approach should allow the first assessment of the status of an informative sample of a broad range of species by 2010. Progress with selecting and assessing species is already being made. For invertebrates, the assessment process has already been initiated for butterflies, dragonflies, freshwater molluscs, freshwater crabs, and reef-forming corals. Red List assessments for these groups will be completed by the end of 2008. In 2008, additional invertebrate groups suitable for the SRLI have been identified and 1,500 species from each will be randomly selected and assessed. For plants, 1,500 species of monocots and pteridophytes have been selected and are being assessed. Many of the major plant groups will be completed in 2010. For a number of smaller plant groups such as cycads and conifers, trend information will also be available in 2009. A total of 1,500 reptile species and 1,500 fish species have already been randomly selected and their Red List evaluations will be completed in early 2008. By this time, all mammals will have been comprehensively assessed for a second time. In 2008, the Red List categories for the sampled reptiles and fishes in 1980 will be retrospectively assessed (using the same approach as was applied to the amphibians; see Butchart *et al*. 2005), to provide preliminary trend information for all vertebrates. By 2010 this new approach will provide insight into the conservation status of over 20 major taxonomic groups and trend information for all vertebrates and a subset of plants. It will also produce a species-based biodiversity indicator that is considerably more broadly representative of all biodiversity than anything hitherto available. Finally it will provide a data set that will enable a broad range of trend indices to be generated ranging from specific taxonomic groups, to functional groups, to species trends in biomes, or biogeographic regions.

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