SEARCH FOR INDICATORS FOR BIODIVERSITY ASSESSMENTS

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Summary

Biodiversity is an inherently difficult to reduce to a single number, but it is possible to capture the main trends with a small number of indicators. Since those indicators are urgently required, they cannot wait until our knowledge of biodiversity is nearly complete before they are applied. For the next several decades, a combination of key direct measurements and informed estimates will be needed to guide policy in this field.

1. Introduction

At the core of rational management of any system is the need to know where you are in relation to where you desire to be. For this reason, biodiversity conservation activities at local, national and international scale have a need for indicators of the condition and trend of biodiversity. They are needed to prioritise the action agenda, set performance targets, and monitor progress towards them. But getting a simple but reliable indicator of trends in biodiversity has proven to be very challenging, for three basic reasons:

1. Biodiversity is inherently complex. In one widely-used conceptual scheme, biodiversity is expressed at three levels (genetic, species and ecosystem), each of which has three aspects (composition, structure and function). Finding one indicator to embrace all these aspects is probably not realistic, even if we had detailed knowledge about them, which we don't;.
2. Biodiversity is incompletely known. About 2 million of an estimated 5 to 30 million species are known to science. How do you obtain an indicator about something that is unknown?

3. The known biodiversity is poorly quantified. There are very few parts of the world, and very few groups of species, for which there are consistent, quantitative records abundance that would permit a statistically rigorous trend analysis.

This is a frustrating situation because a great deal is known about biodiversity; perhaps more than on almost any other aspects of the biosphere, since it has been the topic of study for many centuries, in most parts of the world, by many hundreds of amateur and professional natural historians. It is doubly frustrating because there is a deep sense among most knowledgeable individuals that a crisis of biodiversity loss exists in most parts of the world, and yet it is really hard to prove that is the case, before it is too late to do anything about it. The problem is simultaneously one of insufficient information, and too much information. Even if we had perfect knowledge of the existence of tens of millions, and we had population trends in each species, we would still need to find some defensible way of distilling this knowledge into a handful of indicators that can be grasped for practical management of the problem.

2. Measuring biodiversity

Biological diversity (biodiversity for short) is the variety of life on Earth. One of the difficulties is that the word ‘biodiversity’ has been very loosely used, and as a result its scope has broadened to include all aspects of Life on Earth, rather than primarily focussing on *variety.* There are two basic theoretical components to measuring variety among discrete objects, regardless of the scale, level of organisation, or what feature of diversity is being assessed. The first is the *number* of different categories into which those objects can be placed. The classical example of this is the most widely-used measure of biodiversity, the *species richness*. It is simply the number of species that have been recorded for a given geographical area. The second component is the relative *abundance* of the objects placed in each class. This is best illustrated by playing a thought experiment. Imagine a situation where you have fifty elephants, and fifty rhinoceroses. Most people would agree that this is more diverse than a situation with the same number of species (two), and the same number of individuals (one hundred), but in this case there are ninety-nine elephants and one rhino. This concept is known as *evenness*.

This analysis suggests that a minimally-sufficient grasp of biodiversity, at any scale, level or attribute, needs two indicators. The two indicators need not be richness and evenness as defined above, but because biodiversity is typically very inhomogeneous (in other words ‘patchy’, or unevenly distributed), they do need to cover both the average situation and the extremes. This is analogous to saying, for a continuously-distributed variable, that you really need to know at least the mean and the variance in order to understand the population reasonably well. For example, the Gross Domestic Product per capita is a widely-used measure of average wealth, but you really need to combine it with a measure of inequity, like the Gini coefficient, to understand the distribution of wealth and poverty. Obviously if you currently know nothing, then even a single indicator is an improvement; and you can go further and add other measures beyond two, but two is a practical minimum.

There are biodiversity indices which combine the aspects of richness and relative abundance into a single number. These have their origin in information theory. The oldest is the Shannon-Wiener Index (H')

$$H' = -\sum p_i \ln p_i$$

Where p_i is the proportion of the total abundance of entities that is in class i. However, ecologists prefer the Simpson's Index (D)

$$D = \sum [\ \{n_i(n_i-1)\}/\{N(N-1)\}]$$

Where n_i is the abundance in class I, and N is the total abundance. Note that D is actually a measure of *dominance*, so it goes down as diversity goes up. Biodiversity is therefore often indexed as 1-D or 1/D. However, calculating the variance of D in these forms is difficult, so expressing D as –ln(D) is the recommended form. A nice feature of the Simpson's index is that it can readily be decomposed into its richness (S) and evenness (E) components

$$(1/D) = E * S$$

where S is the number of different classes in the sample.

Many other indices of this general type have been proposed, but none have been systematically adopted, and none offer any major advantages over the Simpson's Index. A drawback of all of them is that you essentially have to have complete knowledge of the populations before you can apply them: you need to know both how many types of entity there are (eg species), and what the abundance of each is (eg population counts, or biomass measurements, or cover estimates). This is seldom the case outside of a research context.

A key concern in the academic research field relating to biodiversity is the issue of scale: to what extent is the answer that you get a function of the scale at which you ask the question? Most biodiversity indicators are scale-dependent: large areas contain more biodiversity than small areas, but the relationship is not one of simple proportionality. The relationship typically takes the form, within a 'relatively homogeneous area' of an asymptotically-saturating 'species-area curve', usually expressed as

$$\log S = \log k + z \log A$$

where S is the species richness, A is the area, and k and z are constants. These curves, which vary from ecosystem to ecosystem, can be used to bring all measures to a common reference size for comparison, or the value of z can itself be used as a measure of biodiversity.

A related issue is that of sampling intensity: If you look more thoroughly, you will usually find more biodiversity. If you plot some measure of biodiversity against sampling effort, you also find an asymptotically saturating curve (called a species accumulation curve). This curve can be used to estimate, for instance, how many species there might actually be in an area which has only been partly sampled. There are a number of ingenious ways of doing this, but if the sampling effort is low, the errors associated with the final estimate will obviously be quite large.

Another widespread way of addressing the patterns of biodiversity over space is the concept of α, β and γ diversity. α diversity is the 'diversity at a point', usually taken as a small plot or quadrat of defined size. (For trees, often about 20 m x 20 m, but there is no absolute standard. Note the caution above regarding the effect of plot size on the number of species present). β is then a measure of how different the species in an adjacent or nearby plot would be; in other words it is the rate of turnover of species along a transect within a seemingly homogeneous patch or across a gradual gradient. γ is a measure of the 'patchiness' of the environment: is it all one big patch, or are there relatively discrete, different patches within it.

In other words, γ diversity is a landscape-level or ecosystem level diversity measure, whereas α diversity is a species-level measure, and β forms a sort of bridge between them. All three combine to deliver a given species-area curve, if the range of scales covered is large enough.

Dropping down in level of organisation, to the genetic level, there are important measures of genetic similarity. Within a population of one species, the degree to which various molecular markers are shared between individuals is an increasingly-feasible approach as the DNA techniques become cheaper and more widespread. In the interim, between-species similarity indices based on cladistics (the shape of the 'evolutionary tree: close-together branches are assumed to share more genes than branches that separated at a distant time) or on taxonomy can be used.Biological diversity exists in human-modified ecosystems as well as in 'natural' ecosystems.

Even highly-transformed urban or agricultural ecosystems have some residual level of biodiversity, which remains important for their functioning. 'Agricultural biodiversity', meaning the diversity in the domesticated species which humans use as the basis of their food and fibre production systems is an especially important subset.

It is often measured by applying richness measures to the number of varieties (or 'land races') of a particular crop or livestock type, or evenness measures to the fraction of the total yield delivered by the different cultivars. With the application of advanced genetic techniques to crop breeding, traditional notions of 'species' or 'cultivar' are becoming blurred, and more and more emphasis will be placed on gene-based measures.

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Biographical Sketch

Dr Bob Scholes is a systems ecologist, employed by the South African Council for Scientific and Industrial Research. His research interests are savanna ecology and global change. He helped design the Global Terrestrial Observing System, served as its Chair, and led its biodiversity task force. He was a member of the Implementation Plan Task Team that designed the Global Earth Observing System of Systems. He is on the Steering Committee of the Diversitas programme, and the Board of the South African National Parks.