# Extracting More Value from Biodiversity Change Observations through Integrated Modeling

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**The International Year of** Biodiversity (in 2010) has come and gone, yet research indicates that biological diversity continues to be lost from our planet at an alarming rate (Butchart et al. 2010). But precisely which biological entities and attributes are declining, from where, how quickly, and as a result of which pressures and drivers? Better answers to these questions will not, on their own, slow the loss of biodiversity. They can, however, play a crucial role in informing the development of high-level policy, legislation, and regulation aimed at addressing underlying drivers of change, and can also inform cost-effective allocation of scarce conservation resources to on-ground actions combatting the impacts of habitat loss, invasive species, and climate change.

In the terrestrial realm, direct measures of biodiversity change based on *in situ* monitoring of the abundance of particular species at selected locations (e.g., the Living Planet Index, *www.twentyten.net/lpi*) have been, and will continue to be, a vital component of global assessment efforts. However, the relatively high cost of *in situ* monitoring places severe constraints on the taxonomic and geographical completeness of data used to produce such measures. Monitoring programs typically focus on selected, better-known elements of biodiversity (e.g., birds and other vertebrates), and monitoring sites are sparsely and patchily distributed, especially outside Europe and North America. Therefore, to obtain a more geographically complete picture of overall biodiversity change, global assessments commonly supplement measures derived from *in situ* monitoring with less direct measures derived from satellite-borne remote sensing and other forms of remote mapping. These include spatially explicit measures of the state of major biomes or ecosystems (e.g., the Global Forest Resources Assessment, *www.fao.org/forestry/fra*), and of the distribution of various pressures and conservation actions or responses (e.g., the World Database on Protected Areas, *www.wdpa.org*).

## Achieving greater integration

These two broad approaches to assessing global biodiversity change have complementary strengths. *In situ* monitoring provides direct information on changes in biodiversity that are difficult if not impossible to detect in any other way. Remote mapping provides a rapid and relatively cheap means of indirectly inferring changes across the vast majority of the planet's land surface that falls beyond the reach of *in situ* monitoring efforts. This high level of complementarity points to one of the biggest challenges now confronting biodiversity change assessment globally: how can we more strongly integrate *in situ* and remote observations to maximize the value of information returned per unit of expenditure on these efforts? Addressing this challenge is a key focus of GEO BON—the new Biodiversity Observation Network emerging under the auspices of the Group on Earth Observations (*www.earthobservations.org*), a partnership of more than 70 member countries and more than 50 participating organizations. Rather than duplicating or competing with the work of other well-established initiatives in biodiversity data acquisition, informatics, and assessment, GEO BON is seeking to add value to these existing efforts. It will do so by gap filling (e.g., by stimulating and coordinating programs to improve the global coverage of *in situ* biodiversity monitoring sites) and by facilitating the integration of *in situ* and remote observations from multiple initiatives across multiple scales (Scholes et al. 2008). GEO BON recognizes that achieving such integration will, in some cases, require extensive use of various forms of modeling.

## A particular challenge

Nowhere is the need for modeling more apparent than in relation to efforts to assess global loss of compositional diversity—that is, the overall variety of biological elements at multiple levels of organization, from genes and species to communities and ecosystems. Unlike the growing list of structural and functional attributes of ecosystems that can now be measured through both *in situ* and remote observation (e.g., tree canopy height, net primary production), most biological elements constituting compositional diversity cannot (yet) be distinguished using satellite-borne remote sensing (especially at the genetic and species level). Integration in this case is therefore as much about model-based inference and extrapolation as it is about calibration and validation of remote mapping. This challenge is further compounded by the unique scaling properties of compositional diversity. The total amount of diversity contained in a given spatial domain is a function not only of the richness of biological elements occurring at individual locations within that domain (alpha diversity) but also of differences in the composition of elements between these locations (beta diversity).

Considerable progress is being made in developing techniques for inferring change in alpha diversity from change in ecosystem intactness (or naturalness), itself derived from remote land-use or land-cover mapping. This approach has been applied prominently in a number of recent global assessments, using techniques such as GLOBIO (*www.globio.info*) to model change in mean species abundance and richness for all terrestrial locations (grid cells) on the planet. However, as argued by Faith and colleagues (2008), higher-level indexes derived by simply aggregating estimates of local, cell-by-cell change in alpha diversity tell only part of the story of the overall change in compositional diversity, because they do not address the beta-diversity component of the problem.

How can beta diversity be more effectively factored into global assessments of biodiversity change? The most straightforward solution is to employ globally mapped units such as biomes, ecoregions, or ecosystem types as broad surrogates for this dimension of diversity. Promising techniques now exist for using these surrogates as beta-diversity "lenses" through which to interpret local changes in intactness inferred from remote sensing, thereby deriving indexes of collective change that factor in both the alpha and beta dimensions of compositional diversity (Faith et al. 2008). The past decade has also seen the parallel development of approaches to distributional modeling of biodiversity that make more direct and explicit use of *in situ* biological observations. These approaches link data on recorded locations and distributional ranges of large numbers of species to remotely generated environmental surfaces (e.g., describing climate, terrain, soil and vegetation attributes). They are used to model, and thereby spatially interpolate, either distributions of individual species or spatial patterns of compositional turnover (dissimilarity) across whole groups of species. Jetz and colleagues (2007) and Ferrier and colleagues (2004) have already demonstrated the feasibility of using individual species distributions and compositional-turnover models as refined lenses through which to interpret remote mapping of ecosystem intactness at a global scale.

## Where to from here?

Alongside others associated with GEO BON, I am excited by the opportunity to use these advances in biodiversity analysis and modeling to help achieve greater integration of multiple *in situ* and remote observations in assessing global loss of compositional diversity. This integration would involve four interacting components:

1. Modeling and interpolation of base (i.e., "natural") spatial patterns in the distribution of biodiversity by linking best-available *in situ* records of large numbers of species to global environmental surfaces.
2. Repeated (time series) modeling of measures of local biodiversity intactness as a function of remotely sensed changes in land use and other key pressures, informed by meta-analysis of *in situ* studies of the impacts of these pressures.
3. Estimation of overall (collective) loss of compositional diversity through model-based integration of the above two components.
4. Use of the results of ongoing *in situ* biodiversity monitoring programs to evaluate, and progressively calibrate, the models underpinning this integration.

Various initiatives already exist that are directly relevant to each of these components. For example, just in relation to the first component, the Global Biodiversity Information Facility (*www.gbif.org*) now provides ready access to an ever-growing compilation of primary species-location data; a working group at the National Center for Environmental Analysis and Synthesis is currently preparing a new generation of global environmental layers for use in biodiversity modeling (*www.nceas.ucsb.edu/projects/12504*); and a well-established community of practice around species distribution modeling, combined with initiatives such as the Map of Life (*www.yale.edu/mapoflife*), are already fuelling rapid advances in global mapping of biological distributions. The challenge that now lies ahead for GEO BON will be to find effective ways of fostering links and partnerships not only between these particular activities but also more broadly between initiatives and communities of practice across all four components of the proposed framework for assessing global loss of compositional diversity.

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