3 An inventory of planet Earth

Discovering and defining the richness of life is central to our knowledge of biodiversity. This chapter covers:

- **Defining types of biodiversity**
- **Quantifying biodiversity**
- **Global patterns of biodiversity**
- **The role of ecosystems using the example of wetlands**

Biodiversity strikes a Pavlovian nerve, conjuring up images of rare mammals and rainforests but it embraces much more than these. There are three main components to biodiversity; genetic, organismal and ecological. The **genetic and subcellular diversity** includes all biodiversity expressed within individual cells plus non-cellular organisms such as viruses. The diversity of genetic information is central to this category but the variety of metabolic pathways and molecular biology of life also represent important diversity. **Taxonomic diversity** is dominated by our focus on species. Species are but one level at which organisms can be classified and the diversity of other categories such as families or phyla provides additional insights. **Ecological diversity** includes whole communities, habitats and ecosystems, including domestic stocks. Recent definitions, e.g. UNEP's Global Biodiversity Assessment, have added **cultural biodiversity** as an explicit concept, human social systems intimately dependent on the ecological system within which they exist. This has created some tensions. In 1996 Makah Indians attended the International Whaling Committee meeting to request permission to hunt five Grey Whales a year, after a 70-year gap, to help maintain their cultural system. Their request was seized upon by Norway, keen to reopen commercial whaling. Small Norwegian coastal towns that would benefit from commercial whaling were compared to the Makah Indians. **Interaction biodiversity** has also been coined to embrace

Table 3.1 ***Recent categories and definitions of biodiversity***

Author	*Genetic and subcellular*	*Taxonomic*	*Ecological*
Eldredge (1992)	Genealogical	Phenotypic	Ecological
Groombridge (1992)	Genetic diversity	Species diversity	Ecosystem
HMSO (1994)	Genetic variation	Diversity of species	Diversity between and within ecosystems
Hawksworth and Harper (1995)	Genetic	Organismal	Ecological
Heywood (1995)	Genetic	Organismal	Ecological

the interactions between species as a fundamentally important factor in natural systems. The very success of the term biodiversity, its rise to prominence and increasing breadth of topics have fuelled some dissension, with scientists accused of pushing the term as a technological, even mythic concept, because of its allure for research funding. (See Table 3.1).

Types of biodiversity

Genetic and subcellular

Genetic, molecular and metabolic diversity are often overlooked. They represent the founding diversity of life, not just as it is today but echoes of the ancient past and potential futures. All three generate diversity within and between species and ecosystems.

Genetic diversity provides the core differences that divide life into its major types, especially important when visible structures and shape provide no reliable guide. This genetic diversity is witness to the deepest divisions of life but also some shared characteristics, stretching across huge taxonomic distances. Such genetic characteristics speak of the relatedness of all life forms one to another. Genetic diversity is the ultimate divisor and link. Genetic and metabolic diversity are especially important to understanding time, evolution and taxonomic characteristics of life. Genetic material is the raw material from which future biodiversity will be spawned.

Genetic diversity is made up of **genes**. A gene controls the expression and development of a particular feature of a living organism. The precise form of the character will vary (e.g. hair or eye colour in humans) and each of the variations of the gene is called an **allele**. So a gene in an organism will be one allele from a larger set. Genes are built of **deoxyribonucleic acid (DNA)**, a linear molecule built like a ladder and twisted into the famous double helix. The rungs of the ladder consist of molecules called **nucleotide bases**, two joined to make each rung. There are four different bases, cytosine, guanine, thymine and adenine, which pair up to build the rungs as base pairs. Cytosine pairs with guanine, adenine with thymine. Each set of three base pairs makes up a triplet and each triplet is the code sequence for an amino acid. There are 64 permutations in which three consecutive base pairs can occur, more than enough to code for the 20 amino acids common to all organisms. So the diversity of the genetic code is a hierarchy starting with the sequence of individual rungs then triplets, the order and length of sets of triplets, the resulting alleles and quantity of genetic material in different organisms. In addition to the active genes there is extra DNA apparently doing nothing.

The result is that genetic diversity even within a single species is so vast that the information is much larger than the total number of individuals. The measurement of genetic diversity is a rapidly improving area. Box 6 outlines methods and measures.

Box 6

Genetic biodiversity: Methods and measures

Methods

- **Protein electrophoresis** Widely used since the 1960s, this technique analyses the different proteins which in turn reflect the different alleles in an individual.
- **Restriction site mapping** A recent advance relying on very specific bacterial enzymes that restrict viral damage to DNA by cutting out damage at specific points. Analysis of these cut points, called restriction sites, allows very precise analysis of gene sequences.
- **DNA and RNA sequencing** Another new approach allowing analysis of all DNA. A frequent alternative is ribonucleic acid (RNA) found in ribosomes (rRNA). Ribosomes are cell organelles that read genetic data and manufacture proteins based on these instructions. 16s rRNA (the name refers to the number of subunits in the RNA and that it is ribosomal) has been particularly important.

Measures

- **Percent polymorphic loci, P** A locus is the position of a gene on the genome. A gene where the frequency of the most common allele is <95 per cent of the total is regarded as polymorphic.
- **Number of alleles, N** This measures not only if a gene is polymorphic but also the number of alleles per gene.
- **Heterozygocity, H** Frequency of alleles, how many there are and the frequency of each, e.g. there may be three alleles, one occurring 85 per cent of the time, a second 10 per cent, a third 5 per cent.
- **Number of segregating sites, S** Restriction site positions can vary in a gene. This detail can be added to the first three items.
- **Allele tree** An attempt to construct evolutionary relationships, providing a sense of relatedness and uniqueness. In much the same way as a rare species can be picked out from among its more common kin, allele trees try to pick out the genetically unusual.

The metabolic diversity of life, particularly among bacteria, is commonly overlooked, but represents a fundamental and ancient diversification (see Box 7). The metabolic abilities of bacteria can be directly useful to humans, e.g. fermentation, or indirectly as part of wider geochemical cycles that are ecosystems services maintaining the health of the environment. Metabolic diversity can be divided between utilisation of different energy sources, energy release (respiration) and nitrogen fixation.

Taxonomic diversity

The number of species alive on Earth today is often thought of as synonymous with the term biodiversity. Work at the species level has practical advantages. Funding bodies (often the general public) recognise species. Conserving a species is a simpler concept than conserving a species' gene pool. Species projects are often easier to organise than conserving whole habitats. However, the species is but one category in a hierarchy of classification. Other categories are important measures of biodiversity, sometimes providing different contradictory messages to species level analyses.

Box 7

Microbial metabolic diversity

Tapping environmental energy sources

Energy from inorganic chemistry (chemoautotrophy)

- Sulphur bacteria. Oxidise sulphur compounds, e.g. hydrogen sulphide, to release energy used to build carbon-based food.
- Iron bacteria. Oxidise iron compounds, e.g. iron ore, to release energy used to build carbon-based food.
- Nitrifying bacteria. Oxidise ammonia to release energy used to build carbon-based food. Nitrite and nitrate byproducts are a valuable input of nitrogenous plant nutrients.
- Hydrogen bacteria. Oxidise hydrogen to release energy used to build carbon-based food.

Trap light energy (photoautotrophy or photosynthesis)

- Athiorhodacea. Split organic matter as hydrogen ion donor.
- Purple and green sulphur bacteria. Split hydrogen sulphide as hydrogen ion donor. Waste product is sulphur dioxide.
- Advanced photosynthesis. Split water as hydrogen ion donor. Waste product is oxygen.

Note that many bacteria can trap energy by photosynthesis and by oxidation of inorganic molecules. The ability to use either method is called mixotrophy.

Metabolic energy release

Anaerobic

- Fermentation. Partial breakdown of carbon compounds.
- Anaerobic photosynthesis. Organic matter broken down as hydrogen donor for photosynthesis generates energy.
- Nitrate reducers. Split oxygen off nitrate and nitrate. Nitrogen gas produced.
- Carbonate reducers. Split oxygen off common carbonate compounds, e.g. calcium carbonate. Waste product, methane, has a possible role as a greenhouse gas.
- Sulphate reducers. Split oxygen from sulphate. Create rotten egg, hydrogen sulphide smell of fetid wetlands.
- Iron reducers. Alter chemical bonds of iron compounds resulting in energy release analogous to oxygen splitting of other anaerobic systems but without oxygen.

Aerobic

Oxidation of organic matter. Primary energy release systems for protistan, fungal, plant and animal kingdoms.

Nitrogen fixation

Bacteria extract atmospheric nitrogen gas and make it available to nitrogen cycle. Major source of nitrogen input into ecosystems.

Systematics is the branch of biological science responsible for recognising, describing, classifying and naming organisms. Part of this work involves a **taxonomic** (taxa = category, nomic = name) hierarchy, including species and other levels at which organisms can be described. Linked to this are taxonomic nomenclatures (naming systems) which provide internationally agreed rules on how species are to be named. International Codes exist for animals, plants and bacteria, plus a provisional system for viruses. The taxonomic classifications also portray our understanding of the evolution and relatedness of life, the **phylogenetic classification.** Humans have a natural tendency to classify things, biodiversity being no exception. Classification depends upon what we can observe and what we think it means (often influenced by social, political and religious attitudes). Taxonomic classifications of life have varied throughout time. Box 8 outlines the development of schemes in Europe.

Box 8

Classifications of life through European history

Classifications of life have changed over time, but even ancient systems can show precise methodologies and criteria. Changes reflect use of increasingly small-scale, internal features (internal organs, internal cell organelles, internal organelle RNA).

Greek Aristotle, in *Historia Animalium*, 486 BC, classified animals by clearly stated criteria for grouping animals together; (1) 'With regard to animals there are those which have all their parts identical . . . specifically identical in form'; (2) 'When other parts are the same but differ from one another by more or less, then they belong to animals of the same genos. By genos I mean for example bird or fish'; (3) 'There also exist animals whose parts are neither the same by form but by analogy'.

Linneaus The famed Swedish biologist tried a global classification of animals using multiple criteria. Life forms must be distinguished by external criteria, e.g. skin, locomotion. Each life form should have roughly equal roles in the economy of nature. Within each life form criteria used for subgroups should be essential for finding or processing food, e.g. teeth for mammals, beak for birds. Linneaus' work resulted in classifications of plants based primarily on reproduction mechanisms and of animals based on feeding.

Cuvier Through the late eighteenth and early nineteenth century Cuvier pioneered comparative anatomy, especially the internal resemblance of animals, as a means of classification. Cuvier saw some characteristics as fundamentally more definitive than others, notably the nervous systems, though practicalities favoured use of bones. Cuvier broke the vision of animal life as a ladder of progression, splitting animals into four lineages (vertebrates, molluscs, articulates, e.g. insects, and radiates) based on form and function. This split is still echoed in current classification of animal lineages.

Whittaker's five kingdoms By the mid-twentieth century advances in cell biology led to a revision of life into five main kingdoms, defined primarily by subcellular features, e.g. cell walls, links between cells, organelles and mechanisms of cell division. The five kingdom system (Monera, Protista, Fungi, Plantae, Animalia) is still widely used. (See Figure 3.1.)

16R rRNA By 1990 analyses of DNA and RNA, particularly work on 16s rRNA sequences suggested a fundamental revision of the five kingdoms. Shared and different 16s rRNA sequences suggested life divided into two main branches, the Bacteria on one hand and a second branch itself split between the Archaea (previously thought of as close allies of the Bacteria) and the Eucarya (everything else).

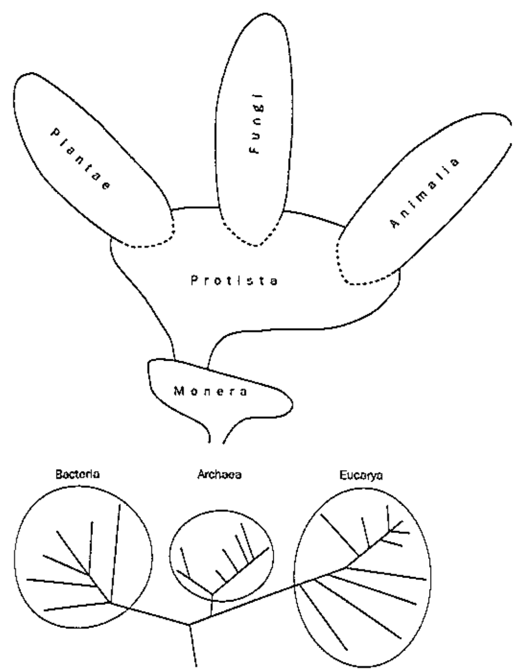

Figure 3.1 ***Whittaker's five kingdoms of life and recent three domain revision based on RNA. The Bacteria and Archaea domains were both part of Whittaker's Monera, while the new Eucarya domain encompasses what were the Protista, Fungi, Animalia and Plantae Kingdoms***

Source: Redrawn from Heywood 1995.

Recently systematics and taxonomy have not been popular fields with biologists or funding bodies but burgeoning biodiversity studies have focused attention on our woefully incomplete catalogue of life. 'You don't know what you've got 'til it's gone', the 1960s environmental protest song lamented. We now realise that you don't even know then. An urgent task in biodiversity research is to rebuild skills in systematics. Table 3.2 gives the typical classification hierarchy, from species up to the fundamental divisions of life into kingdoms or domains. Note that there is marked variation in diversity even at very high levels of classification. Recognised numbers of phlya in the five kingdom classification of life are: Prokaryte 16; Protista 27 (at least); Fungi 5; Animalia 32; and Plantae 9.

Defining species

The **species** remains the focus of most biodiversity research but there is no precise simple universal definition of what a species is. Some alleged species fit all criteria of all definitions, others are hard to fit to any.

The word species literally means outward or visible form. Classifications up to the twentieth century relied on the physical, often outward, similarity of features to distinguish a species. The use of visible characters to define a species is the **morphological species concept.** This approach is widely used with collections of dead specimens or fossils which can provide no other information on breeding and ecology. Species with varied individuals, e.g. camouflaged, mimics or variable growth forms, risk being split into several species.

Insights from evolution and genetics prompted the **biological** (or **isolation**) **species concept.** A species consists of populations of interbreeding individuals, able to reproduce successfully with other populations. Central to this definition is the idea of reproductive isolation, be it a physical barrier or behavioural, physiological or genetic inability to mate and produce fertile young. The isolating mechanisms can be pre- or post-mating. Pre-mating includes separate habitat, time, behavioural and physiological mismatch, mechanical inability to mate and gamete inability to

Table 3.2 ***The taxonomic hierarchy. Each level in the hierarchy is a category at which fundamental features are shared. Each category will consist of one or more of the next category down (e.g. a genus consists of one or more species). Sometimes subcategories are used (e.g. subclass, suborder). Recent analysis of genetic biodiversity has caused a rethink of what had seemed the ultimate, kingdom-level divides, a salutary lesson***

Taxonomic hierarchy	*Human beings*	*Mount Kupe Bush Shrike (Chapter 4)*	*African Elephant (Chapter 4)*
Kingdom or Domain	Kingdom Animalia. Domain Eucarya	Kingdom Animalia. Domain Eucarya	Kingdom Animalia. Domain Eucarya
Phylum or Division	Chordata	Chordata	Chordata
Class	Mammalia	Aves	Mammalia
Order	Primates	Passeriformes	Probosidea
Family	Hominidae	Corvidae	Elephantidae
Genus	*Homo*	*Telophorus*	*Loxodonta*
Species	*sapiens*	*Telophorus kupeensis*	*africana*

fertilise. Post-mating includes hybrid inviability (embryos or young die), hybrid sterility (young are born but cannot reproduce) and hybrid breakdown (young mature and breed but their offspring are less viable). This definition does not work with asexual species. A surprising number of recognised species living side by side appear to mate and exchange genetic material without the species involved coalescing into an indistinguishable mélange. Many plants show interbreeding. Tests of the American Buffalo genome have revealed domestic cattle genes but no morphological blur. Species defined by breeding are also difficult for systematists. Not only are the breeding abilities of fossils impossible to fathom but over evolutionary time species change, so much so that they might be morphologically distinct but at every step interbreeding between immediate parent–offspring generations was possible. The morphologically distinct ancestor and descendent species are linked by a seamless reproductive thread.

Refinements to the biological species concept include: the **recognition species concept**, emphasising not the barriers to reproduction but shared characteristics permitting reproduction; the **cohesion concept**, a species defined by cohesive mechanisms that prevent interbreeding with other species and evolutionary diversification within the species; and the **ecological concept**, species defined by occupation of a niche unique compared to other species in its range and evolving separately from populations beyond its range. All remain flawed by hybridisation and problems of practical measurement.

A third approach is the **evolutionary species concept**. This emphasises the **phylogenetic concept** with species defined as the smallest population (sexual) or lineage (asexual) diagnostically distinct from other such populations and with a discrete lineage. The diagnostic characters are often genetic. When applied to species recognised by morphological or biological concept criteria, the sheer genetic diversity within species often suggests they should be splintered into many separate lineages. The evolutionary concept defines a species by a single distinct lineage with an identifiable evolutionary history and fate.

Ecological diversity

Taxonomic diversity classifies types of organisms and their relatedness but organisms do not live in isolation from one another or the physical world. Humans have long recognised different ecosystems of apparently interdependent life. Ecological science focuses on these patterns and processes, hence ecological diversity as the inclusive term for this third category.

Ecological diversity covers a host of concepts: ecosystems, communities, assemblages, habitats, biomes and biogeographical regions. These are not one and the same, indeed some may not be biodiversity proper. The term **ecosystem** embraces the living organisms and non-living (abiotic) features such as climate and geology of a site. Some have argued that the inclusion of abiotic components excludes ecosystems from biodiversity. A **community** refers to organisms living together, essentially the live component of an ecosystem. Again this deceptively simple idea is problematic. The term implies a linkage, an interdependence of species that may not exist. Even tightly linked communities will harbour fleeting tourist species, moving through without necessarily playing any role while other communities may be very loosely tied assortments, often described as an **assemblage**. Habitat conjures up precise images, e.g. Giant Panda habitat, but the term may not mean anything if the species is not present. Does Giant Panda habitat cease to exist should the Giant Panda become extinct? **Biome** is the term associated with global or continental scale, regional ecosystems defined by vegetation and fauna, in its turn largely determined by climate. A **formation** is a similar concept, relying solely on vegetation data. Even colloquially familiar biome terms such as rainforest or wetland become difficult to define precisely due to global variations or to give sharp boundaries where they grade into each other.

Ecological biodiversity also includes geographical foci such as high diversity hot spots, continental and oceanic islands, plus regions of endemism. If ecological diversity (whether ecosystem, community or any other tricky concept) was nothing more than the sum of its parts (e.g. the species list) this category of biodiversity could be largely ignored, but ecological diversity has its own importance. Ecological patterns emerge at the ecosystem and community level which are more than the sum of the parts of the species present. Ecosystems can (albeit rather mechanically) be said to provide ecosystem services (or functions) such as nutrient and gas cycling. An ecosystem that loses a species may not be merely minus one species but may function in a very different way with knock-on consequences to other ecosystems and perhaps globally. So the ecological category of diversity is important.

Classifications of ecological diversity vary with scale, just like the genetic (nucleotide molecules up to differences between populations) and taxonomic (subspecies to domains). Three main scales are commonly used for ecosystems:

global, regional and national. Global classifications rely on major vegetation types (biomes) typically defined by combinations of dominant vegetation, landscape and climate, sometimes plus biogeographical position. Regional classifications are often based on practical definitions. National classifications work at a finer scale, often based on precise species presence and abundance. Classifications of wetlands global, regional or national, are good examples of ecosystem categorisation, the difficulties of definition and how resulting classifications can vary with the purpose of the systems used.

Wetland classification

Global classifications

At the gross global level wetland habitats are subsumed within the broader biomes. A widely cited definition of wetlands is from the RAMSAR convention (the treaty is outlined in Chapter 5):

> Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary with water that is static, flowing, fresh, brackish or slat, including areas of marine water the depth of which at low tide does not exceed six metres.

Wetlands are characterised by the presence of water at the surface or in the root zone, unique soil conditions and hydrophyte (water loving) plants. Distinguishing different types of wetlands is problematic. The duration and depth of inundation vary. Wetlands are often marginal habitats between truly aquatic and terrestrial systems. Size can vary from small ponds to huge regional expanses. Definitions also vary according to the aim of the classification scheme and cultural traditions, e.g. in the USA swamp means forested, in Europe typically not so. At a global scale nine main wetland types are commonly distinguished using general biome and landscape characters.

1. **Bogs**. Acidic, peat-building wetlands with water and nutrient input from precipitation. Typically in wet, cool climates and characterised by *Sphagnum* mosses.
2. **Fens**. Peat-building but with nutrients and hydrology influenced by surrounding landscape and geology, neutralising acidity. (Note that bogs and fens are often combined together as **mires**, a generic term for peat-based wetlands).
3. **Swamps**. So waterlogged that water usually covers surface and dominated by a few species, e.g. reeds or characteristic trees, e.g. swamp cypress.
4. **Marsh**. Inundation often seasonal. Diverse herbaceous vegetation with little or no peat accumulation.
5. **Floodplains**. Periodic overspill from lakes and rivers. Very varied.
6. **Shallow lakes**. Open water up to a few metres deep.
7. **Salt marsh**. Tidal herbaceous coastal sward of temperate latitudes.

8. **Mangroves**. Tidal coastal woodlands between 32°N and 30°S, characterised by mangrove trees. Exclude saltmarsh from tropics by competition but limited to tropics by climate.
9. **Anthropogenic**. Wetlands created by humans, e.g. paddies.

National classifications of wetlands

At a national level much more detailed classifications can be devised, often differing depending on the purpose for which they are used. In the USA there are over 50 wetland classification systems in use for water regulation, recreation and wildlife conservation. Here is an example from the UK based on detailed botanical classification.

Classification by species and floristic composition: the National Vegetation Classification (NVC)

The NVC is a systematic and comprehensive classification of UK plant communities. Vegetation types have been distinguished by computer analysis of the presence and absence of individual species and their relative abundance. The classifications for four habitat types (woodland, mires, grassland and aquatic) are available. All four contain communities identified as wetland, 100 in all with coastal ecosystems still to be added. Each community type is described in detail, listing plant species, abundance, physical and chemical conditions in the habitat and distribution. Each type is given its own code and name, derived from the diagnostic vegetation, e.g. S9 *Carex rostrata* swamp is the ninth recognised swamp community from the aquatic habitats, characterised by the bottle sedge, *Carex rostrata*.

- Woodland. Seven wet woodland communities.
- Mires (bogs, wet heaths and fens). 38 wetland communities.
- Grassland. Three inundation communities.
- Aquatic. 24 submerged and 28 swamp/tall herb fen communities.

Regional classification of wetlands

The SADCC Wetlands Programme is a wetlands inventory for southern Africa. In 1991 the SADCC Wetlands Conservation Conference for southern Africa, meeting in Gabarone, capitol of Botswana, set up a programme intended to produce a comprehensive inventory for the ten countries of Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe. The driving force was increasing recognition of the value of wetland ecosystem biodiversity. Wetlands have the highest biological productivity compared to equal areas of other ecosystems in the region. They offered multiple uses and harboured the greatest taxonomic biodiversity. The programme collects baseline data on wetland area, distribution seasonality, characteristics and value at a national level. The national scale is important to draw up reasonably clear boundaries and to detect small and unusual combination wetlands.

Sources of data included large-scale satellite remote sensing, aerial photographs, maps and vegetation surveys, as well as the collation of existing reports on individual wetlands. Highly detailed botanical surveys are lacking or insufficient to create classifications as detailed as the UK's National Vegetation Classification but this is not a serious problem given the purpose of the SADCC inventory. The inventory work also produced practical benefits, improving co-operation across political borders that cut through wetlands and between different interest groups, e.g. farmers, foresters and conservationists. The final aim is threefold: to quantify the extent, types and uses of wetlands; to quantify the rate and extent of alteration and loss; and to disseminate the information to managers and users of these precious ecosystems. Wetland classifications in Zimbabwe reflect the different ecosystems and human concerns.

Zimbabwe's wetlands ocupy about 3.3 per cent of the country. No systematic classification exists as yet but the broad categories are: swamps, permanently inundated; floodplains and flats, seasonally inundated; dams, manmade, small impoundments important for irrigation; pans, seasonal waterholes sometimes supplied by pumped water for cattle or wildlife tourism; dambos, small wetlands widely used for horticulture and lakes. Zimbabwe is landlocked and has no coastal ecosystems.

Domestic biodiversity

Biodiversity is widely thought of as an entirely natural phenomenon but definitions now recognise the importance of domesticated species, ecosystems forged from human activity and some cultures intimately tied to their environment. Biodiversity plays a role in the ethical, religious and social values of societies. Differences between cultures affect our valuation of biodiversity, in turn affecting conservation. The fate of biodiversity in different cultures may provide important insights since humans are now the dominant influence on remaining species and ecosystems. Several indigenous cultures are (or were) founded on an ecological intimacy with biodiversity. The native plains Indians of North America relied on the buffalo herds not only as food but as an icon central to their beliefs and customs. The Marsh Arabs of Iraq have a social and agricultural system dependent on their wetland home.

Domestic biodiversity is a tiny fraction of the whole but provides 90 per cent of human food supplies. Domestic stocks include life from all kingdoms. In addition landscapes created by humans, whether farmland, forests, gardens and urban landscapes, are new ecosystems. The extent of human interference with domestic biodiversity varies. Truly domestic species have been subject to marked artificial selection, so that many characteristics will be markedly different to wild ancestors, e.g. cattle, sheep and pigs. Domesticated species (exploited captives) retain many similarities to wild brethren, e.g. reindeer, yak, camels. Feral populations are domesticates that have reverted to living wild. They can create problems, e.g. feral cat predation of native marsupials in Australia, but are unique additions to wildlife.

Domestication leads to a proliferation of forms, **cultivars** in plants and **breeds** in animals, which can be defined by heritable, distinct and uniform characteristics different to other such groups. Plant domestication spans five categories, first the wild ancestor stock. Weedy relatives often flourish in marginal habitats impacted by humans, a genetic bridge between wild relatives and the truly domestic. Primitive cultivars are genetically diverse stock still open to natural selection. Modern cultivars are the result of purely artificial selection of supermarket qualities. Advanced breeding lines are the recent additions, their genomes created by laboratory manipulation, perhaps including genetic diversity impossible through natural processes.

Numbers of domesticated species are small. Of the 320,000 vascular plants, 500 are domesticated and 15–20 are major crop species. The 50,000 vertebrates (excluding fish) have provided 30–40 domesticates, plus 60 semi-domesticated. Another 200 fish and invertebrates are commonly used in aquaculture and four insects (honey bee, various silkworm caterpillars and the cochineal bug). Fungi and microbes are grown commercially for food, brewing and biotechnological uses, e.g. pharmaceuticals. The lack of species is made up for by breeds. Estimates of total numbers of breeds vary, e.g. cattle 780–1090, sheep 860–1200, pigs 260–480 (if we cannot keep track of domestic diversity is it any wonder that numbers of wild species are so difficult to estimate). The core domestic farm mammals (cow, buffalo, horse, ass, pig and sheep) comprise 3,237 breeds of which 474 are rare and an additional 617 have gone extinct since the end of the nineteenth century.

The variety of breeds is a resource. Many have adaptations to local conditions. These adaptations can be exported to new ranges either by moving the animals or controlled breeding. The known traits of breeds allows easier control of artificial selection and discovery of new mutations. The variety is also insurance against the unforeseen and is being eroded by the globalisation and intensification of agriculture. Losses are biased towards the developed world which may have nurtured more breeds and recorded extinctions. Table 3.3 gives global, regional (Africa and Europe) and national (Zimbabwe and UK) cattle and sheep breed diversity and losses.

Table 3.3 ***Surviving and extinct cattle and sheep breeds. Numbers given for global, European, African, UK and Zimbabwean records***

	Global	*Europe*	*Africa*	*UK*	*Zimbabwe*
Cattle					
Extant total	732	209	168	42	4
Extant rare	141	154	10	16	0
Lost	224	101	22	5	3
Sheep					
Extant total	917	356	131	73	3
Extant rare	135	109	1	17	0
Lost	146	97	4	8	0

Source: Groombridge 1992 and Heywood 1995.

The inventory of domestic diversity also includes more ominous items. Manipulations of genes in some animals and plants have created hybrids which would probably be impossible through natural selection. Incorporation of genes from one species into another is now commonplace, creating **transgenic species**. Transgenic sheep, pigs, cattle, horses and rodents have been created containing genes to enhance obvious features, e.g. mouse genes controlling fur structure in sheep enhance fleece productivity. Human genes have also been incorporated into some animal species to produce medical products, e.g. growth hormones. Genes can even be combined between kingdoms with bacterial genes incorporated into some mammals. Such advances now include the ability to coalesce species, most famously the recent goat/sheep hybrid, an example of a **chimera species.**

Disease eradication programmes have also created a dilemma for conservation. One virus, smallpox, once a deadly killer was declared extinct in the wild by 1980. Two stocks remain in laboratories, one in the USA one in Russia. In 1995 the World Health Organisation (WHO) voted not to destroy these stocks. Had the destruction been authorised this would have been the first ever intentional extinction of a species. In 1996 the WHO recommended destruction in June 1999 following a three-year search to check for forgotten or hidden stocks, nervous of illegal stockpiles kept for biological warfare. Instead the intrinsic value of the virus as well as possible future need for research in the event of the rediscovery of a wild stock or near relative brought a reprieve.

Chimeras and deadly viruses are biodiversity's stranger corner but our attitudes to nature have always been coloured by the culture of the day. One Anglo-Saxon bishop issued a letter to his parishes scolding the populace over their fear of werewolves which were, after all, a common feature of the countryside.

Measuring biodiversity

Quantifying the variety and richness of life on Earth is central to studies of biodiversity. This following section provides estimates of taxonomic and ecosystem diversity. But be warned. The numerical data are our best guesses, not definitive answers. For example, Table 3.3 of surviving cattle and sheep breeds disguises serious differences between estimates. If we cannot be sure about numbers of animals that we control, estimating numbers of wild species is even more difficult.

The numbers of known species

Inventories of the diversity of species on Earth today can use known species and estimates of likely numbers (including likely maxima and minima). The numbers known and reliability of estimates vary greatly with taxa. Birds and mammals are well documented, though there are still some surprises, e.g. the Udzungwa partridge, *Xenoperdix udzungwensis*, a bird species first identified in 1991, in a dinner (Box 9).

Numbers of many invertebrates and micro-organisms remain darkly mysterious. Estimates of the rate at which new species are discovered can provide some insight into these voids. Table 3.4 gives estimates of known species, showing how these have changed through time.

Box 9

A new species of bird, the Udzungwa partridge

Our knowledge of bird species is unusually complete but new species can be found. In 1991 two Danish zoologists were exploring Udzunga Mountain, part of the endemic rich Eastern Arc Mountains of Tanzania. One night at supper the expedition cooks produced 'chicken stew'. At the bottom of the pot were the two legs of a bird, not exactly a chicken (African chicken stew is often not exactly chicken) but which the zoologists thought must be one of the chickenlike Francolins. Keeping an eye out for Francolins, not previously known in the area, subsequent sightings of the bird did not match anything in the published literature.

During a return visit in search of the mystery bird local guides snared a male and a female. Comparison of the specimens to museum skin collections revealed that the bird was a new species, related to species from South East Asia. The Udzungwa forest partridge was not merely a new species of bird, but a relict species from 15 million years ago when forests spanned Africa to Asia. The Udzungwa partridge is a classic relict species, contributing to the diversity of this hot spot. (See Figure 3.2.)

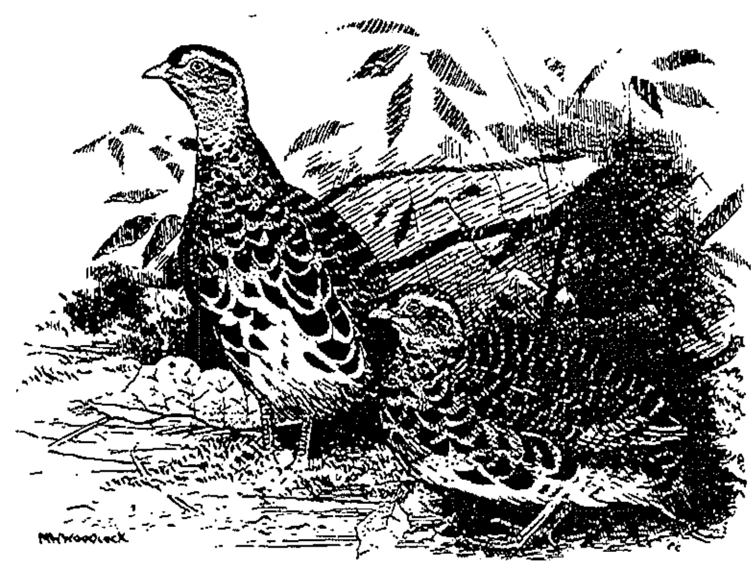

Figure 3.2 ***The Udzungwa partridge***

Source: Reproduced with kind permission from Martin Woodcock and the African Bird Club.

Estimates of global diversity have changed markedly throughout history. It is important to separate these counts of known taxa from estimates of the actual numbers, which use various assumptions to include projections of likely numbers as well as the as yet undescribed.

Table 3.4 *Numbers of described species and estimates of actual numbers for selected taxa, in thousands*

Taxa	*Species described*	*Estimated numbers of species: high*	*Estimated numbers of species: low*	*Working figure*
Viruses	4	1,000	50	400
Bacteria	4	3,000	50	1,000
Fungi	72	2,700	200	1,500
Protozoa and algae	80	1,200	210	600
Plants	270	500	300	320
Nematodes	25	1,000	100	400
Insects	950	100,000	2,000	8,000
Molluscs	70	200	100	200
Chordates	45	55	50	500

Source: Groombridge 1992; Heywood 1995.

The total described inventory for some taxa such as multicellular animals and green plants gives good minimum estimates, but there are problems even with these organisms we have described. For some there is a debate over the numbers of genuine species versus subspecies. In more diverse, typically less well-known taxa, including some of the numerically and ecologically dominant groups such as worms and molluscs (Phyla Annelida and Mollusca respectively), there is confusion because several nominal species (anything that has been described and had a scientific name attached to it) are actually specimens of the same species. Each of the names is merely a synonym for the same thing, perhaps arising because of variable shapes, names given to different stages in the life cycle, earlier names remaining unknown to later taxonomists or confusion due to reclassification. The numbers of known mollusc species varies between 45,000–150,000, with 70,000 a compromise. Extensive tangled synonyms need painstaking revision. Even without these problems the literature of described species is confused and scattered. The apparently simple task of totting up published records gives different totals in different studies. (See Figure 3.3.)

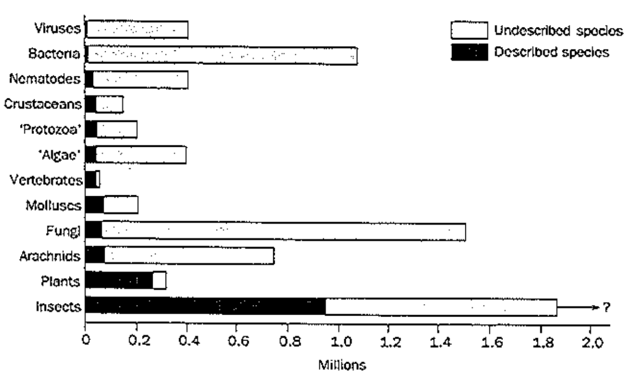

Figure 3.3 ***Estimates of described and likely totals of species for selected taxa***

Source: Redrawn from Heywood 1995.

Species are still being described, even for the best known groups, and description rates provide some sense of the task ahead. Analysis of standard published records of new species between 1979 and 1988 shows remarkable consistency with between 10,912 to 11,599 new species of animal added each year. As a general figure 13,000 new species are described per annum.

Recent estimates range between 1.4 and 1.7 million species. The *Global Biodiversity* review (Groombridge 1992) settles at a figure of 1.7 million described species. UNEP's *Global Biodiversity Assessment* (Heywood 1995) states 1.75 million. But the species we know of are vastly outnumbered by those we do not. Those we do know are a biased sample, typically large attractive taxa (mammals, butterflies), those that are easy to find, in thoroughly studied regions plus pests and parasites associated with any of the above. (See Figure 3.4.) Estimating this likely total is as important and as fraught as totalling up numbers of described species.

Estimating the actual numbers of species

If we cannot agree on the numbers of species we claim to know, the chances of estimating numbers of those we do not know seems rash. However, the actual total of species on Earth today has become something of a Holy Grail in recent years. Many approaches have been used to estimate the actual total of species. Most involve using some data from a taxon, region or ecosystem and scaling up the patterns to global proportions. Each has strengths and weaknesses and usually different answers. The *Global Biodiversity* review (Groombridge 1992) settles for 12.5 million species. (See Figure 3.5.)

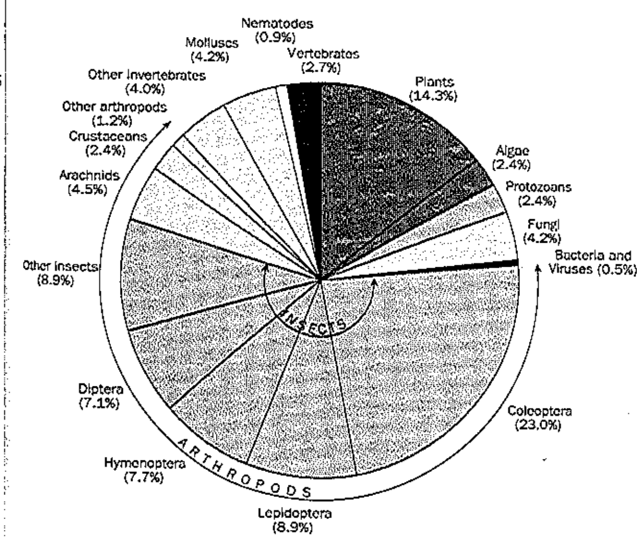

Figure 3.4 ***Proportions of different taxa from described species. The diagram includes taxa likely to contain 100,000+ species plus vertebrates***

Source: Redrawn from Groombridge 1992.

Time series

This technique uses the rates at which new species are being described and extrapolates the trends to look for an asymptote. While we may be reaching an asymptote for a few taxa, e.g. birds and mammals, there have been recent bursts of finds for many invertebrate groups so that time series seem very unreliable. (See Figure 3.6.)

Expert opinion

Specialists with intimate knowledge of particular taxa can be asked to provide their best guess of likely totals and

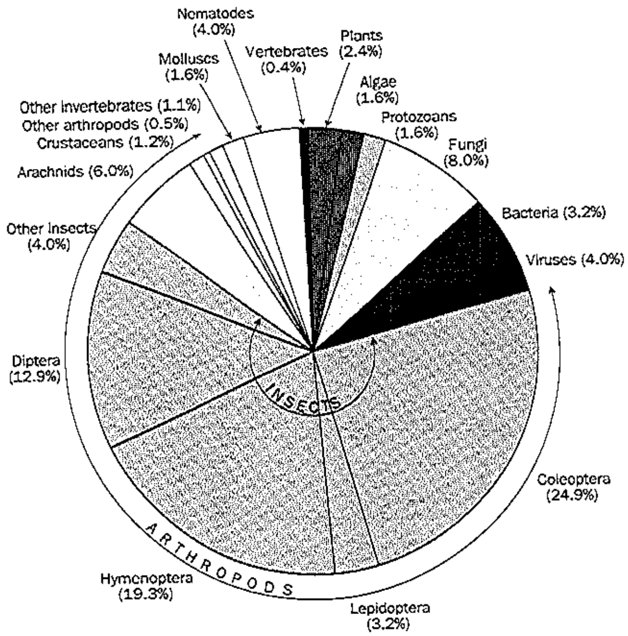

Figure 3.5 ***Proportions of different taxa from conservative estimates of actual total numbers of species. The diagram includes taxa likely to contain 100,000+ species plus vertebrates***

Source: Redrawn from Groombridge 1992.

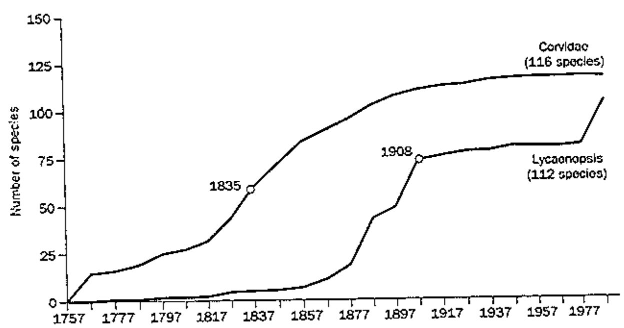

Figure 3.6 ***Numbers of described*** **Corvidae** ***(crows) and*** **Lycaenopsis** ***(part of the blue butterfly family). The dates highlighted indicate points at which half the species known in 1987 were recorded. Note the limited recent additions to Crow list but bursts of additions, some recent, to the butterflies***

Source: Redrawn from Groombridge 1992.

the results summed. Expert opinion has varied greatly over time with estimates being revised ever upward. In the seventeenth century John Ray thought there were betwen 10,000 to 20,000 species while Hutchinson (1959) put the figure at one million.

Empirical relationships

There is a host of ecological patterns, often described in detail for individual communities, that can be scaled up from the original local data to global proportions (Box 10). These include the ratios of species number:body size; species:area; and species:population abundance; plus patterns derived from food webs and plant–herbivore associations. (See Figure 3.7.)

Taxon to taxon, region to region ratios

Such techniques rely on possession of good data for the numbers of taxa (both well-known and more obscure groups) in a particular region. The ratio of species of a well-known taxa (e.g. butterflies) to total taxa (e.g. all other insects) for the reliably surveyed region can then be used to estimate total numbers by

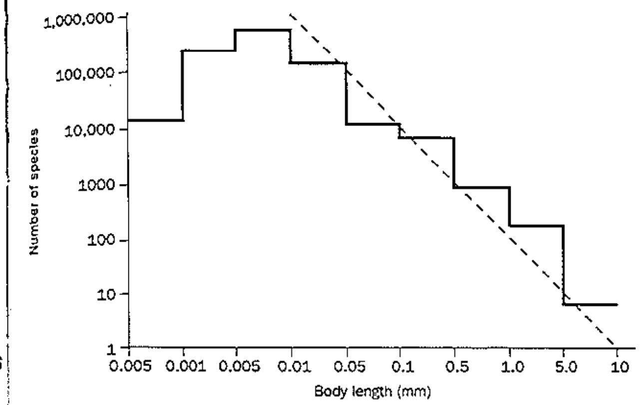

Figure 3.7 ***May's 'crude estimate' of the abundance of terrestrial animals of different body sizes. The dashed line is a similar model for the relationship based on the work of Hutchinson and MacArthur. Patterns such as these can be used as the basis for estimating total species diversity, extrapolating from what is known to include poorly described taxa***

Source: Redrawn from May (1986) *Ecology*, 67.

counting the numbers of the same well-known taxa in comparatively poorly surveyed regions, assuming the same ratio of well-known taxon species to all other species holds true and multiplying up to get an estimate of the total. A classic example has been the use of butterfly to insect ratios from the UK.

The UK's insect fauna is unusually well recorded, so the data are reliable. There are 67 species of extant butterfly to about 22,000 insect species in total, a ratio of 1:328.4. Globally there are some 17,500 species of butterflies. Assuming the UK butterfly:total insect ratio holds globally this gives an estimate for insect species numbers of 5.75 million (see Box 10).

Box 10

Erwin's famous 30 million species

In 1982 entomologist Terry Erwin published a famed minimum estimate of species numbers, an astonishing 30 million. Erwin's estimate was based on a study of the insect fauna found on *Luehea seemannii*, a canopy tree, in Panama. He used insecticide fog sprayed into the tree to knock down insects. He caught some 1,200 species of beetle, of which 162 were specific to the *L. seemannii* tree. He then used a series of assumptions to reach a global estimate of tropical forest insect species richness. First, that there are 50,000 tropical forest tree species and that each would harbour 162 specialist beetle species, i.e. 8,000,000 beetles. Next, that canopy beetles represented 40 per cent of canopy arthropods so total canopy arthropods = 20,000,000. Finally, that there were twice as many canopy species as ground species, so add another 1,000,000 to reach the final 30,000,000. Erwin's assumptions are rightfully open to criticism but the very magnitude of the estimate was enough to prompt resurgent interest in the inventory of life on Earth.

Problems with estimation techniques

- Scaling up Many of the methods used rely on taking detailed data from a local, thoroughly documented site and scaling up to global proportions. Very many ecological patterns and processes are scale dependent. The patterns shown in local studies might not scale up globally in a reliable way. Patterns and processes could be diminished or exaggerated.

- Comparing taxa These gross estimates commonly lump taxa together. Yet this assumes patterns and processes that work well for one taxa may not fit another. Data for ants might not be reliably extrapolated to estimate beetles.
- The fraction of undescribed species Estimates rely on what we already know. Data used as the basis of a model may still be missing many undescribed species. This is a catch 22 situation: to estimate numbers of undescribed species we have to know about the undescribed numbers in the source data we use. (See Box 11.)
- Species definitions The criteria used to define a good species vary with taxa. The minute separations used to distinguish sub and sibling species among the birds are not applied to the desperately underworked micro-organisms. These problems afflict habitats differently. Sub and sibling species separations are poorly drawn in marine studies compared to land.
- The workforce The size, expertise and where in the world the workforce is based all affect estimates.

Box 11

Soil fauna: The other last biotic frontier

Deep sea species diversity has been cited as the last frontier that is largely uncharted. Recent data of soil microarthropods from the soils of a typically harsh but accessible habitat of sand dunes, suggest that soil fauna deserve an equal billing. Samples yielded densities of up to 1,400,000 individuals m^2, compared to previous studies of soil fauna from as low as 3,000 m^2 in Indonesian rainforest, through 110,000 m^2 from Zaïre rainforest litter to 386,000 m^2 from Alpine grassland. The numbers of species was small, only 31, but mostly undescribed. More importantly was the small size of many of the new species, less than 0.2 mm long. Many classic estimates of total species numbers rely on extrapolating known patterns of body size relative to abundance from local studies up to a global scale. The abundance of small-bodied species from this one study of dunes would be enough to increase Robert May's classic 1988 estimate of 10 million terrestrial animal species, based on body sizes down to 0.2 mm, up to 20 million.

The major gaps

The problems of bias among described taxa, estimation techniques and expertise have left major gaps in our knowledge of biodiversity, including particular taxa, habitats and conceptual topics, super diverse groups and reference sites.

Ecosystems

Marine systems

Although marine systems cover the majority of the planet our knowledge is very patchy. While the biodiversity associated with coral reefs has been compared to that of tropical rainforests, other habitats such as the surface waters of open oceans resemble deserts. Recent sampling of deep sea sediments coupled with greater interest in micro-organisms has provided evidence of very high diversity.

Tropical rainforests

Although rainforests appear to support the greatest biodiversity on Earth, research effort is still overshadowed by the sheer size of the task. Particular habitats within the forest have yielded tantalisingly diverse communities, but whether such results can be extrapolated reliably remains unknown.

Taxa

Parasites

Given that most organisms seem to suffer parasitism, it is tempting to imagine parasite diversity as vast as the range of potential hosts. This is especially so in the case of those insects that lay their eggs in or on living hosts (typically other arthropods), the host being killed only once the parasite matures and hatches. Such insects are specifically termed parasitoids, this distinction from other parasites reflecting the almost invariably fatal impact on the host, unlike other parasites. Given that insects make up the overwhelming majority of species, if every species had its own parasitoid (and parasitoids are in turn attacked by their own super-parasitoids), this automatically increases total species massively. However, evidence of parasite and parasitoid biodiversity is sketchy.

Fungi and micro-organisms

Fungi and micro-organisms are the two main under-researched groups. Difficulties of sampling, identification and concepts of species plague work with these two groups. Improving analysis of genetic characters is providing new insights.

Nematodes

Nematodes are a phylum of worms, capitalising on a very uniform body plan but extremely abundant in very many habitats. Problems from lack of expertise and identification have hindered investigation of this phylum but recent evidence hints at high species diversity.

Mites

These are members of the Phylum Arthropoda. Like the nematodes, problems of lack of expertise and identification have held back work but there are suggestions of high species diversity.

Insects

Despite the considerable work devoted to the class Insecta there remain very poorly known groups and habitats.

Conceptual gaps

Super diverse groups

Some taxa have been described as super (hyper, or ultra) diverse (or speciose), reflecting an inordinate variety of species. This accolade suggests that the patterns and underlying processes may be unusually magnified or even different to the typical determinants of diversity. Understanding such differences is important but also difficult and may require separate models to estimate total numbers.

Special species and areas

All diversity is not equal. An individual species, perhaps just one comprising an unusual lineage, might be rated as special, more worthy of protection than another with many related species in a diverse genus. How to measure the phylogenetic isolation and uniqueness of a species is a new field. Some taxa may be very useful indicators of the overall diversity of a site. Their diversity may accurately reflect the variety of other species which cannot be measured for want of time and techniques. Similarly focal taxa are groups combining concepts of the special and representative and could be useful signals of important habitats.

Essential areas and reference sites are also concepts only recently developed. The idea of **Centres of Diversity** has been developed, reflecting the evolutionary heartland (or perhaps last refuge) for a taxon. Linked to this, **complementarity** has been developed as one criterion to assess regional diversity, especially for plants. All the species of a taxon make up the total complement. The single most important site (or country) for this taxon is that with the highest proportion of this complement, the site with the highest proportion of the remaining species, the next most valuable. Conversely Centres of Diversity for birds have concentrated on aggregations of endemic species. Regions of high diversity or endemicity for one taxon are not necessarily so for another. All these ideas, their usefulness and identification are comparatively new, debatable and poorly researched.

Global biodiversity patterns

Taxonomic biodiversity

Global patterns of species diversity are well known for only a few groups. There are marked patterns, in particular concentrations of species within biodiversity hot spots, biogeographical variations between continents and trends such as the increase of species in most taxa towards the tropics. Birds and plants have been studied in detail,

reflecting a bias in expertise and available data, but already producing useful insights for conservation planning.

Bird species number nearly 9,700, the most speciose of terrestrial vertebrates compared to over 4,000 amphibians, 6,550 reptiles and 4,327 mammals. Birds are one of the most thoroughly recorded taxa. Their distribution is unevenly spread across the main biogeographic realms, with 3,083 species in South America, 2,280 in Asia, 1,900 Africa, 950 in the Palaearctic, 900 in Australiasia and 800 in the Nearctic. Within continents the uneven pattern continues. Table 3.5 outlines species, family and endemic diversity from the top five South American countries plus Galapagos islands. (See Figure 3.8.)

Birds have been used as a focus to identify priority areas for conservation, primarily using endemics. Birds are potential good indicators of biodiversity. They are found throughout the world and have diversified in all terrestrial regions and habitats. Their taxonomy and species distributions are well known. There is also evidence for correlation between their diversity and that of other terrestrial vertebrates and vascular plants. The International Council for Bird Preservation has run an extensive global programme to identify Endemic Bird Areas (EBAs). (See Plate 12.) The survey relies on endemics, or more exactly restricted range species breeding over a total range of no more than 50,000 sq. km. Any areas with two or more restricted range species are cited as EBAs. Of birds 2,609 fitted the range criterion, plus 59 known to have gone extinct since 1800. The analyses suggested 221 EBAs, 70 per cent in the tropics, embracing 2,480 species, 77 per cent of known threatened bird species. EBAs are ranked into three categories: Priority I (most important/ threatened) II and III (less important/ threatened). These categories include estimation of biological importance (restricted range species relative to area, taxonomic uniqueness and known significance to other plant and animal taxa) and degree of threat (threat to birds, proportion of area within IUCN recognised protected areas). Table 3.6 gives numbers of EBAs, bird species and numbers in priority categories for the five countries containing the largest number of EBAs. (See Figure 3.9.)

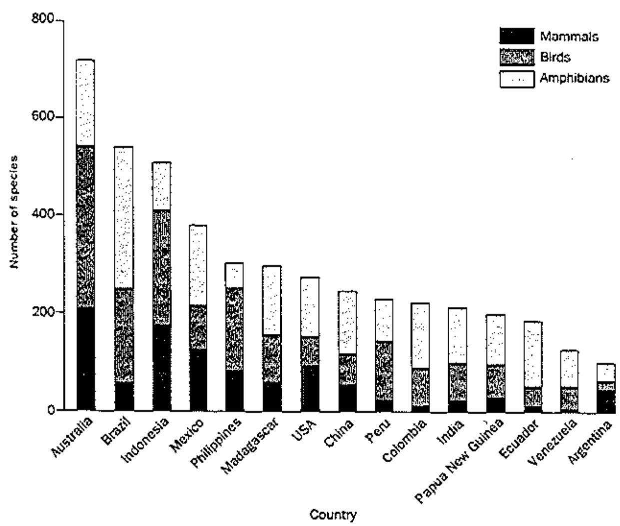

Figure 3.8 ***Top fifteen countries for endemic mammals, birds and amphibia***

Source: Data from Groombridge 1992.

Table 3.5 ***Bird taxonomic diversity of top five South American countries plus Galapagos islands. Note Ecuador's high diversity despite small size and Galapagos' proportion of endemic species***

Country	*Area, km²*	*Species total*	*Endemic species*	*Family total*	*Endemic families*	*Vascular plants, species numbers*
Colombia	1,138,914	1,700+	59	79	20	35,000
Peru	1,285,216	1,700	104	86	23	13,000
Brazil	8,511,965	1,661	179	84	23	55,000
Ecuador	283,561	1,550	12	82	21	16,500–20,000
Venezuela	1,098,581	1,360	41	79	20	15,000–25,000
Galapagos Islands	7,845	136	25	38	0	

Source: Groombridge 1992; Wheatley 1994; Heywood 1995.

All five countries of Table 3.6 harbour tropical rainforest. For comparison Table 3.7 provides details of EBAs for Zimbabwe, Cameroon, Mauritius and UK.

Bird species diversity patterns can now be analysed using extensive DNA databases. Recent evidence suggests that many endemicity hot spots in South America and Africa may be a mix of ancient lineages that have survived and recent (Pliocene/ Pleistocene) radiations of other bird groups. The habitat heterogeneity and disturbance in the hot spots simultaneously allow relict species to cling on in some patches but also act as a spur to radiations in adjacent habitats. These species factories are often found in the zones between major biomes. (See Figure 3.10.)

Plant species diversity is unevenly divided between four main phyla: the Bryophytes (mosses and liverworts) 16,000 species; Pteridophytes (ferns and allies) 10,000–12,000 species; Coniferophytes 700 (Conifers, often called by slightly older name Gymnosperms); Anthophytes, 250,000, perhaps up to 750,000 (flowering plants, often called Angiosperms). Pteridophytes, Coniferophytes and Anthophytes are often separated out from Bryophytes as the vascular plants, defined by possession of effective water transporting tissues. Diversity within the three vascular plant groups is biased towards some families. Anthophyte diversity is dominated by a few families, e.g. Orchidaceae (orchids) with between 25,000–35,000 species, Compositae (thistles, dandelions) 20,000 and legumes (peas) 14,200. The Coniferophytes contain 500 conifers, 100 cycads then some numerically tiny but remarkable species, notably the fossil relict Gingko tree (one species) and the slow-growing, two-leafed *Welwitschia* of southern African deserts. The Pteridophytes consist of 9,000 fern species and, again, small numbers of allied groups including horsetails and Lycopods, plants that were once the dominant vegetation of Palaeozoic forests growing as trees. Plants are unevenly distributed between the continents: Latin America 85,000 species; Africa 40,000–45,000; Asia 50,000: Australia 15,000; North America 17,000; Europe 12,500. Eighteen plant diversity hot spots support 50,000 species, 20 per cent of the world's vascular flora, but between them cover only 5 per cent of the land's area.

Plate 12 ***Mount Kupe, part of the Cameroon Mountain Endemic Bird Area***

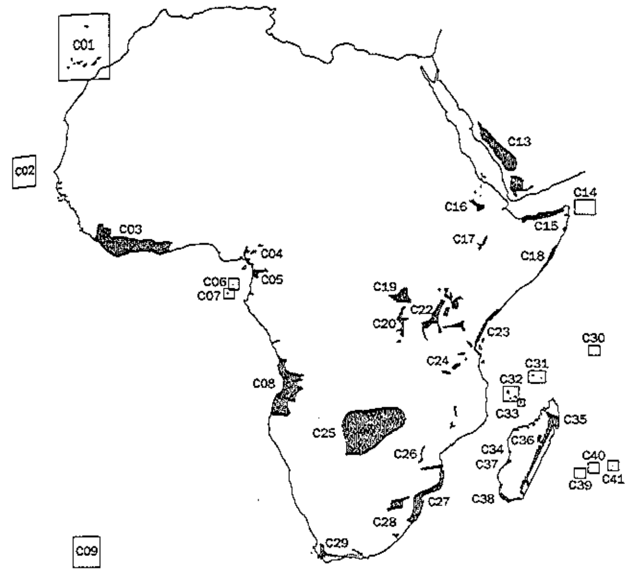

Figure 3.9 ***African Endemic Bird Areas. The prefix 'C' refers to EBAs from Africa, Europe and the Middle East under the International Council for Bird Preservation EBA scheme. Mount Kupe (Chapter 4) is part of the Cameroon Mountain EBA, C04, Mauritius, once home to the Dodo, C40 and Zimbabwe harbours C26, the east Zimbabwean Mountain EBA***

Source: Redrawn from Bibby 1992.

Species richness within the sometimes unnatural confines of political boundaries reflects size, topographic heterogeneity and complexity plus climate. Detailed studies of tree and vine inventories from South American tropical forests have compared species richness to climatic factors such as total rainfall and seasonality, plus soil nutrients. Diversity showed clear increases with total rainfall and length of rainy season. Although climate alone was a very effective predictor of species richness, soil factors could be important, especially increased species richness with increased nitrogen availability at higher altitudes. Such results can be useful to focus attention on known high total rainfall/ long rainy season sites as of particular importance for conservation, even if good species inventories are not yet available. The greatest species richness is in the tropical forests but many oceanic islands have

Table 3.6 ***Five countries with largest numbers of Endemic Bird Areas***

Country	*EBAs (inclusive of those shared with other countries)*	*Restricted range species confined to countries' EBAs*	*Total restricted range species, confined plus shared*	*Priority I EBAs*	*Priority II EBAs*	*Priority III EBAs*
Indonesia	24	339	411	16	7	1
Brazil	19	122	201	8	8	3
Peru	18	106	216	4	7	7
Colombia	14	61	189	4	9	1
Papua New Guinea	12	82	172	3	63	3

Source: Bibby 1992.

very high endemicity. Tiny St Helena in the Atlantic, Napoleon's final exile, has 74 endemics out of 89 species. Table 3.8 gives known vascular plant numbers and endemicity for the top five species rich countries and other countries for comparison. (See Figure 3.11.)

Revelations of plant species richness continue at a smaller scale. A study of a one hectare plot in the Ecuador *terre firme* tropical forest in the late 1980s found 473 species (with stem diameter at standard breast height of greater than 5 cm). Given the estimated 3,000 tree species in Ecuador this represented 16 per cent of the country's tree flora but 49 per cent of species were only represented by one individual. Similar recent inventory work from Colombian forest, working in even smaller plots, 0.1 hectare area but including trees and herbs, found up to 313 species per plot.

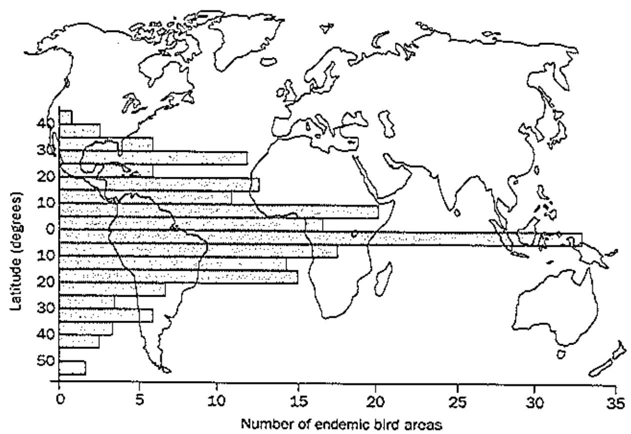

Figure 3.10 ***Latitudinal gradient of numbers of Endemic Bird Areas***
Source: Redrawn from Bibby 1992.

Plant species diversity has also been the target of the IUCN Plant Conservation Programme to identify Centres of Plant Diversity. The rationale for CPDs is that their identification and subsequent protection will conserve the majority of wild plants; 241 CPDs have been identified so far. The main criteria are species richness and numbers of endemics. The Programme also takes into account value of the gene pool to humans, diversity of habitat types, sites containing significant proportions of species adapted to specific conditions found therein and imminent large-scale threat.

Table 3.7 ***Endemic Bird Areas of Zimbabwe, Cameroon, Mauritius and UK***

Country and name of EBA	*Area of EBA, km²*	*Restricted range species confined to EBA (+ shared with other EBA)*	*% of EBA area protected*	*Priority category*
Zimbabwe East Zimbabwe Mountains	4,900	2 (+ 2)	5–10	III
Cameroon Cameroon Mountains	7,300	26 (+ 2)	5–10	I
Cameroon Cameroon/ Gabon Lowlands	40,000	5 (+ 1)	20–30	III
Mauritius Whole island system	1,900	6 (+ 4)	0–5	I
UK No EBAs	—	1	—	—

Source: Bibby 1992.

Table 3.8 ***Flowering plant diversity, selected countries***

Country	*Flowering plant species*	*Conifers and allies*	*Ferns and allies*	*Number of endemics (% of species)*
Brazil	55,000	—	—	—
Columbia	35,000	—	—	1,500 (4.3)
China	30,000	200	2,000	18,000 (56)
Mexico	20,000–30,000	71	1,000	3,624 (13.9)
USSR (as was)	22,000	74	207	—
Madagascar	8,000–10,000	5	500	Up to 8,500 (68)
UK	1,550	3	70	16 (1)
Zimbabwe	4,200	6	234	95 (2.1)

Source: Groombridge 1992; Heywood 1995.

Ecological biodiversity

Describing the extent of global ecosystems

Ecological biodiversity shows global patterns akin to taxonomic trends. Global classifications depict polar to equatorial biomes, largely created and defined by geography and climate. Some habitats are restricted by latitude, e.g. tropical rainforest, coral reefs, but others occur across the planet, though their precise regional form and complement of species varies.

Global biogeography has long recognised differences between the major continents and their allied peripheries. The six main divisions are Nearctic (North America) Neotropical (Central and South America), Palaearctic (Europe, Russia, central and eastern Asia), African (Africa including Madagascar), Oriental (India, Indo-China and South East Asian islands down to Borneo and Australasia (Australia, New Zealand, New Guinea). (See Figure 3.12.)

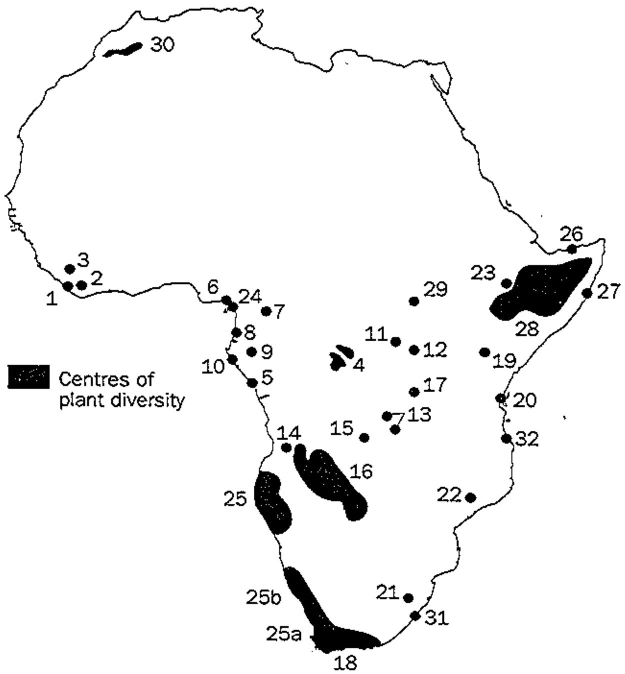

Figure 3.11 ***African Centres of Plant Diversity identified by IUCN. Sites are selected due to particular richness of flora which, if protected, would safeguard the majority of the earth's wild plants***

Source: Redrawn from Groombridge 1992.

Increasingly detailed global classifications of biomes have been devised using remote sensing from satellites. These attempt to classify the main terrestrial ecosystem types producing schemes that broadly reflect global climate systems and sometimes other natural or human factors e.g. soils or landuse. Udvardy's 1975 combination of the use of dominant vegetation type and biogeographic is still widely employed and has been used as a base against which to measure human impacts on biomes at a global scale. (See Figure 3.13.) Udvardy based his system on eight major biogeographic realms: Afrotropical, Antarctic, Australian, Indo-Malayan, Nearctic, Neotropical, Oceanian and Palaearctic. Major vegetation types, biomes, were then assessed within each. The biomes were identified as provinces reflecting regional variations in form. Table 3.9 lists Afrotropical and Neotropical examples.

The distribution of wetlands varies globally, regionally and nationally. The extent of global wetlands has been estimated from compilations of maps and remotely sensed images from satellites. Estimates of the global area of wetlands vary with definitions and inclusion of coastal wetlands but range between 5.3 and 8.6 million sq km, compared to estimates for extant tropical rainforest of 9.4 to 12 million sq. km and for grasslands of 24 to 35 million sq. km. The total extent of wetlands varies with latitude and the different types of wetland are unevenly distributed with vast tracts of bogs dominant across northern temperate and subarctic continents versus the swamps and flood plains of the tropics.

The distribution varies with scale. Table 3.10 compares wetland distributions globally and in Europe. Differences would affect assessment of conservation priorities. (See Figure 3.14.)

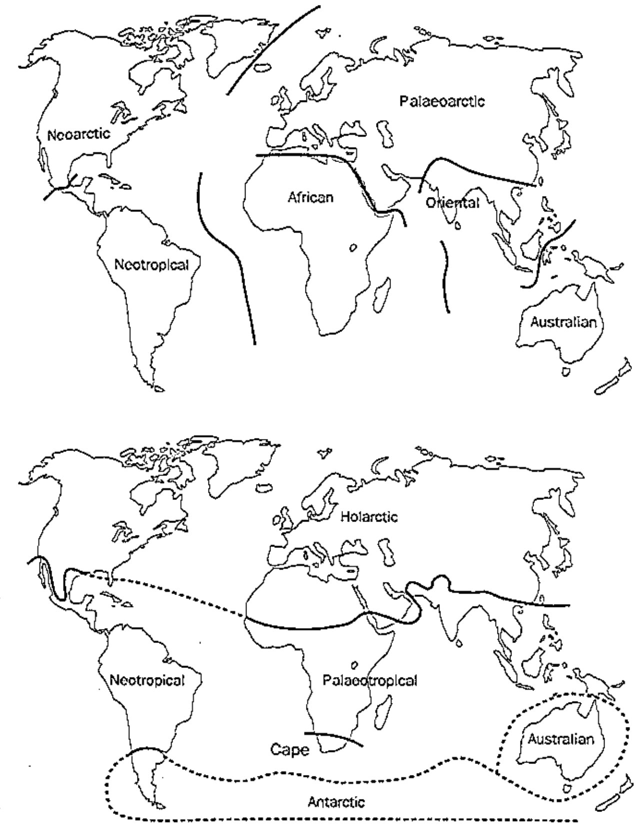

Figure 3.12 ***The classical animal (above) and plant (below) global biogeographical realms***

Source: Redrawn from Heywood 1995.

The importance of global ecosystems: functional biodiversity

Central to the concept of biodiversity is the sense that ecosystems are important for what they do. Ecosystems carry out functions, thereby providing services. Ecosystems are responsible for fluxes of energy and materials. The importance of ecosystems as providers of services adds to our awareness of the dangers from degradation and loss and of the value of biodiversity. Functional biodiversity meshes the concept of the ecosystem, dominated by ideas of flow and flux of resources with the community, the numbers of species. Ecosystems are a synergy of genetic, population, community, ecosystems and landscape biodiversity. Ecosystem function is the sum total of their activity, apparent even when the precise importance of individual species as keystones driving the processes remain unclear. The array of services includes vital global life support through atmospheric quality, climatic control, protection of coasts and nutrient cycling. The importance of functional biodiversity is best revealed by an example of just one ecosystem.

The importance of wetlands

Wetlands throughout the world support their own unique wildlife. By its very existence this biodiversity has an intrinsic value. Tangible, highly valuable benefits also derive from wetland ecosystems. These can be broadly divided into **production** (in ecological terms the living components, in economic, the stock), the **ecosystem functions** (in economics, the services) and the **intrinsic cultural and biological diversity** in its own right (attributes to economists). The astonishing variety of benefits, local to global, provided by wetlands is outlined next.

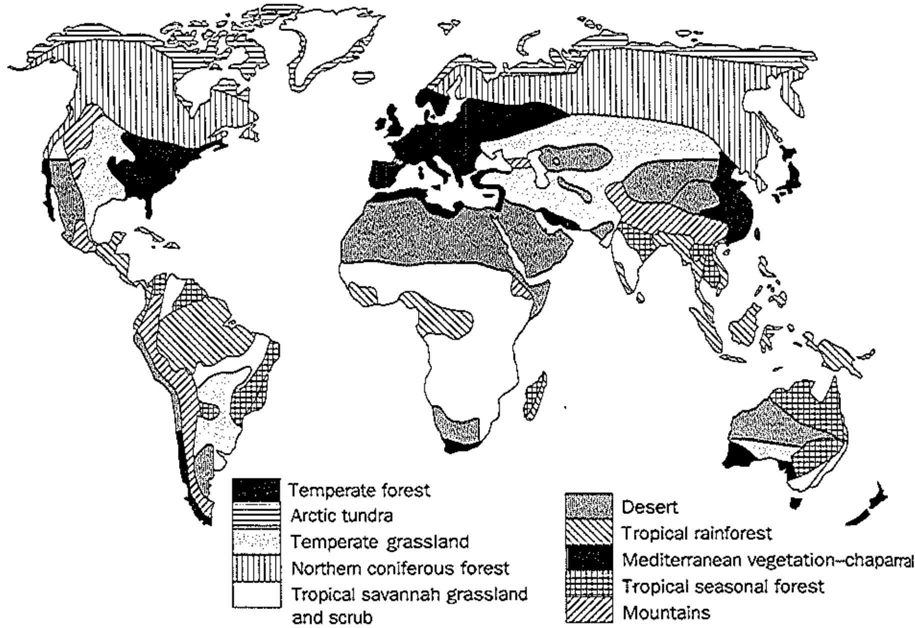

Figure 3.13 ***Gross global vegetation classification***

Source: Redrawn from Heywood 1995.

Production

Wetlands are the most productive natural ecosystems on Earth. The following examples are all sustainable uses of wetlands, though in some cases more intensive versions of the same exploitation also exist, destroying the original habitat. (See Plate 13.)

- Consumptive. Wetlands yield fish, shellfish and prawns. Plant products include wild fruit and vegetables, gardened crops and small-scale arable. In addition plants provide grazing plus harvested fodder, building poles, thatch, craft materials, latex, resin, tanning products, beer and medicines. Note that these products are not the preserve of subsistence economies. High vale crops, e.g. thatch, rushes, sedges and wild cranberries, are harvested in developed countries. Animals are hunted for fur and skins, as well as sport. Energy is provided by fuelwood and peat.
- Non-consumptive. Tourism and recreation rely on the wetland landscape and wildlife without being direct consumers. (See Plate 14.)

Services

- Storage. Wetlands act as major water stores, allowing ground water recharge as water slowly seeps into deep aquifers and also discharge, as ground water tops up surface aquatic habitats such as rivers and lakes. Note that wetlands can act as both recharge and discharge sources, perhaps switching roles with the seasons. Even small wetlands can act as insurance supplies during drought. Trapped sediment can build up land. Peat bogs are major sinks for carbon dioxide because peat is organic (primarily plant) material that cannot completely decay so that the carbon is not recycled.
- Buffering. Buffering is the ability to slow, compensate and ameliorate against change. Wetlands buffer many potentially destructive environmental processes, reducing both the size and rate of change. Coastal wetlands provide shore defences, dissipating wave and storm energy. Wetlands act as flood overspill areas holding water which may do damage elsewhere, slowing the rise of floodwaters and desynchronising floodwater peaks from different rivers which might otherwise combine. Climate is also buffered so that in hot weather wetlands act to cool the local climate and in the cold to warm up their environs. This benefit has been used in fruit farms in the USA to guard against sudden cold snaps.
- Cleaning. Wetlands are effective filters, particularly between rivers and their surrounding catchments. Materials are trapped and held, the wetlands acting as sinks, and rates of flow are slowed, allowing extra time for natural processes to neutralise potentially harmful inputs. Wetlands are known to trap and clean sediment run-off, organic detritus, sewage, excess nutrients (especially phosphorous and nitrogen compounds), acidic inputs, metals, pesticides and pathogens. These effluents can be from a readily identifiable point source such as a mine working or sewage treatment plant. In addition wetlands are particularly useful to control diffuse, non-point source inputs that plague so many catchments, e.g. nutrient run-off from farmland, which cannot easily be collected and cleaned by technical intervention.
- Pathways. The waterways ramifying throughout many wetlands provide pathways for natural fluxes such as nutrient recycling and alluvial deposition, increasing fertility. Open water also provides literal routes for movement by animals and humans.

Attributes

Cultures utilising wetlands have developed customs, architecture and landscapes as a result of this interdependence. In some cases the entire society is intimately tied to the wetland system, creating unique cultural systems, e.g. the Marsh Arabs.

So often dismissed as miasmal wastes in urgent need of draining, wetlands are actually a vital asset (see Box 12).

Islands and hot spots: the Earth's extra special places

Biodiversity is not evenly distributed. Within the general patterns of taxonomic and ecosystem distribution there are striking concentrations of species, associated with certain ecosystems. Identification of these special places is important for practical conservation and to understand the underlying causes that drive diversification. These foci can be special by virtue of several sometimes contrasting, factors:

Table 3.9 ***Example vegetation types and extent from Udvardy's system***

Realm	*Biome and province*	*Area, km²*
Afrotropical	**Tropical Humid Forest**	
	Congo rainforest	2,195,019
	Guinean rainforest	709,112
	Malagasy rainforest	147,862
	Evergreen Sclerophyllous vegetation	
	Cape Sclerophyll	99,663
Neotropical	**Tropical Humid Forest**	
	Amazonian	2,864,623
	Campechean	279,695
	Colombian coastal	273,266
	Guyanan	1,090,396
	Mudieran	1,988,840
	Panamanian	128,872
	Atlantic forest	223,944
	Evergreen Sclerophyllous vegetation	
	Chilean sclerophyll	47,988

Source: Hannah *et al.* 1995.

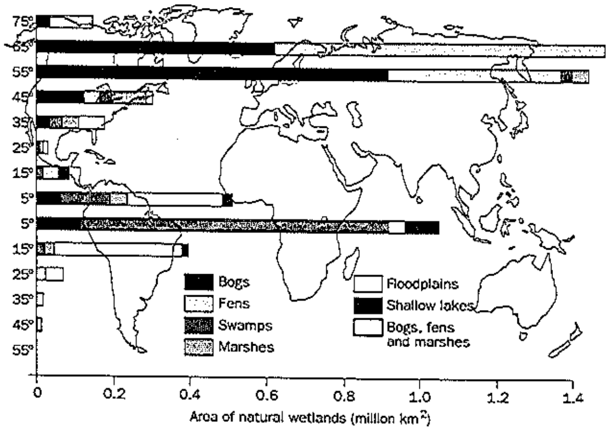

Figure 3.14 ***Latitudinal extent of different wetland types***

Source: Redrawn from Aselmann and Crutzen 1989.

- very high total species numbers;
- endemicity, whether of common or unusual lineages;
- unusual combinations, characteristics of communities;
- super speciose taxa.

These jewels in biodiversity's crown fall into three contrasting types. First **continental hot spots** which are sites of very high diversity, often also with unusual endemics, sometimes called mega, hyper and super diversity centres. Second, there are **large islands** (sometimes called **continental islands**) harbouring diverse distinctive faunas which include relict fauna long extinct on the main continents. Finally, there are small **oceanic islands**, often low in total species numbers (though a few individual taxa can be unusually speciose) but with high proportions of endemics, unusual combinations of species, and peculiar evolutionary lineages. Merely listing high diversity centres by country is possible but not very informative since many, especially the continental centres, do not occupy the whole of a country and some straddle borders.

Table 3.10 ***Extent of freshwater wetlands, globally and in Europe versus Africa (1,000 km)***

	Bogs	*Fens*	*Swamps*	*Marsh*	*Floodplain*	*Lakes*	*Mangrove*	*Anthro-pogenic*
Global	1,867	1,483	1,130	274	823	114	27	1,300 (rice paddies)
Europe	54	93	1	4	1	1	0	Minor
Africa	0–38		85	57	174	39	6	46

Source: Groombridge 1992.

Plate 13 ***The value of wetlands: direct use production. Saw sedge*** **(Cladium mariscus)** ***harvested at Whicken Fen, Cambridgeshire. The sedge is used to protect peaks and angles of thatched roofs and is a high value crop***

Continental hot spots

Biodiversity hot spots defined by endemism and the uneven distribution of species have been cited for birds and plants in earlier sections. A few countries, primarily tropical, have been described as Megadiversity Countries, unusually rich in all forms of biodiversity, although data for such categorisation relies on higher vertebrates, plants and a few insect groups. The Megadiversity Countries are Mexico, Columbia, Ecuador, Peru, Brazil, Zaire, Madagascar, China, India, Malaysia, Indonesia and Australia. However, political boundaries are an inappropriate guide and generalisations do not take into account the uniqueness and biodisparity found in other countries. Eighteen global hot spots identified by endemicity of many taxa have been identified. Table 3.11 summarises data for four.

Globally significant continental hot spots are often regions of habitat heterogeneity caused by habitat change. The resultant patchwork allows older taxa to survive and radiation of new species. (See Figures 3.16 and 3.17.)

Islands

Island diversity centres are very different to the continental hot spots, often poor in species but sheltering unusual relicts, strange combinations and extraordinary

Box 12

The role of wetlands. Global and national ecosystem services

Global: methane production

Methane, CH_4, is a greenhouse gas, also important in the formation of ozone. Concern at possible global warming has prompted detailed analysis of global biogeochemical cycles, including methane production which arises from natural sources such as digestive processes of ruminant animals such as cows and decay of organic matter, plus human sources such as use of fossil fuels and burning. Atmospheric methane is increasing by about 1 per cent per year, i.e. 40–50 Teragrams (1 Teragram = 10^9 kg) which, allowing for the balance between production, recycling and use, requires about 400–600 Teragrams to be pumped into the atmosphere annually. Estimates of methane production from wetlands are 40–160 Teragrams per year from natural wetlands, plus 60–140 Teragrams from rice paddies. The most important regions are northern latitude fens between 50-70°N, subtropical paddies between 0–20°N and southern hemisphere tropical swamps between 0–10°S. Although methane emissions from wetlands are highly variable depending on seasonal temperature and waterlogging and estimates of global methane fluxes are still tentative, the suggested mean methane emissions from wetlands may represent up to half the global annual production of methane and are therefore very important for planetary health.

National: dambo horticulture in Zimbabwe

Small seasonally inundated valley wetlands, sometimes herbaceous, sometimes wooded, are found in the headwaters of drainage basins throughout southern Africa. Zimbabwe, although primarily an arid country, is particularly rich in these ecosystems, known by the local name of dambos. Zimbabwean dambos have been used since at least the Iron Age as part of a shifting system of cultivation and grazing. Dambos are fertile and remain moist even in years with poor rainfall so they are an especially valuable safety net in an uncertain world. Dambo wetlands are primarily used as small (0.1–2 hectare) market gardens. The fertility and water supply permit diverse crops from staples such as maize and rice to water greedy pumpkins and fruit, which can be cropped all year. Limited grazing and beekeeping are possible. Dambos also act as water sources for drinking, rivers, irrigation and livestock during drought and as water stores, mopping up excess during rare floods. Dambos are a special asset to the rural poor as the horticultural garden produce is a valuable source of income. The nature of this local, small scale horticulture is a valuable economic opportunity for rural women. During recent drought years 80 per cent of households with access to market gardens on dambo wetlands remained self-sufficient in food. (See Figure 3.15.)

evolutionary radiations. Islands also have a historic role in our awareness and understanding of biodiversity, whether the evolutionary inspiration of the Galapagos Islands, or that icon of extinction, the Dodo, from Mauritius.

Islands have distinctive ecological communities. Historical contingency (what was living there before islands split from mainlands, when the separation occurred) and the vagaries of colonisation create unusual combinations of wildlife. Relict faunas long extinct on main continents survive and in some cases flourish. In situ speciation creates spectacular radiations, such as the very speciose fruit flies of Hawaii. Animals take up unexpected roles; on Hawaii one moth has a caterpillar that does not chew leaves but is a deadly ambush predator, snatching other insects. A few taxa

Table 3.11 ***Example of continental biodiversity hot spots***

	Higher plant species	*Endemic mammal species*	*Endemic reptile species*	*Endemic amphibian species*	*Endemic swallowtail butterfly species*
Cape region, South Africa	6,000	15	43	23	0
Colombian Choco	2,500	8	137	111	0
Western Ghats, India	1,600	7	91	84	5
South West Australia	2,830	10	25	22	0

Source: Bibby 1992.

have become particularly characteristic of islands, e.g. pigeons, rails and tortoises, all capable of erratic but long-distance dispersal, yet not so mobile that once established new arrivals dilute the evolutionary aftermath. The same traits develop among these taxa: gigantism in birds and reptiles; dwarfism in mammals; flightlessness in birds. The wildlife of islands is also distinguished by being extinction prone.

There are two main types of high diversity islands, continental islands such as New Zealand, Australia and Madagascar and tropical oceanic islands, e.g. Hawaii, Galapagos and Mauritius.

Plate 14 ***The value of wetlands: ecosystem services. The Insh marshes in Scotland, a Royal Society for the Protection of Birds reserve, act as a buffer, holding flood waters that spill out over the marshes from the River Tay, helping to protect land downstream from flooding***

Continental islands

Table 3.12 gives comparative biodiversity data for Australia, New Zealand, Madagascar and Kenya as a contrasting continental country.

Oceanic islands

Oceanic islands supporting special diversity are typically very isolated, volcanic (the altitude creating diverse habitats) and tropical. Low-lying tropical atolls lack habitat diversity while temperate islands are often too exposed to extremes of weather. (See Table 3.13).

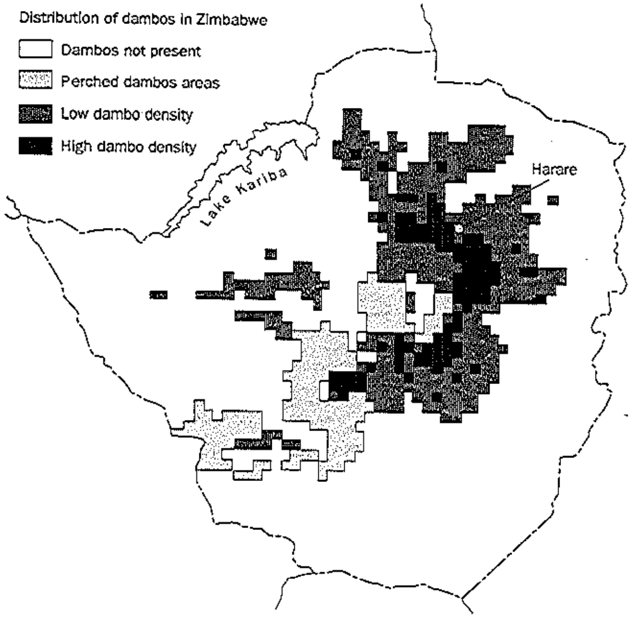

Figure 3.15 ***Extent of dambos in Zimbabwe***

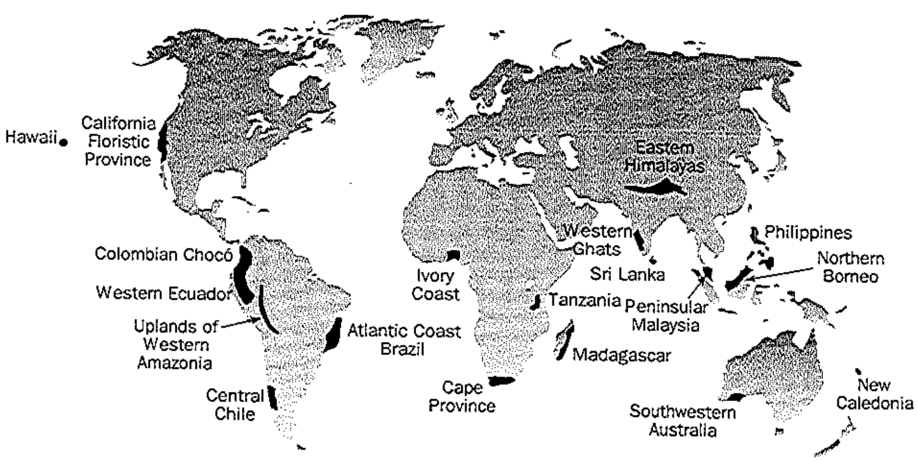

Figure 3.16 ***Global biodiversity hotspots, defined by endemicity and also threat from human pressures, identified by Wilson 1992***

Source: Redrawn from Wilson (1992).

Table 3.12 ***Diversity, threat and uniqueness of three continental islands, with Kenya as a comparison. Note that counts of extinct species exclude those lost from very small islands around the mainlands***

	Australia		*Madagascar*		*New Zealand*		*Kenya*	
	Total	*Endemic*	*Total*	*Endemic*	*Total*	*Endemic*	*Total*	*Endemic*
Flowers			8,000–10,000		2,160		6,000	
Gymnosperms	15,000 (Flowers, Gymnosperms, Ferns combined)	80%	5	68%	22	82%	6	4%
Ferns			500		189		600	
Mammals	282	210	105	67	—	3	309	10
Birds	571	351	250	97	285	74	1,067	7
Reptiles	700	616	252	231	40	40	187	15
Amphibians	180	169	144	142	3	3	88	10
Fish	113	110	40	38	30	27		
IUCN Plant Centres of Diversity	8		1		3		1	
Endemic Bird Centres	7		5		2		2	
Threatened species								
Plants	2,024		194		232		144	
Mammals	38		50		1		17	
Birds	39		28		26		18	
Reptiles	9		10		1		2	
Amphibians	3		0		3		0	
Fish	16		0		2		0	
Animals known to have gone extinct	18		3		14		0	
Extinct endemic plants	173		0		5		0	
Unusual wildlife	Marsupial and reptile diversity		Lemurs. Extinct flightless Elephant Bird		Flightless birds (Kiwi, extinct Moa)			

Source: Groombridge 1992.

Island wildlife has proven particularly susceptible to extinction, due to several factors.

- Evolutionary innocence. Island species have proven very vulnerable to introduced competitors, predators, parasites and diseases. Many islands lack taxa such as large mammalian predators and ants, the very groups that are dominant ecological keystone taxa on mainlands. Relict fauna and particular traits such as flightlessness further increase the threat posed by alien arrivals.

Table 3.13 ***Diversity, threat and uniqueness of three oceanic island systems. Note that the data exclud introduced species***

	Hawaiian Islands (Pacific)	*Galapagos Islands (Pacific)*	*Mauritius (Indian Ocean)*
Vascular plants	900 of which 850 are endemic	540 of which 170 are endemic	878 of which 329 are endemic
Threatened native plants	343	82	269
Introduced plant species	4,000	195	—
IUCN Plant Centres of Diversity	1, whole archipelago	1, whole archipelago	1, whole archipelago
Endemic Bird Centres	1, whole archipelago	1, whole archipelago	1, whole archipelago
Animals known to have gone extinct	86	5	41
Extinct endemic plants	108	2	24
Species of land snails	c 1,000, all endemic	90 of which 66 are endemic	109 of which 77 are endemic
Extinct snail species	29	1	25
Unusual wildlife	High endemism, super-species rich taxa, e.g. fruit flies	High endemism, unusual species, e.g. marine iguana	High endemism, once home to the Dodo

Source: Stone and Stone 1989; Groombridge 1992.

- Small populations. Many island species occur as small, isolated populations specialised to live in a narrow habitat range and with no pool from which recolonisation can boost numbers. Genetic diversity may be enfeebled by inbreeding and bottlenecks due to population size. In addition coevolution of island taxa one with another may result in extinctions cascading through the island once one or two species are lost and ecological links are broken.
- Lack of disturbance. Physical disturbance to island habitats can be increased once humans arrive, e.g. direct action such as fire to clear land or indirectly through impacts of introduced animals such as pigs grubbing up land.
- Human exploitation. Direct human harvesting has wiped out species such as the Dodo and Moas and endangered others, e.g. Giant Tortoises. Habitat loss as humans clear land is just as great a threat, especially given the small habitat areas and species' ranges of many island taxa.

Islands remain under threat, even the most famous. The Galapogos have become a recent focus of concern, in part due to increased tourism but also due to protests from local people who are angry at restrictions due to conservation laws. Protests have culminated in intentional habitat destruction and threats to conservationists.

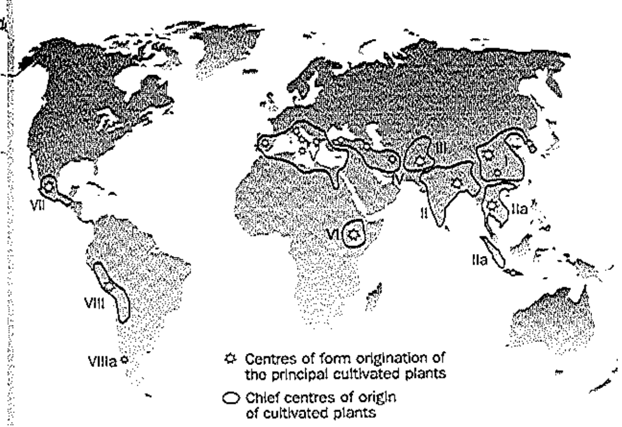

Figure 3.17 ***Centres of origin of cultivated plants, based on the work of Vavilov. Stars indicate the centres of origination for the form of crop plant used, the outlined surrounding areas the broad region from within which the plant was domesticated***

Source: Redrawn from Heywood 1995.

More things in Heaven and Earth . . .

Fragments of ancient continents, far flung islands and impenetrable jungle – our fascination with biodiversity is in part the mystery and unknown. Sad to say, despite recent expeditions there is unlikely to be a population of Brontosaurs lurking up the River Congo but there are other surprises. Mauritius, which is now recognised as an oceanic hot spot, was the home of the Dodo, *Raphus cucullatus*, discovered in 1598 and extinct by 1670. The Dodo was the epitome of the absurd, a fat waddling flightless pigeon permanently clad in juvenile plumage, too stupid to avoid being eaten into extinction. Recent analysis of fossil bone structures reveal an athletic leggy creature confirmed by the earliest illustrations. The Dodo was an innovative design but fatally maladapted to human interference.

Continental hot spots also hold surprises. Several virulent diseases, Lassa fever and Ebola virus, seem to flare from African rainforest hot spots. Ebola outbreaks not only kill humans. In 1994 a 40-strong Chimpanzee clan (*Pan troglodytes*) in the Tai Forest of the Ivory Coast lost 12 to Ebola. Ebola virus replication is error prone; the frequent mutations that result permit infection of a variety of species. The Tai chimps were proficient hunters of small mammals and perhaps picked up the disease from the rodents that have boomed since 1990 when Liberian refugees from civil war crossed into the area. The Dodo and the Tai chimps may seem idiosyncratic but they prompt important questions. How do human pressures, whether hungry sailors or refugees, impact natural systems? Chapter 4 describes species extinctions, ecosystem loss and the underlying causes for the degradation of biodiversity.

Summary

- Biodiversity is categorised as genetic, organismal and ecological. Domestic and cultural categories can be added.
- Measures of the richess of extent of any category remain fraught. Estimates of total species alive today range between 10 and 30 million.

- Functional biodiversity is very important to planetary health. Ecosystems function, as a result of species activities, providing services to the wider environment.

Discussion points

1 Is the Giant Panda more important than the Polio virus?

2 If all the wetlands in your country were gone what would have been lost?

3 The biodiversity of islands can be strange, special and frightening. Why?

See also

Role and value of biodiversity, Chapters 1 and 4.
Islands and extinction, Chapter 4.
Measuring biodiversity loss rates, Chapter 4.

General further reading

'Magnitude and distribution of biodiversity'. D. L. Hawksworth and M. T. Kalin-Arroyo (eds). 1995. In V. H. Heywood (ed.). *Global Biodiversity Assessment*. Section 3. CUP for UNEP, Cambridge.

Global Biodiversity. Status of the Earth's Living Resources. B. Groombridge (ed.). (1992). Chapman and Hall, London.

Both books are essential and contain detailed inventories of biodiversity patterns.

The Diversity of Life. Edward O. Wilson. 1992. Harvard University Press.
Reviews extent of biodiversity, especially importance of hotspots.

Putting Biodiversity on the Map. C. J. Bibby (ed.). 1992.
International Council for Bird Preservation, Cambridge.

'How many species are there on earth?' R. M. May. 1988. *Science*, vol. 241, 1441–1449.
Robert May reviews revived interest in this question prompted by rise of biodiversity research in 1980s.

4 Extinction

Extinction and habitat loss epitomise our sense of biodiversity crises. This chapter covers:

- **Extinction rates and ecosystem loss**
- **Causes of extinction**
- **Human pressures on biodiversity**
- **Valuing biodiversity.**

Extinction can bring with it all the familiarity and fame akin to that of a dead pop star. The Dodo and dinosaurs are household names, evocative of failure. Neither deserve this epitaph and the confusion between types of extinction, natural versus anthropogenic, hinders our understanding of the rates and causes of loss. This chapter describes losses to biodiversity during the current crisis, driven by human activities, the causes, both ecological and economic and the consequences.

Current losses of biodiversity

Prophets and loss: estimating current extinction rates

The fate of all species is extinction, perhaps leaving evolutionary descendants as a lingering echo. Extinction, whether background or mass, is a natural process unleashing evolutionary creativity. Quantitative and qualitative changes to extinction rates define the current biodiversity crisis. However, the growing awareness of extinction, fuelled by slogans such as 'extinction is forever', has proved difficult to quantify. Several approaches have been used to measure recent extinction rates and to project future trends.

Confirmed extinctions

The precise start of the current crisis, defined by the impact of the human, is hard to delimit. Unusual bursts of extinction coincided with human arrival in Australia (30,000–50,000 years ago), North and South America (11,000–12,000 ya), Madagascar (1,400 ya) and New Zealand (1,000 ya). In every case the same types of animals were disproportionately affected, with severe losses of large mammals