2. MEASURING DIVERSITY

All three of the policy concerns listed at the beginning of Chapter 1 suffer from ambiguity associated with the term "diversity." Measurements of diversity and debates about their meaning filled a substantial fraction of the ecological literature for several decades, beginning in the 1950s, with no clear resolution emerging (Goodman, 1975). Thus, it is not surprising that there is no consensus yet on how "biodiversity" should be measured.

Defining Diversity

At the level of genes and species, two attributes are of primary concern: the number of elements (genes or species) and their distinctiveness. Measuring genetic diversity presents the least difficulty. Indirect measurements of diversity based on the relatedness of individuals have been used by population geneticists for decades, and these methods are complemented now by techniques ranging from electrophoresis to DNA sequencing (Falconer, 1981). So, techniques already available for measuring genetic diversity are able to provide the raw data needed for managing populations and making conservation decisions. However, such data have not been collected to any significant extent for wild populations, and their application is limited by an incomplete understanding of the relationship between genetic diversity, population dynamics, and species survival.

Measuring species diversity is more problematic. Often, species diversity is equated with species richness—the number of species in a given area or sample—but a more informative measure of diversity would incorporate the relatedness of the species involved. Using such a measure of "taxonomic richness," a region containing many closely related species would rank lower than one containing an equivalent number of distantly related species (May, 1990; Vane-Wright *et al.*, 1991; Williams *et al.*, unpublished manuscript).

For example, Vane-Wright *et al.* (1991) have developed measurements of taxonomic richness for various regions of the world based on the patterns of distribution and the relatedness of bumblebees in the *Bombus sibericus* group. They found that while a quadrant in Ecuador possesses the highest bumblebee species richness, a similar-sized area in China contains a much greater fraction of taxonomic richness and would be more important from the standpoint of conserving species diversity, all else being equal.

Effective methodologies for measuring

taxonomic richness are being developed only now (Cousins, 1991), and the data on species distributions needed to apply such methodologies to real conservation problems are still fragmentary. Moreover, the problem of developing a single measure of taxonomic richness that encompasses largely unrelated groups of species (say, primates, butterflies, and plants) promises to be challenging. Nevertheless, this type of measurement ultimately will improve our ability to set priorities and to monitor actions related to the conservation of species diversity.

In the absence of good measurements of taxonomic richness, the richness of genera or families may provide a somewhat more accurate reflection of species diversity than simple measurements of species richness. Measures of the richness of genera and families are commonly used when dealing with extinction at geological time scales. When complete information on species identity is unavailable (as in the fossil record or among many groups of invertebrates today) or when certain genera are particularly species-rich, measurements of richness at higher taxonomic levels may be a better reflection of the taxonomic diversity present. However, such measurements are not without their own problems; considerable subjectivity is involved in defining genera, and better studied taxa (such as plants and vertebrates) may be split into more genera than others.

Problems associated with measuring biodiversity at the community level are even greater. Any number of community attributes are components of biodiversity and may deserve monitoring for specific objectives. Nevertheless, given the importance of conserving communities and ecosystems, several "generic" measurements of community-level diversity can provide useful information to policy-makers.

Temporary though such patterns may be on a geological time scale, community classification schemes can be developed at many levels of resolution based on existing species distribution patterns. For example, biogeographic provinces have been defined for the world (Udvardy, 1975) and, at much more fine-grained scales, for specific countries, provinces, and regions. Community classifications provide a baseline for evaluating changes in the extent of natural communities. The fact that the baseline itself is shifting is not a major concern over time periods of decades; a bald-cypress swamp, for example, is a sufficiently distinct entity over time scales of a few hundred years to be useful in conservation planning.

Another approach is to establish classifications based primarily on the physical environment (soils, topography, and climate) and to monitor the extent to which relatively undisturbed communities exist across the range of diversity in the physical environment. Given the fundamental role of the physical environment in determining the composition of species in any region, this approach focuses on conserving the "arenas" of biological activity, rather than on the temporary occupants of those arenas (Hunter *et al.*, 1988). The existing worldwide classification scheme closest to this approach is the "ecoregion" map developed by Bailey (1989). To a much greater extent than biogeographic provinces, the definition of ecoregions relies heavily on physical attributes of the environment such as climate and soils.

For the development of indicators relevant for national and international policies, the approach of conserving arenas of biological activity has numerous advantages. Whether using biogeographic regions or ecoregions as the basic classification, the consistency of their definition and application at a global scale allows effective comparison of indicators among regions. The fine-grained community classification schemes developed for individual nations or regions cannot be compared easily at a global level. However, these fine-grained approaches are likely to be much more valuable for conservation planning at the subnational level.

The Issue of Scale

The issue of scale is implicit in the choice of indicators of community-level diversity, but it is also of major importance in developing indicators for species and genetic diversity. At a global scale, the loss of species diversity is equivalent to species extinction—the complete disappearance of the species. However, viewed from a national or local standpoint, the local disappearance of a species (extirpation) is of serious concern, even if the species has not become extinct globally.

Moreover, at the local level the rationale for biodiversity conservation is often somewhat different from the rationale globally, and some indicators may be more appropriate for local concerns than others. The rationale for biodiversity conservation can be divided into utilitarian values, such as economic, social, cultural, and scientific uses (both to meet current needs and to meet obligations to future generations), and the nonutilitarian or more strictly ethical values, such as knowing that society has conserved species for their own sake. From a global standpoint, both rationales are important. However, the rationale from a local standpoint often relates more directly to the utilitarian values. Moreover, considerations of the needs of future generations are likely to take a back seat to the urgent needs of today.

In developing indicators of biodiversity, two techniques to deal with the issue of scale were adopted: the use of indicators of both local extirpation and global extinction, and the presentation of measurements in both absolute numbers and percentages. Based on the absolute numbers of reptiles at risk, Madagascar, with 231 endemic reptiles and a massive loss of habitat, clearly represents a global concern, but based on the percentage of species at risk, a country like Germany, with only 12 reptile species, but 9 of which are threatened with extirpation (75 percent), is clearly in urgent need of action too. (OECD, 1991). (Of Madagascar's 256 total reptiles, only 12 are listed as threatened by the IUCN, although this probably understates the true level of threat because only a part of Madagascar's reptile taxa have been surveyed to determine their status.) Most species at risk of extinction today are found in tropical forests, but some islands have a much higher percentage of species at risk, and Mediterranean ecosystems may be a close second in terms of numbers of threatened species (Reid and Miller, 1989). The fact that a larger and growing proportion of freshwater fish are threatened with extinction, as compared to marine fish, may be helpful in promoting additional conservation action.

A second, scale-related problem in designing biodiversity indicators stems from the fact that politically defined regions are the sphere of decision-making, while biologically defined regions (such as biogeographic regions, life zones, or ecoregions) are the appropriate unit for analyzing the status of, and trends in, biodiversity. Ideally, planners and policy-makers should have access to data aggregated along both political and biophysical units. However, data are most readily obtained for political units, and this scale of measurement is likely to be the most useful one for policy-makers, even if it obscures important biological information. With the development of Geographic Information Systems (GIS) data bases over the next decade, it will become increasingly possible to present indicators that bear upon both political or biological regions. The unit of measurement is not specified in the following list of indicators. Most of them can be applied either to biologically or politically defined regions, depending on the availability of data.

A third issue is the time scale of the indicator. Some measurements change relatively slowly with time and thus may not provide the immediate information needed for policy and management decisions. For example, measurements of species extinction clearly indicate the success or failure of conservation actions, but they are obviously too late to help in preventing extinctions. Policy-makers need timely information that provides some sense of the relative seriousness and urgency of the actions needed. Such information may be a

mix of "ultimate" indicators, such as species extinctions, and more time-sensitive (though often less definitive) ones, such as trends in population size.