BIODIVERSITY AND PRIORITY-SETTING

Biodiversity,

or biological diversity, is the total variety of life on earth.

It includes all genes, populations, species and ecosystems and the ecological processes of which they are part. At the ecosystem level, biodiversity underpins the ecological processes which are vital to human life, for example in influencing global climate patterns, in mediating the carbon cycle, in safeguarding watersheds, and in stabilizing soils to prevent desertification. At the species level, components of biodiversity in the form of domesticated and wild animals, plants and micro-organisms provide a vast array of goods and services which are often essential to the survival of humanity as well as being of enormous economic value. Other more wide-reaching but less tangible values may also be ascribed to biodiversity. There is the value of the various components of biodiversity that have yet to be discovered or realized; there is the value attached by many people to the mere fact that biodiversity exists; and there is the value of leaving existing levels of biodiversity to future generations. Taken together, these underscore the immense importance of biodiversity to mankind, and provide compelling arguments for maintaining it.

HOW MUCH DO WE KNOW ABOUT BIODIVERSITY?

Although we have accumulated a great deal of information on biodiversity (see Groombridge 1992 and UNEP 1995 for comprehensive reviews and further references), our knowledge still remains highly incomplete and biased. To date some 1.7 million species, of all forms of life, have been named and described scientifically. This is believed to include a high proportion of the true number of the world's larger terrestrial plants and animals, particularly the so-called higher vertebrates (birds, mammals, reptiles and amphibians), but a far smaller percentage of other groups, especially invertebrates, fungi and micro-organisms, which between them comprise the vast majority of living species. Estimates for the total number of species on earth vary from 10 million to 100 million. Although there is increasing consensus that the true figure is probably at the lower end of this range, this still implies that more than 80% of species have yet to be scientifically described. Even among the best-known taxonomic groups (birds and mammals) new discoveries are still regularly made (see Box 2 on p. 46). Detailed or complete information on distribution is available for only a very small proportion of described species—again, mostly large and conspicuous ones—and there is reliable information on population numbers for even fewer.

Our knowledge of biodiversity is geographically as well as taxonomically biased. Most information is available for terrestrial temperate regions with far less known about other parts of the world, particularly the tropics and aquatic regions. Even within temperate latitudes there are extremely few areas, or even sites, for which anything approaching complete species inventories exist, even if micro-organisms are excluded. Nevertheless, we do know enough to be able to make a number of general observations about the distribution and current status of biodiversity.

HOW IS BIODIVERSITY DISTRIBUTED?

One of the most important attributes of biodiversity is that it is not evenly distributed. Ultimately this is because each species has its own unique range, largely a product of the interaction between existing ecological conditions and the species' evolutionary history. It should be noted, however, that many species share broadly similar (but usually not identical) distribution patterns.

Ecological effects

The following very general rules determining the distribution of biodiversity appear to apply to terrestrial ecosystems:

- Warmer areas support more species than colder ones.
- Wetter areas support more species than drier ones.
- Less seasonal areas support more species than very seasonal ones.
- Areas with varied topography and climatic conditions support more species than uniform ones.

It is also true that, all other things being equal, larger areas are more diverse than smaller ones.

Globally, perhaps the single most important overall trend is the increase in species diversity with decreasing latitude, so that the number of species in any given area is, on average, far higher in tropical latitudes than in temperate or polar regions. There is also a marked tendency for diversity to be higher in forests than in other terrestrial ecosystems, although there are exceptions to this, notably the extremely high floristic diversity of Mediterranean heath-type vegetation. Tropical moist forests are widely accepted to be the most diverse terrestrial ecosystems.

Evolutionary influences

While the diversity of a given area and the kinds of organisms that can survive there are very largely determined by existing ecological conditions, it is evolutionary history that determines which species actually occur there. Because geographical features present barriers to the dispersal of species (e.g. dry land forms a barrier to most aquatic organisms, while water-bodies present barriers to many terrestrial organisms), each species tends to remain confined to the particular part of the world in which it evolved, even if habitats suitable for it exist elsewhere. For this reason, rain forests in, say, Papua New Guinea and Peru will have very different floras and faunas even though the ecological conditions in them are very similar.

Of course, some species and groups of species are very good at dispersing—and those that in addition have broad habitat tolerances have generally become widespread. However, many species remain confined to small areas, either because they cannot disperse from them, or because they have highly specific habitat requirements, or both. These species are often referred to as endemics (the concept of endemism can in fact be applied at any geographical scale, so that species can be considered endemic to a continent, although in practice the term is usually applied to species with small or restricted ranges). As a general rule, isolated areas support a higher proportion of endemic species than areas which are contiguous with or close to other similar areas; furthermore, the longer an area has been isolated, the higher is the proportion of endemic species likely to be found there. For terrestrial species the most obvious isolated areas are islands, and it is unsurprising that a significant proportion of restricted-range species occur only on them (see Box 1).

Existing biogeographical patterns are complicated by the fact that the landscape itself is not a static entity, but is constantly changing owing to climatic and geological factors. This means that barriers to the dispersal of different species may appear and disappear over time. There are some areas of the world, however, where environmental conditions have stayed predictable such that they have re-

Box 1. *The special case of islands.*

As would be expected from the general rules outlined in this chapter, patterns of diversity on islands are heavily influenced by their degree of isolation (both past and present), by their age and by their size. Generally, islands tend to be poorer in species than equivalent mainland areas, with geologically young islands being particularly depauperate. Truly 'oceanic' islands—those which have never been part of a continent (mostly those resulting from volcanic activity in the middle of oceans)—can become populated with organisms only through colonization. They thus tend to be very poor in groups of species for which water represents an important barrier to dispersal, such as non-flying mammals and amphibians, but relatively richer in groups which can cross such barriers, most notably birds.

mained forested during the cool and arid climatic episodes of the ice ages. These places are often referred to as 'refugia' and have accumulated species over a long time. At the global level the most important mechanisms affecting species distribution are plate tectonics. The break-up of the supercontinent Pangaea 180 million years ago into Gondwanaland and Laurasia, and thence into the continents as they exist today, has largely determined the patterns of distribution of the major groups of terrestrial organisms. Changing sea-levels have affected this by, for example, allowing the continents of North and South America to be successively linked then separated through the Central American isthmus.

Biogeographers now recognize six major biogeographic realms each with a distinctive though not completely separate fauna and flora. These are the Palearctic (Europe, North Africa and northern and western Asia), the Nearctic (North America), the Neotropical (Central and South America), the Afrotropical (Africa south of the Sahara and Arabia), the Indomalayan (India and south-east Asia) and the Australasian (Australia, New Guinea and associated islands). Within these biogeographic realms, many of the species are specialized to particular ecological conditions, leading to groups of species which are characteristic of particular vegetation zones and which share broadly similar distributions.

Human impacts

Natural patterns of distribution have been further influenced by one overwhelmingly important factor: the actions of humans. Mankind has played a major role in decreasing the ranges and populations of many species and, more rarely, in increasing those of others, either deliberately (in the case of domesticated species and some wild species) or accidentally (for example in the case of many weeds and commensal pests, such as rats and mice, and species of disturbed habitats). There is increasingly persuasive evidence that these impacts stretch back for millennia, so that most of the world as it exists today—or at least the terrestrial part of it—has been modified by man. The principal effect of this has undoubtedly been, and continues to be, a progressive loss of biological diversity.

HOW QUICKLY IS BIODIVERSITY BEING LOST?

The extinction of species is perhaps the single most significant measure of the loss of biodiversity. Species extinction is, of course, a natural process. The fossil record strongly suggests that all species have a finite lifespan, with the number of extinct species vastly outnumbering the number of living species. However, there is evidence that rates of extinction brought about directly or indirectly by human agency greatly exceed background or 'natural' rates of extinction and that these rates are accelerating. It seems incontrovertible that we are heading towards an extinction spasm which, if unchecked, has the potential to be the greatest since the end of the Mesozoic era, 60 million years ago, which saw the extinction of the dinosaurs, plesiosaurs and pterosaurs in what was possibly the aftermath of a single catastrophic event, namely the collision of an asteroid with the earth.

Estimating current extinction rates and predicting future ones are both problematic processes. Because our knowledge of species is incomplete, many estimates are based not on observed or recorded species extinctions, but rather on extrapolations from estimates of habitat loss coupled with assumptions derived from biogeographic theory relating numbers of species to area of habitat. The most widely applied assumption is that a tenfold reduction in area (i.e. loss of 90% of habitat) eventually results in the loss of half the species present. Most quoted global extinction rates have been based on estimates of species richness in tropical forests combined with estimates of actual and projected deforestation rates (on the assumption that the great majority of species are found in tropical forests). Early, very high estimates (11–15% of species lost per decade) have generally been revised downwards, with the most recent estimates indicating perhaps 2–5% of species lost per decade. Taking a conservative estimate of 10 million species on earth this would amount to a potential loss of 20,000–50,000 species per year, the vast majority of which would be invertebrates.

Another attempt to predict extinction rates used data on known extinctions of major animal and plant taxa since 1600, and examined rates at which species had been added to or removed from Red Lists of threatened species (i.e. those most at risk of extinction), concluding that half the planet's 9,600 bird and 4,600 mammal species would be lost within 200–300 years, and half the 2,200–2,600 palm species in 50–100 years (Smith *et al*. 1993). A more recent prediction of avian extinction rates, also comparing two Red Lists but using sounder and more rigorous data, suggested that the time to extinction of half the world's birds will be 800–2,800 years (Crosby *et al*. 1994). Although less pessimistic than the previous study, even this rate of extinction is 100–1,000 times greater than might be expected under natural conditions as illustrated by the fossil record.

There are many potentially important factors which have not been taken into consideration in these global models of extinction rates, and they are generally intended to serve only as very rough indications. There can be no doubt however that, whatever the real rate, the loss of biodiversity is accelerating, being no longer driven by the earth's climatic fluctuations and geological upheavals as in past eras, but instead linked ultimately to rapid human population growth and unsustainable economic activity.

PRIORITY-SETTING FOR CONSERVATION

Just as mankind is responsible for the current loss of species, so we are also capable of taking action to stem this loss. Given that resources are limited and destructive activities are expanding, it is widely recognized that choices must be made, so that attention is focused on those components of biodiversity most in need of conservation action. There are many different ways of addressing this issue, each approach having its own advantages and its own drawbacks.

Single-species approaches

One important approach involves identifying those individual components of biodiversity, usually species, which most merit conservation action. These species are generally either large and charismatic, or highly endangered, or both. A wide range of actions may be undertaken to attempt their conservation, involving protection and sometimes intensive management of habitat and captive breeding/propagation and reintroduction. This approach often finds legal expression in national legislation such as the US Endangered Species Act, which requires that all endangered species occurring in the USA have recovery plans developed for them. A notable number of plant and animal species have undoubtedly been saved from extinction—at least temporarily—in this way (e.g. Whooping Crane *Grus americana* and black-footed ferret *Mustela nigripes*).

However, such approaches are often very expensive and labour-intensive and can accommodate no more than a fraction of the species currently under threat. These may well serve as flagships for conservation, particularly if they are high-profile species such as Arabian oryx *Oryx leucoryx* or white rhinoceros *Ceratotherium simum*, but efforts to conserve them are likely to benefit other species (e.g. through the setting aside of large areas of habitat) only in an incidental rather than in a systematic way.

Area-based approaches

Identifying areas which are important for more than just one species, and then attempting to protect them, might be expected to be a more efficient approach to conservation in the long term. However, there are both practical and theoretical difficulties in identifying areas which are important for biodiversity in this wider sense. One of these is the fact that data on the distribution of the world's species are so incomplete and so heavily biased towards large, conspicuous forms, that decisions have to be made on the basis of partial knowledge. Secondly, when identifying priority areas for biodiversity conservation, the question of geographical scale is fundamentally important; the major reason for this is that diversity generally increases with increasing area but the rate of increase is rarely uniform and varies from place to place (see Box 2). Lastly, the importance of any given area for biodiversity very often cannot easily be quantified in a single measure but rather may need to be seen as a function of several separate attributes, including:

- Its richness—expressed by the number of species present.
- How representative it is—indicated by how well a particular area holds the key habitats and species representative of a wider area.

Box 2. The importance of scale.

The relative apparent diversity (and thereby importance) of different areas will often depend on the scale at which diversity is measured. As an example, one square metre of semi-natural European chalk grassland will contain many more plant species than one square metre of lowland Amazonian rain forest, whereas for an area of one square kilometre this relationship will be reversed. This implies that an area which may appear important at a local level may cease to be so when considered from a regional or global standpoint.

As areas increase in size beyond a certain level, the practical value of assessing and comparing them tends to decrease. This is because large areas may be diverse for different reasons. Such areas may be diverse because they have a large number of different habitats or ecosystems, any individual one of which may be low in diversity, or they may have a small number of highly diverse ecosystems. Approaches to conservation planning will differ in the two cases. In addition, there is a limit to the size of an area which it is realistic to consider protecting or managing for conservation, or which is helpful at indicating priorities. This limit, which varies both in space and time, is determined by political and economic processes outside the control of biology. As an extreme example, identifying South America as the most diverse of the earth's continents gives no guidance on where conservation efforts should be directed as there is no prospect whatever of protecting the entire continent or of abandoning the others.

- Its uniqueness—reflected in the number of species with restricted ranges which it harbours (and particularly in the number of species endemic to the selected area), or in the number of ecosystems of limited extent which are present.
- Its degree of threat—often represented by the number of threatened species present (and particularly by the number of highly threatened species), or by the percentage loss of its natural habitats.
- Its genetic contribution—demonstrated by some calculation of the taxonomic distinctiveness of species present.
- Its population value—as shown by the numbers of individuals of species present (particularly relevant where the area holds key sites which harbour a significant proportion of the species' total population).

Area-based approaches to priority-setting for conservation vary depending on which of these attributes is considered paramount. Some of the advantages and disadvantages of the first three attributes are outlined below. However, none of these priority-setting approaches operates in a vacuum, for most countries in the world already have a more or less extensive protected-area network (see Box 3).

Richness: the megadiversity approach

It is self-evident that areas with high levels of biodiversity will be important for its long-term maintenance. Identifying such areas should therefore provide valuable guidance in the targeting of conservation efforts. This approach is exemplified at a broad scale by the megadiversity country approach (Mittermeier 1988), which identified a relatively small number of countries with a significant proportion of the world's biodiversity, as measured by known numbers of species. However, approaches such as this which use measurement and comparison of overall known diversity to set priorities do not take into account the degree of overlap between different areas. The closer two areas are geographically, the greater is the pro-

Box 3. Finding gaps in protected-area networks.

Many existing protected areas have been established for reasons other than the maintenance of biodiversity—for amenity or recreational value or to protect spectacular landscape features. Even where such areas do have the aim of protecting wild species, they have often been established for large, well-known but not necessarily threatened ones. Expediency has also played a major role in that the areas set aside are often those that do not have immediate or obvious value for other purposes, so that for example montane areas are usually well represented in protected-area networks while lowland areas on soils with high agricultural potential are not. An important part in conservation planning therefore is 'gap analysis', which determines the extent to which biodiversity conservation priorities are already covered in existing protected-area networks (Scott ***et al***. 1993). One problem with gap analysis is that there is often no straightforward way of combining different attributes such as the richness, uniqueness and representativeness of different areas in order to assess their importance for biodiversity conservation, and thereby to produce an overall ranking of conservation priorities (see Box 4).

Box 4. Complementarity: a tool for prioritizing areas.

Where detailed data are available, the concept of 'complementarity' has proved to be an interesting development in conservation biology. Complementarity analysis attempts to find the most efficient way, or at least one of the most efficient ways, of including all examples of a particular set of species in a network or system. When applied to conservation problems it is generally used to choose the minimum set of areas which includes at least one population of all representatives of a given group of plants or animals.

Several different computer-based algorithms have been developed to perform complementarity analyses, which may be carried out at any scale. They usually begin by choosing the most diverse area, then the area with the largest number of species not included in the first area and so on until all species are represented. They have been used globally, for example, to determine a set of countries which includes populations of all known swallowtail butterflies (Collins and Morris 1985) and locally to design a reserve network which includes all members of the plant family Proteaceae in Cape Province of South Africa (Rebelo 1994).

Complementarity analyses avoid the need to choose between richness, uniqueness and representativeness in ranking areas in importance for biodiversity, but they themselves have a number of limitations. Firstly, and most important, they presuppose the availability of all relevant biodiversity information for all the areas to be considered. Secondly, although it is relatively straightforward to identify a set of areas which include ***all*** representatives of a given group (as long as the relevant distributional information is available), in practice the possibility of protecting all such areas is almost always remote. The realistic question usually seeks to know which is the best subset of this set of areas (for example, which are the best six out of twenty given areas, or what is the minimum set of areas which will provide 80% or 95% coverage of a given group of species). Thirdly, it can only target strictly limited subsets of species—such as one family of butterflies or one genus of wasps—becoming inoperably complex the more inclusive it becomes.

portion of species they are likely to share. This applies particularly when the areas to be compared are determined geopolitically (e.g. are countries or provinces) rather than biogeographically: the ranges of species, on continents at least, very rarely adhere to political boundaries. Areas, particularly geopolitical units, which are adjacent are likely therefore to share a high complement of their wild species. Thus two adjacent and highly diverse countries (e.g. Ecuador and Peru) may share so many of their species that including both of them in a list of highest-priority countries leads on the one hand to redundancy and on the other to possible exclusion of countries which are less diverse but have more distinctive fauna and flora.

Representativeness: the ecosystem approach

An alternative approach which attempts to avoid the problem of overlap uses ecosystems as the basic units for analysis and tries to ensure that representative samples of each ecosystem are protected. This is based on the assumption that the world can be divided into a series of largely discrete ecosystems each of which has its own distinctive species composition and physical structure. By protecting representative samples of each, a high proportion of the world's biodiversity should be protected. This approach is exemplified in the IUCN Systems Reviews carried out in the mid-1980s (IUCN/UNEP 1986a,b,c) and, more recently, by the ecoregions analysis of Dinerstein *et al*. (1995).

In reality, however, the natural environment cannot always be easily divided into a series of discrete units but in many places seems to form a variable continuum. This being the case, the mapping of boundaries between ecosystems invariably involves a degree of arbitrariness—as does deciding whether any given area is truly representative of some larger ecosystem. In addition, habitat or ecosystem classification systems are highly scale-dependent (see Box 2), such that no one system is appropriate to use at all scales. Very broad-based systems (those at continental or global level) may provide a general overview and highlight major gaps but give little guidance on exactly where conservation activity should be directed, whereas more detailed systems become increasingly site-specific and are of less value in making comparisons and in priority-setting.

Uniqueness: the hotspot approach

A potentially highly efficient approach to identifying conservation priorities is to use knowledge of the distributions of species to identify areas which are particularly rich in narrowly distributed species, such as islands and continental refugia. These areas will by definition contain a high complement of just those species which may be expected by virtue of their small ranges to be most vulnerable to extinction and therefore most in need of conservation action.

A study which emphasized the importance of narrowly distributed species was the botanical 'hotspots' analysis of Myers (1988a, 1990), who identified 18 sites—primarily in tropical forest, but also including Mediterranean vegetation located in the temperate zone—which in total contained over 50,000 endemic species of plants (20% of the world's known plant species) in 746,400 km^2 (0.5% of the world's land surface). This approach has been developed for birds in this study.

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