

Biodiversity: An Overview

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This introduction is intended to map out in general terms some of the principal themes to be encountered in the field of biological diversity. It will provide a context for understanding the activities at WCMC which are themselves explained through the remainder of this WWW. This overview is compiled into one document and can be navigated through the following sections;

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What is biodiversity?

The word 'biodiversity' is a contraction of biological diversity. Diversity is a concept which refers to the range of variation or differences among some set of entities; biological diversity thus refers to variety within the living world. The term 'biodiversity' is indeed commonly used to describe the number, variety and variability of living organisms. This very broad usage, embracing many different parameters, is essentially a synonym of 'Life on Earth'.

Management requires measurement, and measures of diversity only become possible when some quantitative value can be ascribed to them and these values can be

compared. It is thus necessary to try and disentangle some of the separate elements of which biodiversity is composed.

It has become a widespread practice to define biodiversity in terms of genes, species and ecosystems, corresponding to three fundamental and hierarchically-related levels of biological organisation.

Genetic diversity

This represents the heritable variation within and between populations of organisms. Ultimately, this resides in variations in the sequence of the four base-pairs which, as components of nucleic acids, constitute the genetic code.

New genetic variation arises in individuals by gene and chromosome mutations, and in organisms with sexual reproduction can be spread through the population by recombination. It has been estimated that in humans and fruit flies alike, the number of possible combinations of different forms of each gene sequence exceeds the number of atoms in the universe. Other kinds of genetic diversity can be identified at all levels of organisation, including the amount of DNA per cell, and chromosome structure and number.

This pool of genetic variation present within an inter-breeding population is acted upon by selection. Differential survival results in changes of the frequency of genes within this pool, and this is equivalent to population evolution. The significance of genetic variation is thus clear: it enables both natural evolutionary change and artificial selective breeding to occur.

Only a small fraction (often less than 1%) of the genetic material of higher organisms is outwardly expressed in the form and function of the organism; the purpose of the remaining DNA and the significance of any variation within it is unclear.

Each of the estimated 10^9 different genes distributed across the world's biota does not make an identical contribution to overall genetic diversity. In particular, those genes which control fundamental biochemical processes are strongly conserved across different taxa and generally show little variation, although such variation that does exist may exert a strong effect on the viability of the organism; the converse is true of other genes. Further, an astonishing amount of molecular variation in the mammalian immune system, for example, is possible on the basis of a small number of inherited genes.

Species diversity

Perhaps because the living world is most widely considered in terms of species, biodiversity is very commonly used as a synonym of species diversity, in particular of 'species richness', which is the number of species in a site or habitat. Discussion of global biodiversity is typically presented in terms of global numbers of species in different taxonomic groups. An estimated 1.7 million species have been described to date; estimates for the total number of species existing on earth at present vary from five million to nearly 100 million. A conservative working estimate suggests there might be around 12.5 million. In terms of species number alone, life on earth appears to consist essentially of insects and microorganisms.

The species level is generally regarded as the most natural one at which to consider whole-organism diversity. Species are also the primary focus of evolutionary mechanisms, and the origination and extinction of species are the principal agents in governing biological diversity in most senses in which the latter can be defined. On the other hand, species cannot be recognised and enumerated by systematists with total precision, and the concept of what a species is differs considerably between groups of organisms.

Further, a straightforward count of the number of species only provides a partial indication of biological diversity, for implicit within the term is the concept of degree or extent of variation; that is, organisms which differ widely from each other in some respect by definition contribute more to overall diversity than those which are very similar.

The more different a species is from any other species (as indicated, for example, by an isolated position within the taxonomic hierarchy), then the greater its contribution to any overall measure of global biological diversity. Thus, the two species of Tuatara (genus *Sphenodon*) in New Zealand, which are the only extant members of the reptile order Rhynchocephalia, are more important in this sense than members of some highly speciose family of lizards. Developing this argument, a site with many different higher taxa present can be said to possess more taxonomic diversity than another with fewer higher taxa but many more species. Marine habitats frequently have more different phyla but fewer species than terrestrial habitats; i.e. higher taxonomic diversity but lower species diversity. Measures under development endeavour to incorporate quantification of the evolutionary uniqueness of species.

The ecological importance of a species can have a direct effect on community structure, and thus on overall biological diversity. For example, a species of tropical rain forest tree which supports an endemic invertebrate fauna of a hundred species evidently makes a greater contribution to the maintenance of global biological diversity than a European alpine plant which may have no other species wholly dependent on it.

Ecosystem diversity

The quantitative assessment of diversity at the ecosystem, habitat or community level remains problematic. Whilst it is possible to define what is in principle meant by genetic and species diversity, and to produce various measures thereof, there is no unique definition and classification of ecosystems at the global level, and it is thus difficult in practice to assess ecosystem diversity other than on a local or regional basis and then only largely in terms of vegetation. Ecosystems further differ from genes and species in that they explicitly include abiotic components, being partly determined by soil parent material and climate.

Ecosystem diversity is often evaluated through measures of the diversity of the component species. This may involve assessment of the relative abundance of different species as well as consideration of the types of species. In the first instance, the more equally abundant different species are, then in general the more diverse that area or habitat is considered to be. In the second instance, weight is given to the numbers of species in different size classes, at different trophic levels, or in different taxonomic groups. Thus a hypothetical ecosystem which consisted only of several species of

plants, would be less diverse than one with the same number of species but which included animal herbivores and predators. As different weightings can be given to these different factors when estimating the diversity of particular areas, there is no one authoritative index for measuring diversity. This obviously has important implications for the ranking of different areas.

Biodiversity: its meaning and measurement

The differences between these conceptual perspectives on the meaning of biodiversity, and the associated semantic problems, are not trivial. Management intended to maintain one facet of biodiversity will not necessarily maintain another. For example, a timber extraction programme which is designed to conserve biodiversity in the sense of site species richness may well reduce biodiversity measured as genetic variation within the tree species harvested. Clearly, the maintenance of different facets of biodiversity will require different management strategies and resources, and will meet different human needs.

Even if complete knowledge of particular areas could be assumed, and standard definitions of diversity be derived, the ranking of such areas in terms of their importance with respect to biological diversity remains problematic. Much depends on the scale that is being used. Thus, the question of what contribution a given area makes to global biological diversity is very different from the question of what contribution it makes to local, national or regional biological diversity. This is because, even using a relatively simplified measure, any given area contributes to biological diversity in at least two different ways - through its richness in numbers of species and through the endemism (or geographical uniqueness) of these species. The relative importance of these two factors will inevitably change at different geographical scales, and sites of high regional importance may have little significance at a global level. Neither of these factors include any explicit assessment of genetic diversity.

Although the word biodiversity has already gained wide currency in the absence of a clear and unique meaning, greater precision will be required of its users in order that policy and programmes can be more efficiently defined in the future.

Biodiversity: Changes in time and space

Changes over time

The fossil record of life in geological time is very incomplete. There is marked variation between higher taxa and between species in different ecosystems in the extent to which individuals are susceptible to preservation and to subsequent discovery. Chance factors have played a large part, and interpretation by palaeontologists of the available material is beset by differences of opinion. Thus, the record is relatively good for shallow-water hard-bodied marine invertebrates, but poor for most other groups, such as plants in moist tropical uplands.

Two salient points appear well- substantiated. Firstly, taxonomic diversity, as measured by the number of recognised phyla of organisms, was greater in Cambrian times than in any later period. Secondly, and keeping in mind the difficulty of disentangling artefacts of the record from the underlying pattern, it appears that species diversity and number of families have undergone a net increase between the Cambrian and the Pleistocene epoch, although interrupted by isolated phases of mass extinction (few of which are reflected in the fossil record of plants).

Changes in space

In general, species diversity in natural habitats is high in warm areas and decreases with increasing latitude and altitude. On land, diversity is also usually higher in areas of high rainfall and lower in drier areas. The richest areas are undoubtedly tropical moist forests. If current estimates of the number of species (mainly insects) comprising the microfauna of tropical moist forests are credible, then these areas, which cover perhaps 7% of the world's surface area, may well contain over 90% of all species. If the diversity of larger organisms only is considered, then coral reefs and, for plants at least, areas with Mediterranean climate in South Africa and Western Australia, may be as diverse. Gross genetic diversity and ecosystem diversity will, by definition, tend to be positively correlated with species diversity (although there are indications that some tropical species show more genetic diversity than related temperate species, and some habitat generalists more than habitat specialists).

The reasons for the large-scale geographic variation in species diversity, and in particular for the very high species diversity of tropical moist forests, are not fully understood and involve two interconnected questions: the origin of diversity through the evolution of species and the maintenance of diversity. Both these involve consideration of the present and historic (in a geological or evolutionary sense) conditions prevailing in particular areas, principally climatic but also edaphic and topographic. Climatically benign conditions (warmth, moisture and relative aseasonality) over long periods of time appear to be particularly important.

It is often assumed that areas with so-called climax ecosystems will be more diverse than areas at earlier successional stages. However, an area with a mosaic of systems at different successional stages will probably be more diverse than the same area at climax provided that each system occupies a sufficiently large area of its own. In many instances, human activities artificially maintain ecosystems at lower successional stages. In areas that have been under human influence for extended periods, notably in temperate regions, maintenance of existing levels of diversity may involve the maintenance of at least partially man-made landscapes and ecosystems, mixed with adequately sized areas of natural climax ecosystems.

Loss of biodiversity

The loss of biological diversity may take many forms but at its most fundamental and irreversible it involves the extinction of species.

Over geological time, all species have a finite span of existence. Species extinction is therefore a natural process which occurs without the intervention of man. However, it is beyond question that extinctions caused directly or indirectly by man are occurring at a rate which far exceeds any reasonable estimates of background extinction rates, and which, to the extent that it is correlated with habitat perturbation, must be increasing. Unfortunately, quantifying rates of species extinction, both at present and historically, is difficult and predicting future rates with precision is impossible.

Documenting definite species extinctions is only realistic under a relatively limited set of circumstances, where a described species is readily visible and has a well-defined range which can be surveyed repeatedly. Unsurprisingly, most documented extinctions are of species that are easy to record (e.g. land snails, birds) and inhabit sites which can be relatively easily inventoried (e.g. oceanic islands). The large number of extinct species on oceanic islands is not solely an artefact of recording, because island species are generally more prone to extinction as a result of human actions.

Rather than being derived from observed extinctions, therefore, quoted global extinction rates are derived from extrapolations of measured and predicted rates of habitat loss, and estimates of species richness in different habitats. These two estimates are interpreted in the light of a principle derived from island biogeography which states that the size of an area and of its species complement tend to have a predictable relationship; fewer species are able to persist in a number of small habitat fragments than in the original unfragmented habitat, and this can result in the extinction of species. Even on best available present knowledge, these estimates involve large degrees of uncertainty, and predictions of current and future extinction rates should be interpreted with very considerable caution. Pursuit of increased accuracy in the estimation of global extinction rates, however, whilst of great concern, is not a crucial activity; it is more important to recognise in general terms the extent to which populations and species which are not monitored are likely to be subject to fragmentation and extinction.

Loss of biodiversity in the form of crop varieties and livestock breeds is of near zero significance in terms of overall global diversity, but genetic erosion in these populations is of particular human concern in so far as it has implications for food supply and the sustainability of locally-adapted agricultural practices. For domesticated populations, loss of wild relatives of crop or timber plants is of special concern for the same reason. These genetic resources may not only underlie the productivity of local agricultural systems but also, when incorporated in breeding programmes, provide the foundation of traits (disease resistance, nutritional value, hardiness, etc.) of global importance in intensive systems and which will assume even greater importance in the context of future climate change.

Erosion of diversity in crop gene pools is difficult to demonstrate quantitatively, but tends to be indirectly assessed in terms of the increasing proportion of world cropland planted to high yielding, but genetically uniform, varieties.

The causes of loss of biological diversity

Species may be exterminated by man through a series of effects and agencies. These may be divided into two broad categories: direct (hunting, collection and persecution), and indirect (habitat destruction and modification).

Overhunting is perhaps the most obvious direct cause of extinction in animals, as it has affected several large and well-known species. In terms of overall loss of biodiversity, however, it is undoubtedly far less important than the indirect causes of habitat modification and loss. Nevertheless, as it self-evidently selectively affects species which are or have been considered a harvestable resource, it has important implications for the management of natural resources.

Genetic diversity, as represented by genetic differences between discrete populations within wild species, is liable to reduction as a result of the same factors affecting species. The genetic diversity represented by populations of crop plants or livestock is liable to reduction as a result of mass production; the desired economies of scale demand high levels of uniformity.

Virtually any form of sustained human activity results in some modification of the natural environment. This modification will affect the relative abundance of species and in extreme cases may lead to extinction. This may result from the habitat being made unsuitable for the species (for example, clear-felling of forests or severe pollution of rivers), or through the habitat becoming fragmented. The latter has the effect of dividing previously contiguous populations of species into small sub-populations. If these are sufficiently small, then chance processes lead to raised probabilities of extinction within a relatively short time.

A major, though at present largely unpredictable, change in natural environments is likely to occur within the next century as a result of large-scale changes in global climate and weather patterns. There is a high probability that these will cause greatly elevated extinction rates, although their exact effects are at present unknown.

Maintaining Biological Diversity

The maintenance of biological diversity at all levels is fundamentally the maintenance of viable populations of species or identifiable populations. This can be carried out either on site or off site. Some integrated management programmes have begun to link these basically dissimilar approaches.

In situ conservation

The maintenance of a significant proportion of the world's biological diversity at present only appears feasible by maintaining organisms in their wild state and within their existing range. This is generally preferable to other courses of action because it allows for continuing adaptation of wild populations by natural evolutionary processes and, in principle, for current utilisation practices to continue (although these often require enhanced management).

Ex situ conservation

Viable populations of many organisms can be maintained in cultivation or in captivity. Plants may also be maintained in seed banks and germplasm collections; similar

techniques are under development for animals (storage of embryos, eggs, sperm) but are more problematic. In any event, ex situ conservation is clearly only feasible at present for a small percentage of organisms. It is extremely costly in the case of most animals, and while it would in principle be possible to conserve a very large proportion of higher plants ex situ, this would still amount to a small percentage of the world's organisms. It often involves a loss of genetic diversity through founder effects and the high probability of inbreeding.

Why conserve biological diversity ?

This question can be asked from a number of different perspectives, all conditioned by a variety of cultural and economic factors. The various answers given, arguing for the maintenance of biological diversity, have tended to become increasingly confused. Different goals have different implications for the elements and extent of biological diversity that must be maintained. Among these goals are the following:

- the present and potential use of elements of biodiversity as biological resources
- the maintenance of the biosphere in a state supportive of human life
- the maintenance of biological diversity per se, in particular of all presently living species.

Biological diversity as a resource

It is evident that a certain level of biological diversity is necessary to provide the material basis of human life: at one level to maintain the biosphere as a functioning system and, at another, to provide the basic materials for agriculture and other utilitarian needs.

Food

The most important direct use of other species is as food. Although a relatively large number of plant species, perhaps a few thousand, have been used as foodstuffs, and a greater number are believed to be edible, only a small percentage of these are nutritionally significant on a global level, and only very few of these have been intensively managed on a commercial scale. Similarly, very many animal species are eaten (mostly fishes), but only a very small percentage are globally of nutritional significance. A few dozen species, mostly mammals, are managed in some kind of husbandry system, and a handful of these are globally significant.

It is clear that successful cultivation of agricultural crops on a large scale requires a suite of other organisms (chiefly soil microorganisms and, in a few cases, pollinators) but these probably amount to a statistically insignificant percentage of global biological diversity. Highly productive agricultural systems also require the virtual absence of some elements of biological diversity (pest species) from given sites.

Whilst relatively little diversity is currently used in commercial food production, the very high probability of global climate change, predicted to result in large-scale shifts in

natural vegetation and in agricultural systems, has focused attention on the need for conservation of plant genetic resources in order to maintain crop productivity under different climatic regimes. This 'insurance value' of diversity is also evident in contemporary conditions, where increased genetic uniformity is correlated with increased crop yield variation.

Pharmaceuticals

Medicinal drugs derived from natural sources make an important global contribution to health care. An estimated 80% of people in less- developed countries rely on traditional medicines for primary health care; this shows no signs of decline despite availability of western medicine. Some 120 chemicals extracted in pure form from around 90 species are used in medicines throughout the world. Many of these cannot be manufactured synthetically: the cardiac stimulant digitoxin, the most widely used cardiotonic in western medicine, is extracted direct from dried *Digitalis* (foxglove); synthetic vincristine, used to treat childhood leukaemia is only 20% as efficacious as the natural product derived from *Catharanthus roseus* (Rosy Periwinkle).

As with agriculture, and excluding traditional medicines, at present only a very small percentage of the world's biodiversity contributes on a global scale to health care. Many argue that technological advances within the pharmaceutical industry, and in particular those involving the design and manufacture of synthetic drugs, will mean that this contribution is more likely to fall than rise. However, natural diversity might be increasingly valued for the 'blueprints' it provides for new synthetic drugs.

Other material values of biological diversity

Many natural or semi-natural ecosystems, some of which may be of high biological diversity, are of considerable benefit to man. Examples are:

- the role of forests in watershed regulation and stabilisation of soils in erosion-prone areas
- the role of mangroves in coastal zone stabilisation and as nursery areas for fisheries species
- the role of coral reefs in supporting important subsistence fisheries
- the role of natural ecosystems protected as national parks in generating income from wildlife tourism.

In general, however, these values are only indirectly related to biological diversity. That is, a certain level of species richness is required for these functions but there is not necessarily a direct correlation between the value of the ecosystem and its diversity, nor in all cases do a particular set of species have to be present. Thus, mangrove ecosystems are generally of far lower diversity than adjacent lowland terrestrial forests but in resource terms are likely to be of comparable value. The savannas of east and southern Africa, which are of great importance in generating revenues from tourism, are

less diverse than the moist forests in these countries which have far less potential for tourism.

The precautionary principle

While it is evident that at present a relatively small proportion of the world's biological diversity is actively exploited by man, other elements of biological diversity may be important for different reasons:

- they have values which are unused or unknown at present but which could enhance the material well-being of mankind if these values were discovered and exploited
- they may become useful or vital at some time in the future owing to changing circumstance.

These factors support a precautionary line in maintaining biological diversity - that is, actually or potentially useful resources should not be lost simply because we do not know about or value them at present. However, although this precautionary argument has wide applicability it has limited force. It is based on estimates of the potential value of a given element of biological diversity which must be balanced against the actual cost of maintaining it or refraining from destroying it. Thus, unless a given element is identified as vital, it must have a finite value and there must therefore come a point at which the projected costs required to maintain it will outweigh any probable benefits. The fact that these costs and benefits are rarely if ever precisely quantifiable means that such calculations will involve the estimation of probabilities and risks.

Conclusions on resource values

Experience and general ecological theory indicate that no single species is indispensable in maintaining basic ecological processes on a global scale and that, in general terms, the rarer a species is, the less likely it is to play an important ecological role on even a local level. In other words, every species has a finite resource value and, although in some cases this value may be very high, in the case of increasingly rare species it tends to zero.

Similarly, with respect to species which may be directly useful to man, chiefly as food and pharmaceuticals, the vast majority of species can be said with high probability to have little potential. Experience enables us to identify those groups of taxa where there is a higher probability of value (e.g. wild relatives of crop species, and certain plant families for pharmaceuticals).

General conclusions to be drawn from the above discussion may be that considering species only as material resources, it would be more cost-effective to:

- maintain systems and areas rich in species than those poor in species
- maintain those known to be useful, or regarded as having a high probability of being useful, than to maintain other species.

These conclusions indicate that resource values of biodiversity, and in particular the cost-benefit approach to conservation, do not of themselves provide justification for the wide-ranging approach to biodiversity conservation that many seek to pursue. Such arguments must have limited applicability and limited force, and considerable caution must be exercised when citing them, especially when extrapolating from the particular (the rationale for maintaining particular species or a certain level of biological diversity) to the general (that all biological diversity is inherently valuable as a resource and must therefore be preserved).

Biodiversity and the biosphere

Human activities are affecting the biosphere on a global scale. It is important in the present context to establish the extent to which losses in biological diversity may contribute to these changes in having an impact on man.

One of the most obvious of such global changes is the perturbation of the carbon cycle, leading to a steady increase in atmospheric CO₂ levels. This will probably have far-reaching, although at present unpredictable, effects on global climate patterns which may in turn have serious consequences for human welfare.

A significant part of this is ascribable to industrial processes, especially the burning of fossil hydrocarbon fuels for energy generation. However, it is believed that alteration of existing natural or semi-natural ecosystems is also important. In particular the large-scale destruction of tropical moist forests is implicated, both in contributing to atmospheric CO₂ through burning and in decreasing the carbon-fixing potential of the biosphere. The high risk of serious consequences for humans of global climate changes is itself a strong argument for decreasing rates of forest clearance. It must, however, be stressed that this argument applies to tropical moist forest as 'forest', rather than as 'a highly diverse ecosystem'. Diversity is important only to the extent that it contributes to the system functioning as a carbon sink and the argument applies equally to other systems with a similarly high capacity for carbon fixation, such as tropical freshwater swamps, although these are far less diverse than tropical moist forest. In more general terms, there appears to be no direct or obvious link between the importance of an ecosystem in maintaining essential global ecological processes and its diversity, although more research is required.

Non-resource values of biological diversity

It is evident that resource-based arguments for the maintenance of biological diversity have very considerable but finite force; therefore any fundamental justification for striving to maintain all currently existing biological diversity must lie outside the realm of material resource values. Such justification usually devolves onto two principles - ethics and aesthetics - which themselves lie outside the realm of science.

Ethics

For some cultures, ethical beliefs provide the strongest grounds for maintaining biological diversity, and indeed in some eastern countries much of the remaining diversity in densely populated areas can be attributed directly to religious practices. However, without recourse to an absolutist moral code, it is difficult to argue compellingly for an ethical imperative for the maintenance of all existing biological diversity. Whilst the killing of any living organism may be morally unacceptable to some people, there are problems in extending this argument to the conservation of biological diversity. At an extreme level, any individual organism that is not genetically identical to another represents a facet of this diversity, and a strict ethical argument would proscribe its destruction. It may be understandable to object to the killing of an elephant on moral grounds, but is it any less moral to eat wheat, which is grown from genetically diverse seeds, than to eat potatoes, most of which are grown from genetically identical clones? Similarly, there are difficulties in demonstrating that a species, which is to some extent a human construct, has any greater 'right' to existence as an entity than any one of the individuals of which it is comprised.

Nevertheless, the fact remains that ethics provides a powerful argument against the destruction of biological diversity. In practice, this argument is often contingent on other grounds, particularly the precautionary principle. For example, it may be considered immoral to destroy something which is now, or may be in the future, regarded as valuable to others. This is embodied in the 'stewardship' argument. The principle of inter-generational responsibility underpins the ethical case for conservation in the developed world, although it may be of little practical relevance to a desperate farmer faced with the reality of survival in a developing country.

Aesthetics

Arguments for the maintenance of biological diversity for its aesthetic appeal are compelling but have limited force, as they must be dependent on relative aesthetic judgements. Such judgements could presumably discard some organisms (those not visible, for example) as not worthy of being maintained. They are also unlikely to hold sway in the face of counter arguments that certainly exist for the destruction in the wild of harmful organisms, such as malarial Plasmodium species. Further, because genetic diversity is not susceptible to aesthetic appreciation, aesthetic criteria can be applied only to species and ecosystem aspects of biodiversity.

Regardless of individual aesthetic judgements, it is undoubtedly the case that humans very strongly favour variety in most areas of their experience. This need is particularly evident in the realm of the natural world. That is, diversity itself, and biological diversity in particular, is held in some poorly-definable but fundamental sense to be a highly desirable phenomenon. This is no mere notion, but a need that is very deeply felt, and a fundamental part of the spiritual life of many people. It is not important that the reasons for this cannot be fully articulated; the need is strongly manifest and should have force in determining action.

Overall, while it is evident that neither ethical nor aesthetic arguments provide of themselves sufficient grounds for attempting to maintain all existing biological diversity, a more general and pragmatic approach recognises that different but equally valid arguments (resource values, precautionary values, ethics and aesthetics, and simple self-interest) apply in different cases, and between them provide an overwhelmingly powerful case for biodiversity conservation.

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