Biological Diversity: meaning and measurement

What is biological diversity?

A definition of biodiversity is:

"... *the number, variety and variability of all living organisms in terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are parts*." [1]

[1] This definition is taken from the Convention on Biological Diversity adopted at the UNCED conference in Rio de Janeiro in 1992.

It is evident from this definition that biodiversity is intended to capture two dimensions: first, the number of biological organisms and, secondly, their variability. There are three levels at which biodiversity is usually discussed:

1. genetic diversity
2. species diversity
3. diversity of ecological function

The first two of these three have usually been of interest to economists because of the **direct values** provided by genetic material and species to human production and consumption. But the third is also of interest (and an interest that is growing in importance) because of the **functions** that species perform in ecological systems, and the valuable services that those ecosystems provide **indirectly**.

We shall now say a few words about each.

1. Genetic diversity within a population or populations

Genetic diversity within the populations that constitute a species is important as it affects the evolutionary and adaptive potential of the species, and so we might measure biodiversity in terms of the number of populations.

2. Species diversity

We might wish to measure biodiversity in terms of the numbers of distinct species in particular locations, the extent to which a species is endemic (unique to a specific location), or in terms of the diversity (rather than the number) of species.

3. Ecosystem diversity

In many ways, the diversity of ecosystems is the most important measure of biodiversity; unfortunately, there is no universally agreed criterion for either defining or measuring biodiversity at this level.

For the purposes of this classification of levels, a species can be taken to be a set of individual organisms which have the capacity to reproduce, while a population is a set that actually do reproduce. A population is, that is, a reproductively isolated subset of a species.

Measurement of Biodiversity

Biodiversity is usually considered in terms of species, and the number of distinct species is often used as the indicator of biodiversity. There are problems with this measure. For example, within one population of any species there will be considerable genetic variation. Suppose a harvesting programme targets individuals within that population with a particular characteristic (such as large size). The target individuals are likely to possess genetic material favouring that characteristic, and so the harvesting programme reduces the diversity of the gene pool in the remaining population. Managed harvesting programmes, therefore, may result in loss of biodiversity even though the number of extant species shows no change.

The Current Extent of Biodiversity

We have very poor information about the current extent of biodiversity. The number of species that currently exist is not known even to within an order of magnitude. Estimates that can be found in the literature range from 3 –10 million (May, 1988) to 50–100 million (Wilson, 1992). A current best guess of the actual number of species is 12.5 million (Groombridge, 1992). Even the currently known number of species is subject to some dispute, with a representative figure being 1.7 million species described to date (Groombridge, 1992). About 13000 new species are described each year. Table 1 reports current knowledge about species numbers for a variety of important taxonomic classes.

Table 1 Numbers of described species and estimates of actual numbers for selected taxa (thousands)

Taxa	Species described	Estimated number of species: high	Estimated number of species: low	Working figure
Viruses	4	1000	50	400
Bacteria	4	3000	50	1000
Fungi	72	2700	200	1500
Protozoa and algae	80	1200	210	600
Plants	270	500	300	320
Nematodes (worms)	25	1000	100	400
Insects	950	100000	2000	8000
Molluscs	70	200	100	200
Chordates	45 [a]	55	50	50

Why does biodiversity matter?

Biodiversity is important in the provision of environmental services to economic activity in a number of ways.

1. In relation to **inputs to production**, those flora and fauna are the source of many useful products, particularly pharmaceuticals, foods and fibres; the genes that they contain also constitute the materials on which future developments in biotechnology will depend. In terms of agriculture, biodiversity is the basis for crop and livestock variability and the development of new varieties.

2. In relation to **direct impacts on individual utility**, the diversity of flora and fauna in ecosystems contributes to the amenity services that we derive from the environment.

3. In regard to **life-support services**, diverse ecological systems facilitate environmental functions, such as carbon cycling, soil fertility maintenance, climate and surface temperature regulation, and watershed flows.

We mentioned earlier that biodiversity is usually discussed at three levels:

- genetic diversity
- species diversity
- diversity of ecological function

The nature and role of biological diversity in ecological systems

The benefits to humans from high levels of biodiversity that we have listed above on this page relate principally to the first and second of those three levels. However, ecologists (and many ecological economists) see the greatest long-term importance of biodiversity in terms of the third level, which impacts on ecosystem resilience and evolutionary potential. The following box explains some key concepts.

Ecology: Ecosystems, Stability and Resilience - Some key ideas explained

Ecology is the study of the distribution and abundance of plants and animals. A fundamental concept in ecology is the ecosystem, which is an interacting set of plant and animal populations, together with their abiotic, i.e. non-living, environment. An ecosystem can be defined at various scales from the small and local – a pond or field – through to the large and global – the biosphere as a whole.

Stability and resilience

Two concepts of fundamental importance in ecology are stability and resilience. The ecologist Holling (1973, 1986) distinguishes between stability as a property

attaching to the populations comprised by an ecosystem, and resilience as a property of the ecosystem. Stability is the propensity of a population to return to some kind of equilibrium following a disturbance. Resilience is the propensity of an ecosystem to retain its functional and organisational structure following a disturbance. The fact that an ecosystem is resilient does not necessarily imply that all of its component populations are stable. It is possible for a disturbance to result in a population disappearing from an ecosystem, while the ecosystem as a whole continues to function in broadly the same way, so exhibiting resilience.

Common and Perrings (1992) put these matters in a slightly different way. Stability is a property that relates to the levels of the variables in the system. Cod populations in North Atlantic waters would be stable, for example, if their numbers returned to prior levels after a brief period of heavy fishing was brought to an end. Resilience relates to the sizes of the parameters of the relationships determining ecosystem structure and function in terms, say, of energy flows through the system. An ecosystem is resilient if those parameters tend to remain unchanged following shocks to the system, which will mean that it maintains its organisation in the face of shocks to it, without undergoing catastrophic, discontinuous, change.

Some economic activities appear to reduce resilience, so that the level of disturbance to which the ecosystem can be subjected without parametric change taking place is reduced. Expressed another way, the threshold levels of some system variable, beyond which major changes in a wider system take place, can be reduced as a consequence of economic behaviour. Safety margins become tightened, and the integrity and stability of the ecosystem is put into greater jeopardy. This aligns with the understanding of pollution as that which occurs when a waste flow exceeds the assimilative capacity of the receiving system, and that which if it occurs itself reduces the system's assimilative capacity.

When such changes takes place, dose–response relationships may exhibit very significant nonlinearities and discontinuities. Another way of putting this is to say that dose–response relationships may involve thresholds. Pollution of a water system, for example, may have relatively small and proportional effects at low pollution levels, but at higher pollutant levels, responses may increase sharply and possibly jump discontinuously to much greater magnitudes.

Diverse gene pools represent a form of insurance against ecological collapse: the greater is the extent of diversity, the greater is the capacity for adaptation to stresses and the maintenance of the ecosystem's organisational and functional structure. What is particularly important about the latter is that particular species may not be performing those functions in a particular context. But if they are capable of providing those functions in other circumstances, they have **option values**.

Measures of biodiversity (briefly discussed earlier) can be thought of as using some measure of distance between different components in a set. There are many possible criterion of distance. A commonly used one is genetic difference. But whether genetic differences are the basis of a biodiversity distance depends on what problem we wish to address.

Perrings et al (1995) give the following example. Consider domesticated and wild grasses, of actual and/or potential value as a staple food source. If consumption is

the main consideration, then biological or genetic differences between the two would be of little significance if they were of roughly equal value in consumption utility terms. The loss of wild grasses - and a substitution of them by domesticated grasses - loses little. But suppose that the criterion that matters is the ability of species (or sets of species) to provide ecological functions under a variety of circumstances, and that wild grasses have that property to a much higher degree. Then wild grasses potentially play a much greater role in contributing to resilience of ecosystems, and so have option (or insurance) values not possessed by domesticated grasses.

Perrings et al (1995) write:

"But it is the self-organising ability of the (eco)system, or more particularly the resilience of that self-organisation, which determines its capacity to respond to the stresses imposed by predation or pollution from external (including human) sources. The importance of biodiversity is argued to lie in its role in preserving ecosystem resilience, by underwriting the provision of key ecosystem functions under a range of environmental conditions."

There are four principal, sequential and inter-related, system functions that shape the behaviour of an ecosystem:

1. exploitation (processes responsible for colonisation of disturbed systems)
2. conservation (resource accumulation building stores of energy and materials)
3. creative destruction (abrupt changes resulting from external disturbances that release stores of energy and materials)
4. reorganisation (released materials mobilised ready for new exploitation phase)

Ecological behaviour is non-linear and discontinuous. Resilience - in the sense described earlier - depends in the main on the effectiveness of the last two of these four system functions.

We must be careful, however. There is no simple relationship between the amount of biodiversity and resilience; it is not necessarily true that greater diversity leads to greater resilience. What is generally accepted though is that the ability of species to provide system functions under a wide variety of conditions is of fundamental importance.

The Causes of Biological Diversity Loss

The drivers of environmental impact

The environmental impact of economic activity can be looked at in terms of extractions from, or insertions into, the environment. In either case, for any particular instance the immediate determinants of the total level of impact are the size of the human population and the *per capita* impact. The *per capita* impact depends on how much each individual consumes, and on the technology of production. This is a very simple but useful way to start thinking about what drives the sizes of the economy's impacts on the environment. Box 1 reports estimates of a measure of global impact that is relevant to biodiversity and reductions in it.

Box 1 Human appropriation of the products of photosynthesis

The basis for life on earth is the capture by plants of radiant solar energy, and its conversion to organic material by the process of photosynthesis. The rate at which plants produce plant tissue is primary productivity, measured in terms of energy per unit area per unit time – calories per square metre per year say. Gross primary productivity is the total amount of solar energy that is fixed by photosynthesis, whereas net primary productivity is that less the amount of energy lost to the environment as respiration, and so the amount that is actually stored in the plant tissue. Net primary productivity is the measure of the energy that is potentially available to the animals that eat the plants.

Table 2 shows estimates of the proportion of net primary productivity that is appropriated by humanity. About 70% of the earth's surface is covered by water. The aquatic zone produces about 40% of total global net primary productivity. The terrestrial zone, although accounting for only 30% of the surface area, accounts for about 60% of total primary productivity.

For each zone, and for both zones together, Table 2 shows estimates of human appropriation on three different bases:

	Percentages		
	Low	Intermediate	High
Terrestrial	4	31	39
Aquatic	2	2	2
Total	3	19	25

Table 2 Human appropriation of net primary productivity

Source : Vitousek *et al*. (1986)

- Low – for this estimate what is counted is what humans and their domesticated animals directly use as food, fuel and fibre.
- Intermediate – this counts the current net primary productivity of land modified by humans. Thus, for example, whereas the low estimate relates to food eaten, the intermediate estimate is of the net primary productivity of the agricultural land on which the food is produced.
- High – this also counts potential net primary productivity that is lost as a result of human activity. Thus, with regard to agriculture, this estimate includes what is lost as a result, for example, of transforming forested land into grassland pasture for domesticated animals. It also includes losses due to desertification and urbanisation.

For the aquatic zone, it makes no difference which basis for estimation is used. This reflects the fact that human exploitation of the oceans is much less than it is of land-based ecosystems, and that the former is still essentially in the nature of hunter–gatherer activity rather than agricultural activity. It also reflects that what are reported are rounded numbers, to reflect the fact that we are looking at – for both zones – approximations rather than precise estimates.

For the terrestrial zone, the basis on which the human appropriation of net primary productivity is measured makes a lot of difference. If we look at what humans and their domesticates actually consume – the low basis – it is 4%. If we look at the net primary productivity of land managed in human interests – the intermediate basis – it is 31%. Commenting on the high terrestrial figure, the scientists responsible for these estimates remark:

An equivalent concentration of resources into one species and its satellites has probably not occurred since land plants first diversified.

(Primary Source: Vitousek *et al.*, 1986, p. 372)

For ecologists, human appropriation of net primary productivity is the most fundamental human impact on the natural environment, and is the major driver of the current high rate of biodiversity loss. In a speech at the Natural History Museum on 28 November 2001, the ecologist Lord Robert May, President of the Royal Society and formerly the UK government's chief scientist, stated that:

"There is little doubt that we are standing on the breaking tip of the sixth great wave of extinction in the history of life on earth. It is different from the others in that it is caused not by external events, but by us – by the fact that we consume somewhere between a quarter and a half of all the plants grown last year."

(Quoted in *The Guardian*, 29 November 2001)

What is causing the loss of biological diversity?

As Fisher (1981, page 75) argues, much of the concern about resource exhaustion appears to involve renewable resource use and the endangerment of species. He quotes one early assessment by a biologist:

"The worst thing that can happen - will happen [in the 1980s] - is not energy depletion, economic collapse, limited nuclear war, or conquest by a totalitarian government. As terrible as these catastrophes would be, they can be repaired within a few generations. The one ongoing process in the 1980s that will take millions of years to correct is the loss of genetic and species diversity by the destruction of natural habitats. This is the folly our descendants are least likely to forgive us." Wilson (1980)

This prognosis is supported by the following assessment that introduces the discussion of diversity found in Chapter 8 of the 1994-95 edition of *World Resources*:

"By some accounts, the world is on the verge of an episode of major species extinction, rivalling five other documented periods over the past half billion years during which a significant portion of global flora and fauna were wiped out. Unlike previous die-offs, for which climatic, geologic and other natural phenomena were to blame, the current episode is driven by anthropogenic factors: the rapid conversion and degradation of habitat for human use; the accidental and deliberate introduction of exotic species; overharvesting animals, fish and plants; pollution; human-caused climate change; industrial agriculture and forestry; and other activities that destroy or impair natural ecosystems and the species within them."

WR (1994), page 147.

It is common to have in mind land-based organisms when discussing loss of biodiversity. However, there is evidence that the biodiversity of freshwater lakes, streams and rivers may be the most threatened terrestrial ecosystem. Furthermore, marine waters, which contain over 90% of the world's living biomass, may be experiencing substantial loss of biodiversity (see WR, 1994, pages 184 and 192).

We turn our attention now to the **causes** of biodiversity decline. A part of this phenomenon is due to the hunting or harvesting of particular species for recreational or commercial purposes. But this explains only a very small part of the total picture.

Far more important are losses associated with general economic activity. The drainage of wetlands for agriculture, dam construction and the flooding of valleys for power generation, the use of pesticides, the development of wilderness areas, and toxic contamination of soils have all been associated with unintended species collapses or extinction. In fact, almost all forms of human activity pose this threat. Incidental and unintended impacts are the most important causes of species extinction, dwarfing in significance species loss arising from excessive harvesting.

Proximate versus Fundamental Causes

The causes of biodiversity decline are, therefore, many and diffuse. It is useful to draw a distinction between *proximate* and underlying or *fundamental* causes. Proximate causes refer to the mechanisms that trigger the loss of biological diversity; the immediate neighbours, if you like, in the chains of cause and effect links. Fundamental causes are those conditions - cultural, economic, and institutional - which generate and sustain the proximate causes. This distinction is important for policy purposes. Attempts to reduce the loss of biodiversity must take account of the fundamental causes. Efforts concentrated on proximate causes may be doomed to failure if the pressures emanating from underlying conditions are not redirected.

Proximate

Even in the absence of human pressures, there are several natural mechanisms that can result in biodiversity loss or species extinction. These include environmental and demographic stochasticity (random variability), genetic failure and natural catastrophes. Details of the ways in which these mechanisms operate can be found in Jeffries (1997).

But our interest lies in human induced processes. Each of the following processes can induce biodiversity decline:

- land conversion away from high diversity supporting uses
- exploitation of wild species
- introduction of exotic species into new environments
- homogenisation of agricultural practices
- air, water and ground pollution
- climate change.

Some examples of each of these are given in Box 2 on the following page.

Fundamental

While there is little disagreement about the proximate causes of biodiversity decline, there is less consensus about the underlying causes. The explanations given are not mutually inconsistent with each other, however. Rather, they differ in terms of how the problem is conceptualised, and what are perceived as most 'fundamental'. A very useful classification of suggested underlying causes of biodiversity loss was given by Swanson (1995b). He identifies four classes of explanation:

1. The expansion of human society

This explanation is essentially one of scale and dominance. Human population growth and changes in its geographical distribution have dramatically increased pressures on the environment (as shown on the previous page dealing with human appropriation of net primary productivity). These pressures have intensified as *per capita* production and consumption have risen with economic development.

Economic and ecological systems are linked. As the scale of the economic system grows relative to that of the natural environment, the dynamics of both systems are affected. In particular, the dynamics become more discontinuous. Threshold effects become to come into play as assimilative and carrying capacities are

exceeded (see Perrings, 1995). In this view, biodiversity and the resilience of ecological and economic systems interact in a reciprocal causal relationship: biodiversity is a contributor to ecological and economic resilience (and so provides insurance against the loss of ecological services). But at the same time, a loss of ecological resilience tends to reduce the extent of biodiversity.

This perspective gives the greatest cause for concern. It sees human interests as being fundamentally in competition or conflict with the interests of other species. Policies designed to save biodiversity require the general processes of human expansion be stopped.

2. Poverty and underdevelopment

A second candidate for the underlying cause of biodiversity loss is poverty and underdevelopment. There are various mechanisms through which this may act, including deforestation and the loss of soil fertility by an inappropriately managed expansion of extensive margin of agriculture. Essentially, this kind of explanation is one which stresses some form of vicious cycle of poverty. Poverty is associated with extensive, wasteful and short-term use of resources. This has three consequences: first, economic activity is very damaging to the environment, with little or no attention being paid to these impacts; second, environmental damages generates negative feedback on future production possibilities; and third, little value is added by these activities, and so financial resources to break out of underdevelopment are not forthcoming. The initial position of poverty is thereby reproduced over time. It is the resulting general environmental degradation that gives rise to the proximate causes of biodiversity loss.

In one important respect, this explanation is somewhat misleading. There is a reasonable degree of positive correlation between poverty and environmental richness. The more diverse a region is currently, the greater will be the absolute amount of biodiversity loss from any given set of impacts. Most of the industrialised countries are located in northern regions where biodiversity has naturally been lower. Moreover, these countries have already lost many of their large reserves of genetic material, through forest and wilderness conversion.

Having said this, if this explanation does have validity, it does give cause for optimism. Poverty and underdevelopment can be overcome, and major strides in this direction have been taken in recent decades. Matters are far more difficult to deal with where the problem is associated with high levels of economic activity, as in the previous explanation.

3. Human choices about the pattern of development

Biodiversity loss may be viewed as a result of our development choices. In his summary of this perspective Swanson writes:

"*Human society has a choice in regard to the amount of diversity that will be retained along its development path, and ... this choice has thus far been made in a haphazard fashion, resulting in unmanaged diversity depletion.*"

Swanson (1995b), page 2.

Swanson uses the notion of society's asset portfolio. Existing plans have a bias towards a low weight being attached to biological assets in that portfolio. We have freely chosen, for whatever reason, a narrowly constructed portfolio. It is perfectly conceivable for us to select a more diverse portfolio '*either through the more intensive use of a smaller area of land or by the more extensive use of a wider range of species*'.

Stressing the role of free choice may be important in putting responsibility firmly on human shoulders, but one cannot avoid feeling that this perspective is a good description of what has happened but does not constitute a satisfactory explanation (much in the same way that to say that peoples' free choices explain population growth).

4. Inappropriate policies and policy failure

It is relatively easy to make a good case for the proposition that consistently poor policy choices, or failures to properly think through the consequences of choices, are causes of biodiversity decline. Examples can easily be cited: development programmes introduced in response to poverty or perceived need to develop quickly; agricultural support programmes; the ineffective use of extensive margins, these are just a few.

The kinds of misguided policy are too numerous to list. But underlying most cases of policy failure seem to be two factors: the presence of formidable amounts of ignorance and uncertainty; and the lack of policy integration - different arms of government pursue what are perceived as independent objectives without coordination, when in reality the objectives are interconnected (and so their pursuit warrants integration).

Anyone trained as an economist is likely, however, to feel that an important element is lacking in this story, plausible as it is in other respects. The explanation does not address the patterns of incentives facing individuals or organisations. Perhaps decision makers are not failing at all in terms of their own objectives. This suggests that we should look at the institutional framework within which choices are made and incentive structures are determined.

5. Institutional failure

Swanson characterises this explanation as '*failure to create institutions that internalise the values of biodiversity within the decision-making of states and individuals making conversion decisions*' (Swanson, 1995b).

This brings us back to the ideas of 'market failure' that we have discussed at length in other classes. Resources may be inefficiently allocated (in this case, biodiversity being insufficiently conserved) for a variety of institutional reasons. One of these - which is directly relevant to biodiversity - concerns the bias in information property rights towards information deriving from human capital and against information retained in conserved natural capital. Here we have a situation where no institutional framework exists that rewards diversity for its information content.

Any discussion of biodiversity loss cannot be complete without a recognition of its international nature: biodiversity is a global public good. You will already know

that public goods are likely to be inefficiently allocated in market-based economies. But this problem is substantially enhanced by the international nature of this public good. The reasons why are fairly clear: effective allocation of resources - including an economically efficient allocation of resources into biodiversity conservation - requires international coordination of actions and policies. In a world lacking sovereign global institutions, and where coordination needs to take place across more than just regional blocs, such as the EU or NAFTA areas, such coordination will be very difficult to achieve. For an extensive discussion of this matter, see Chapter 10 of the Perman et al text.

Whether this is a case of policy failure or institutional failure is a moot point. It is probably both.

Many other instances of market failure could be cited, and their linkages to biodiversity decline traced out. We will leave this to your further reading. However, the institutional failure explanation does imply in a fairly clear way some directions forward that might be taken in constructing instruments to stem the loss of biodiversity.

Box 2 Some examples of proximate causes of biodiversity decline

Land conversion away from high diversity supporting uses

Possibility the most well known (and well-researched) example of land use change leading to biodiversity decline is the clearing of rainforests. These ecosystems are the most diverse terrestrial systems; forest conversion breaks up continuous woodland areas into parcels which are unable to support the diversity of species that they held in their natural states. We will look at one example of this.

In 1973, a new species of frog – the gastric brooding frog, named because the female nurtures her young in her stomach – was discovered in the Conondale range of Queensland, Australia. Initial studies suggested that its biological materials were potentially of immense medicinal benefit. However, the frogs' habitat was suffering from severe logging pressures, and fears were expressed that habitat conversion would lead to a loss of the species. The gastric brooding frog became the symbol of an intense local and international conservation campaign, organised under the slogan 'Don't log the frog'. All was to no avail. The last wild gastric brooding frogs were seen in 1979, and the species is now thought to be extinct.

Exploitation of wild species

The number of species which are known to have been driven to extinction as a result of targeted human action is relatively small. A much larger number have a high probability of becoming extinct in the medium- to long-term future. Several examples are well known. While blue whales (and several other whale species) and African elephants are not extinct, there have been fears that they could easily become so. These fears are justified not only because present numbers are small, but also because several of the conditions favouring extinction seem to be present in these cases.

Populations of large mammals are particularly vulnerable. Unlike most fish species, the biotic growth potential of large mammals is sufficiently low to mean that heavy harvesting can drive the stock to zero. A well-known example is the American plains buffalo, which has survived only through a combination of good fortune and carefully nurturing of small numbers of the animals in some safe havens. Indeed, hunting and trapping have left many land creatures perilously close to or beyond the point of extinction.

African elephants have for long been regarded as common property resources. In recent decades, elephant stocks have fared quite differently from place to place, depending on how governments and local communities have managed stocks, arranged economic incentives and controlled access. Several southern African states (such as Zimbabwe, Botswana and South Africa) manage the stocks as capital assets, strictly limiting access and allowing limited high-income-generating hunting. The most successful conservation programmes seem to have taken place where local people have had strong financial incentives for participating in these programmes, and so support strong anti-poaching measures. Kenya has experienced serious falls in its elephant population, not having established strong economic incentives for local people to participate in elephant protection.

Two large Asian countries - China and India - are threatened with substantial losses of species in the near future. Threatened species in China include a number of large mammals, including the giant panda, tiger, snow leopard, white-lip deer and golden monkey (see WR, 1994, page 79). The main influences appear to be general habitat change arising from population growth and the associated pressures for increasing food output. Other contributory factors are hunting, and collection of specimens for taxidermy and for preparation of medicines (particularly in the case of plants). Similarly, many large mammal populations are threatened in India, including the tiger, elephant and some apes.

Both China and India have recognised these threats for at least two decades, have instituted systems of protected areas, and have plans to increase the protected land area by large quantities over the next two decades. These schemes show many interesting qualities; for example, Chinese plans include attempts to create corridors, providing natural links between nature reserves within the country and to reserves outside China.

Similar proposals to construct corridors have been mooted for the former socialist countries of Central and Eastern Europe. Previous no-go areas along national boundaries offer the prospects of providing, at little real cost, very ecologically diverse nature reserves connected to one another by ecological corridors following the national boundaries.

However, the limited success to date of these protected areas in attaining conservation objectives demonstrates the importance of providing appropriate economic incentives to local populations. In India, for example, local tribes people displaced from land devoted to tiger reserves have no incentive to conserve the animal, and their poaching has added to the pressures on tiger numbers (WR, 1994, page 99). The designation of protected status is of little use in itself unless there are concomitant changes in human behaviour; these can only be expected if local people are granted secure land tenure, property rights are firmly established, and the enforcement of those rights is supported by the state.

This brings us back to the question of open access. Blue whale stocks have suffered from open access, together with very slow rates of natural growth. Efforts by the International Whaling Commission to conserve blue whale stocks have been largely ineffective. The passenger pigeon, which effectively became extinct through hunting in the late-nineteenth century, also shows the dangers of extinction associated with open access.

While hunting or harvesting has been a major cause of extinction (or threats to extinction) of many large animal species, there are strong grounds for believing that most cases of species extinction do not result directly from excessive harvesting of the resource. Indeed, very often, species becoming extinct were never harvested at all. Most species extinction results from habitat change. Habitats do evolve naturally, of course, and so extinction is not only the result of human activity. But economic activity imposes very rapid and substantial changes to environmental systems, and it is this that is the cause of most species loss.

The important point that emerges from this is the potential for irreversible effects of resource use. This characteristic of irreversibility suggests that there may be benefits from cautious or conservative use of resources, especially when there is uncertainty about the role and functions of species that might be lost by development.

Introduction of exotic species into new environments

The last known member of the *Partula turgida* population, a snail species endemic to French Polynesia, died in London Zoo in 1996 (Jeffries, 1997). This species, along with many other Polynesian island snails, was driven to extinction by the introduction of a predatory snail *Englaninia rosea*. The latter species had, in turn, been introduced as a device to control the population of giant African land snails. These had been imported for human consumption. Escape of African land snails was followed by an explosion in their numbers, with the species becoming a serious pest through crop damage.

Homogenisation of agricultural practices

One component of the so-called green revolution in agriculture has been the selection and development of crop cultivars with high yield characteristics. These crop development processes involve selection of genetic varieties with high primary productivity potential - that is, they grow quickly and deliver high crop yields. Secondary characteristics of plants are of little or no commercial relevance, and are correspondingly selected out of the commercial varieties. But this process leads to crops which are critically dependent upon the maintenance of unchanging environmental conditions. When those change - due to climate change, entry of new diseases or predators, or when soil conditions change, for example - the selected species is vulnerable to collapsing primary productivity or worse. The Irish potato famine of the nineteenth century illustrates the possible consequences of dependence on one genetic variety that is particularly vulnerable to disease.

But more importantly in the long-term, selection processes of this kind promote genetic uniformity; even where species do not become extinct, the extent of genetic diversity can fall significantly. This loss is enhanced by spillover effects on surrounding ecosystems. Monocultural agriculture - be it timber plantations, cereal

crops or whatever - tend to be associated with changes in the pattern of land use which cause loss of habitats for other plant and animal communities.

Air, water and ground pollution

Pollution has very pervasive effects on biological diversity. European forests and water systems have been badly damaged by acid precipitation, and the use of pesticides and herbicides in agriculture has serious ecological effects, including the loss of several bird species due to DDT impacts. It has been conjectured that the large falls that have been observed in male fertility in many parts of the world is the result of long-term accumulations of pollutants in various environmental media. As yet, it is too early to say whether this speculation is well founded.

Climate change

We know that major episodes of rapid climate change in the past have been associated with catastrophic episodes of biodiversity loss. For example, at the end of the Palaeozoic period (about 250 million years in the past), over 95% of species were lost in the Permian extinction. This is thought to have been caused by major climate change associated with continental plate movements forming the supercontinent, Gondwanaland.

What is not yet clear is whether the current human-caused climate change due to the so-called greenhouse effect will have an effect anywhere near so large in magnitude. Much will depend on the pace of climate change, rather than the level of eventual climate change. If the change is sufficiently slow, natural adaptation and evolutionary processes may be sufficient to avoid a great loss of biodiversity, even though its composition may change. The high degree of homogenisation of land use today, though, suggests that these natural mechanisms may not work very successfully.

End of Box 2

International Conventions and Accords that Relate to Biodiversity

UNCED: Rio de Janeiro 1992

The conference itself was preceded by over two years of preparatory international negotiations. Delegations were sent from 178 nations and the meeting was attended by 107 heads of government (or state). During UNCED several parallel and related conferences took place in Rio de Janeiro; the meeting for 'non-governmental organisations', mainly pro-environment pressure groups, involved more participants than UNCED itself. It has been estimated that, in total, over 30 000 people went to Rio de Janeiro in June 1992.

The preparatory negotiations dealt with four main areas: draft conventions on biodiversity conservation, global climate change, forest management, and the preparation of two documents for adoption at UNCED. The main UNCED outcomes were as follows. There was complete agreement on the non-binding adoption of the *Rio Declaration* and *Agenda 21*. The first of these comprises 27 statements of

principle in regard to global sustainable development. The second is an 800-page document covering over 100 specific programmes for the attainment of global sustainable development: many of these programmes involve resource transfers from the industrial to the developing nations. UNCED also agreed on the creation of a new UN agency, a Commission for Sustainable Development, to oversee the implementation of *Agenda 21*. Agreement was also reached on the, non-binding, adoption of a set of principles for forest management. The industrial nations reaffirmed their previous non-binding commitments to a target for development aid of 0.7% of their GNP. It should be noted that it is still true that only a few of the industrial nations actually attain this target.

Two conventions were adopted, by some 150 nations in each case, which would be binding on signatories when ratified by them. These covered global climate change and biodiversity conservation: the latter was not signed by the USA at the Rio meeting, but the USA did sign in 1993 after a change of administration. Although binding, these conventions did not commit individual nations to much in the way of specific actions. The *Convention on Biological Diversity (and subsequent agreements)* deals with two main issues – the exploitation of genetic material and biodiversity conservation. In regard to the latter, signatories agree to create systems of protected areas, for example, but undertake no commitments regarding their extent. The *Framework Convention on Climate Change* was mainly about the principles according to which future negotiations – known as Conferences of the Parties, COPS – were to try to establish commitments and rules. A major principle was that commitments would be limited to the developed nations.

Many environmental activists, as well as many concerned to promote economic development in poor nations, regarded the actual achievements at UNCED as disappointing, but it did confirm that sustainable development was, and would remain, firmly on the world political agenda. While specific commitments were not a major feature of the outcomes, there were agreements with the potential to lead to further developments. The creation of the Commission on Sustainable Development is clearly an important institutional innovation at the international level.

The convening of, and the outcomes at, UNCED suggest that the need to address the economic and environmental problems arising from economy–environment linkages is widely accepted. Equally, UNCED and subsequent events suggest that even when the existence of a problem is widely agreed by national governments, agreement on the nature of appropriate policy responses is limited. Further, there is clearly reluctance on the part of national governments to incur costs associated with policy responses, and agreed action is even more difficult to realise than agreement about what should be done. The difficulties involved in achieving international action on environmental problems are discussed in Perman et al Chapter 10, along with progress that has been made since 1987.

World Summit on Sustainable Development: Johannesburg 2002

The United Nations Commission on Sustainable Development, established as a result of UNCED in 1992, organised the 2002 World Summit on Sustainable Development, WSSD, in Johannesburg to build upon the achievements of UNCED. To find out more about its achievements, visit the web link above.

The Use of Economic Instruments for Protecting Biodiversity

1. A set of brief case studies produced by the WWF about using economic tools to deliver conservation goals. This is a good general guide, at a relatively basic level, and many case studies (that you might want to selectively pick from):

- Direct Link to Document.
- External Site Link

2. Valuation of ecosystems

- Direct Link to Document
- External Site Link

3. International Environmental Policy: Perman et al Chapter 10

This chapter discusses, in the context of game theory, the difficulties in securing international cooperation with respect to environmental objectives, including biodiversity conservation.

- Direct Link to Chapter

Further Reading on Ecological Aspects of Biodiversity

Krebs (2001) is a successful ecology text that is comprehensive but assumes no prior knowledge of the subject. Folke (1999) is a brief overview of ecological principles as they relate to ecological economics, and provides useful references to the literature. As it is set out here, the idea of resilience as a property of an ecosystem is developed in Holling (1986). The paper by Ludwig *et al*. (1997) is a clear, but technical, exposition of the basic mathematics of Holling resilience and how it relates to another concept of resilience that appears in the ecology literature.

Barbier *et al*. (1994) is a good introduction to biodiversity issues. Wilson's classic work (Wilson, 1988) on biodiversity has been updated as *BiodiversityII* (Reaka-Kudla *et al*., 1996). UNEP (1995) is the definitive reference work in this field, dealing primarily with definition and measurement of biodiversity loss, but also containing good chapters on economics and policy. See also Groombridge (1992) and Jeffries (1997) for excellent accounts of biodiversity from an ecological perspective. Measurement and estimation of biodiversity are examined in depth in Hawksworth (1995), and regular updated accounts are provided in the annual publication *World Resources*. The extent of human domination of global ecosystems is considered in Vitousek *et al*. (1997); for the range of uncertainty attending such estimates see Field (2001).

Source: Jeffries (1997, p. 88), based in turn on Groombridge (1992) and Heywood (1995)

[a] Of the 45000 chordates (vertebrate animals), there are about 4500 mammals, 9700 birds, 4000 amphibians and 6550 reptiles

Biodiversity Loss

Just how fast is the stock of genetic resources being depleted? Given that the number of species existing is not known, statements about rates of extinction are necessarily imprecise, and there are disagreements about estimates. Table 2 shows data for *known* extinctions since 1600. The actual number of extinctions would certainly be equal to or exceed this. The recorded number of extinctions of mammal species since 1900 is 20. It is estimated from the fossil record that the normal, long-run average, rate of extinction for mammals is one every two centuries. In that case, for mammals the known current rate of extinction is 40 times the background rate.

Table 2 **Known extinctions up to 1995**

Group	Extinctions
Mammals	58
Birds	115
Molluscs	191
Other animals	120
Higher plants	517

Source : Groombridge (1992)

To quote Lord Robert May:

"If mammals and birds are typical, then the documented extinction rate over the past century has been running 100 to more like 1000 times above the average background rate in the fossil record. And if we look into the coming century it's going to increase. An extinction rate 1000 times above the background rate puts us in the ballpark of the acceleration of extinction rates that characterised the five big mass extinctions in the fossil records, such as the thing that killed the dinosaurs."

(*The Guardian*, 29 November 2001)

According to Wilson (1992) there could be a loss of half of all extant birds and mammals within 200 to 500 years. For all biological species, various predictions suggest an overall loss of between 1% and 10% of all species over the next 25 years, and between 2% and 25% of tropical forest species (UNEP, 1995). In the longer term it is thought that 50% of all species will be lost over the next 70 to 700 years (Smith *et al.*, 1995; May, 1988).

Lomborg (2001) disputes many of the claims made about the severity of the impacts of man's economic activity on the natural environment. He takes issue, for example, with most of the estimates of current rates of species loss made by biologists. His preferred estimate for the loss of animal species is 0.7% per 50 years, which is smaller than many of those produced by biologists. It is, however, in Lomborg's own words: 'a rate about 1500 times higher than the natural background extinction' (p. 255). There really is no disagreement about the proposition that we are experiencing a wave of mass extinctions, and that it is due to the human impact on the environment.

The Economics of Biological Diversity Loss: Explored Using Influence Diagrams

The first objective

In this topic, we shall investigate what economics has to say about biodiversity loss. In particular we shall look at its underlying causes, its consequences, and policy measures available to reduce the rate of loss of biodiversity.

The second objective

But in fact there are two objectives to this topic. The second objective is to introduce you to a tool for exploring and analysing complex processes, and representing what you have learned using a graphical device known as an "Influence Diagram".

The synthesis

The culmination of this lesson should be - if all goes well - the bringing together of these two objectives. This will be done by means of the construction (by you, not me!) of an influence diagram representing the problem of biodiversity loss and the economic policy instruments which might help in mitigating that loss.

Decision Explorer

To this end you may find it useful to download an item of software called "Decision Explorer" from this class web page. Decision Explorer has various facilities, one of which is to allow the user to construct an influence diagram. However, if you have difficulties downloading or installing the software, it is perfectly feasible to use PowerPoint or other such packages to construct an Influence Diagram.

Sources of Information about Influence Diagrams

Here are a couple of web links where you may find out more information about just what an "Influence Diagram" consists of.

- Influence Diagrams (Lumina.com)
- Influence Diagrams (Wikipedia)
- Influence Diagrams (Open University)
- Decision Analysis (a bit more advanced and technical)
- Influence Diagrams (also advanced)

Understanding Biodiversity Loss and Policies to Reduce that Loss

Here are the questions we wish to address here about biodiversity. I have structured these in a logical order, as one might adopt if writing a book or chapter of a book, or a survey paper on this topic. In fact, they are (approximately) the sequence of headings we use in the web pages in this topic:

- What is biodiversity?
- How is it measured?
- What is happening to the extent of biodiversity?
- Biodiversity loss: does it matter?
- Why is biodiversity desirable?
- What are the consequences of its loss
- What are the causes of biodiversity loss?
  - Proximate
  - Underlying
- Policy options available, and difficulties in implementing those options

I have put these into Decision Explorer in a simple list form. Here is a screenshot:
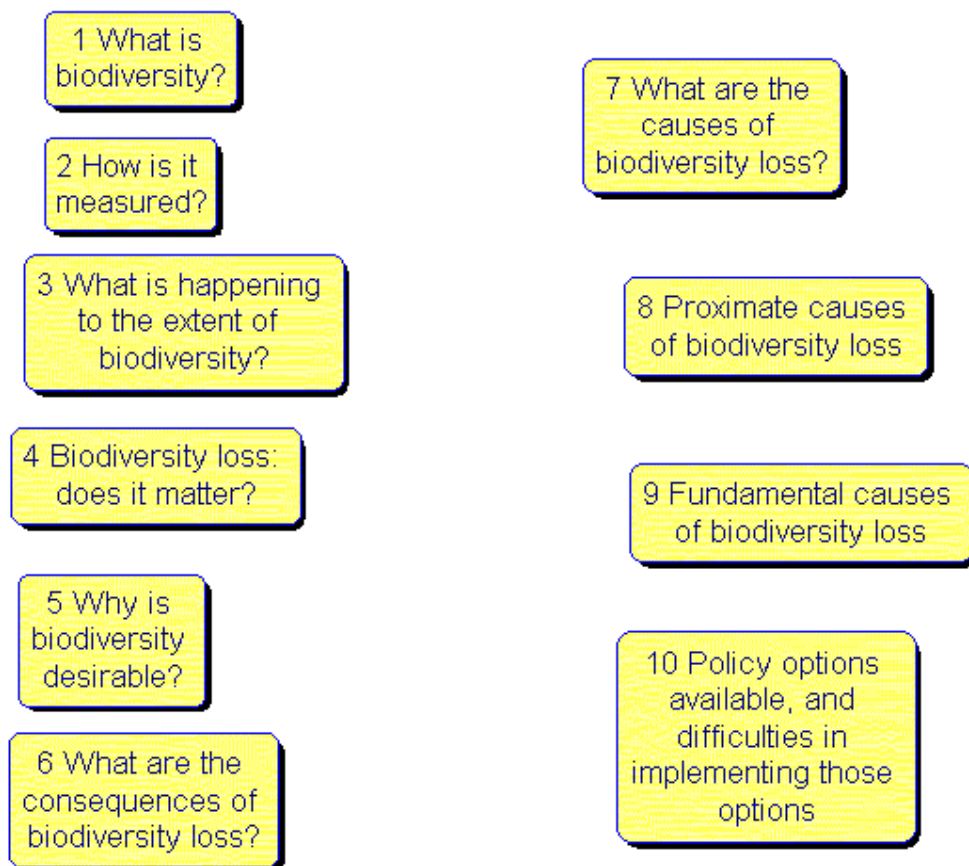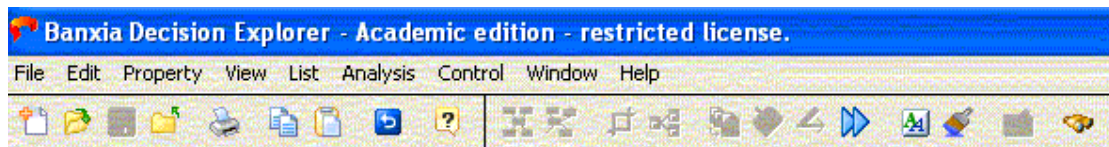
But it is clear than it will be useful to group these questions into three central clusters:

1. Is biodiversity loss a problem?

2. What are the causes of the problem, and are they human induced?

3. What policy actions can reduce the rate of biodiversity loss?

Here is a simple cognitive maps relating to the first of these clusters:

1. Is biodiversity loss a problem?

1 Biodiversity loss is a problem … Biodiversity loss is not a problem

2 BD loss is having significant adverse effects … No significant effects from BD loss

3 If BD loss is happening it causes large adverse effects … BD loss would not cause large adverse impacts

4 Large scale BD loss is happening … There is no large scale BD loss

5 Measurement of Genetic or Species or Ecosystem Diversity … No reliable measurement

7 Criterion of diversity measure agreed … No agreement