Biodiversity encompasses the full range of variation in organisms that is reflected in taxonomic, functional, genetic, and phenotypic characteristics. Nonetheless, our understanding of biodiversity is primarily restricted to patterns of taxonomic diversity (i.e., species richness) at a limited spatial and temporal scales. Moreover, the full spectrum of critical ecosystem services provided by biodiversity to human societies is underappreciated (e.g., clean air and water, pharmacutical products, XXX). Ironically, the 21st Century may be heralded as the Century of Biodiversity — not because we fully cataloged life on earth and not because we elucidated the evolutionary mechanisms that give rise to higher taxa — rather the next 100 years will witness an unprecedented loss of biodiversity as a consequence of global change and accelerating habitat alteration, loss, and fragmentation associated with human activities. Attempts to mitigate these effects, prevent species loss, and preserve ecological integrity require understanding mechanisms that give rise to the spatial and temporal complexion of biodiversity.

Many of the overarching questions in ecology as well as the pressing environmental problems facing society are predicated on the spatial and temporal dynamics of ecological patterns and processes (May 1999, Thompson et al. 2001). In part, answers and solutions remain elusive because of the scale-dependent nature of pattern and process in ecological systems. In addition, most research fails to include a synoptic approach to understanding and conserving biodiversity.

Although there have been numerous efforts to measure and monitor biodiversity, the lack of high-quality data has hampered both ecological understanding and the provision of relevant information to policy makers. Biodiversity data from existing monitoring and research programs are inadequate for at least three reasons:

- Many monitoring programs are poorly designed (e.g., the questions they are intended to answer are not well defined, and/or the methods selected are inappropriate to the objectives), resulting in sub-optimal data;
- The spatial and temporal scales of monitoring activities are frequently inappropriate to the scales at which inferences from those monitoring activities are made;
- Statistical and technological tools for analyzing monitoring data remain relatively primitive;

Detecting ecological patterns, ecologically meaningful trends, and distinguishing the effects of human activities from those of natural disturbances – particularly at large scales - are notoriously difficult (Dayton et. al. 1998; Bradshaw et. al. 2001). Recent controversies over both fundamental questions in ecology (e.g., scale dependence in the relationship between biodiversity and productivity) and applied questions (e.g., the magnitude and causes of declines of neotropical migratory songbirds, James et. al. 1996; Thomas 1996; and amphibians, Blaustein et. al. 1994; Alford and Richards 1999 and references therein illustrate some of these difficulties).

Recommendations

Competition among research groups striving to become part of a network imposes certain constraints on research, which, though perhaps necessary from an organizational point of view, are anathema to a well-grounded scientific agenda. To be competitive, research collaborations must be well-focused, which in practice means that they are delimited by geographic and conceptual boundaries that may have little to do with the domains of factors affecting processes within the system of study. Thompson et al. (????) indicated that defining the spatial-temporal domains of ecological processes was one of the most important issues for ecologists, one which would require a reevaluation of the way ecologists bound their conceptual models. The existence of a set of domains of causality that vary in spatial and temporal extent complicates these models and requires a clear topology of ecological causative factors (Thompson et al. ????).

For example, (We could either repeat the Hawaiian example from Thompson here or devise a new one. The interaction of local soil factors, inputs of Sahara dust, and changes in the hurricane frequency and strength in the Caribbean is another example of varying domains of causality).

Designing an effective network for measuring and monitoring biodiversity involves a series of seven systematic steps:

1. Specify Goals of the Network
2. Develop Conceptual Model
3. Identify Relevant Spatial and Temporal Extents and Foci
4. Establish Sampling Design and Select Indicator Variables
5. Specify Sources and Levels of Uncertainty
6. Define Methods of Analysis
6. Determine Statistical Power of Sampling Design Within the Framework of the Conceptual Model
7. Develop a Plan for Ongoing Analysis of Data and Identify Benchmarks for Evaluating the Adequacy and Efficiency of the Network

Below we briefly discuss each of these steps…

Specify Goals

Many monitoring projects go wrong at this step. We cannot emphasize enough the importance of providing an explicit statement of the questions the monitoring program is intended to answer. Without such a statement, it is impossible to evaluate the effectiveness of the monitoring program.

Develop Conceptual Model

The conceptual model provides an overview of the scientific understanding of the ecological patterns and processes of interest and specifies the state variables that describe the system. This knowledge is used to determine what variables or measures are likely to be useful. Measurements and inferences to biological systems are affected by the scale of observation, thus the temporal and spatial scales at which processes operate and populations and communities respond must be estimated and clearly identified in the conceptual model (Noon et al. 1999).

Identify Relevant Spatial and Temporal Extents and Foci

Establish Sampling Design and Select Indicator Variables

No monitoring design can feasibly encompass all ecological processes and species (Bradshaw et. al. 2000). Therefore, the design of monitoring programs requires careful consideration of candidate species and processes for measurement. Selection of variables should be made in the light of the overall goals and underlying conceptual model of the ecological system or components of interest (NRC 2000). Although biodiversity has many dimensions, since we are limited in the number of things we can measure, it is popular to rely on monitoring surrogates such as species richness, functional groups, indicators, keystones.

etc., etc.

Define Methods of Analysis

For monitoring programs to be useful they must be efficient, informative and reliable (Thomas 1996). For example, given an objective of detecting a population decline, and a fixed level of effort or resources, how many sites should be monitored? How many samples are required to detect a trend in population size when there is uncertainty in observations and significant environmental variation? How likely is it that a particular sampling procedure will detect a rare species?

Insert example from Gross et al. and lack of power here.

Most frequently used statistical techniques do not answer these questions because they are rooted in the tradition of null-hypothesis testing. Typical management programs hinge on the implicit assumption that if no problem is observed, none exists. The burden of proof rests with monitoring programs. If monitoring programs fail to detect an impact or a rare species, these impacts are assumed to be absent. In these circumstances, the reliability of the monitoring system becomes critically important. This reliability, in turn, depends on statistical power, the ability of a method to detect real outcomes, often against a background of natural environmental variation, measurement error, and ignorance of biological processes.

Given the importance of reliable monitoring, the persistent failure of ecologists to explicitly incorporate reliability considerations in the design of sampling programs is notable (Fairweather 1991, Mapstone 1995). The task of stipulating an appropriate level of statistical power and an acceptable effect size is not simply a statistical decision. It entails judgments about the biological importance of an effect (Mapstone 1999). Such considerations are critically important because analysis indicates that without reliability calculations, experimenters often are overly optimistic about the reliability and representativeness of their samples. The risk of false optimism may be compounded by experimental designs that fail to account for the independence of replicates (Hulbert 1984).

Several potential new initiatives are contemplated for establishment of global monitoring of biodiversity trends. While well intentioned, such programs have the potential to waste time and use limited resources (Hughes 1992). More seriously, given the magnitude of current rates of human exploitation of biodiversity, a consensus is needed as to priority questions monitoring should aim to answer. Once those questions have been identified, the development of credible, extensive, and selectively intensive monitoring is essential, to provide warnings and adequate opportunities to avoid biotic catastrophe (Beddington 1995).