What is Biodiversity

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Chapter 1

Global Processes[1]

1.1 Atmosphere and Climate Regulation

Life on earth plays a critical role in regulating the earth's physical, chemical, and geological properties, from influencing the chemical composition of the atmosphere to modifying climate.

About 3.5 billion years ago, early life forms (principally cyanobacteria) helped create an oxygenated atmosphere through photosynthesis, taking up carbon dioxide from the atmosphere and releasing oxygen (*Schopf 1983*[87]; *Van Valen 1971*[104]). Over time, these organisms altered the composition of the atmosphere, increasing oxygen levels, and paved the way for organisms that use oxygen as an energy source (aerobic respiration), forming an atmosphere similar to that existing today.

Carbon cycles on the planet between the land, atmosphere, and oceans through a combination of physical, chemical, geological, and biological processes (*IPCC 2001*[73]). One key way biodiversity influences the composition of the earth's atmosphere is through its role in carbon cycling in the oceans, the largest reservoir for carbon on the planet (*Gruber and Sarmiento*[36], in press). In turn, the atmospheric composition of carbon influences climate. Phytoplankton (or microscopic marine plants) play a central role in regulating atmospheric chemistry by transforming carbon dioxide into organic matter during photosynthesis. This carbon-laden organic matter settles either directly or indirectly (after it has been consumed) in the deep ocean, where it stays for centuries, or even thousands of years, acting as the major reservoir for carbon on the planet. In addition, carbon also reaches the deep ocean through another biological process – the formation of calcium carbonate, the primary component of the shells in two groups of marine organisms coccolithophorids (a phytoplankton) and foraminifera (a single celled, shelled organism that is abundant in many marine environments). When these organisms die, their shells sink to the bottom or dissolve in the water column. This movement of carbon through the oceans removes excess carbon from the atmosphere and regulates the earth's climate.

Over the last century, humans have changed the atmosphere's composition by releasing large amounts of carbon dioxide. This excess carbon dioxide, along with other 'greenhouse' gases, is believed to be heating up our atmosphere and changing the world's climate, leading to 'global warming'. There has been much debate about how natural processes, such as the cycling of carbon through phytoplankton in the oceans, will respond to these changes. Will phytoplankton productivity increase and thereby absorb the extra carbon from the atmosphere? Recent studies suggest that natural processes may slow the rate of increase of carbon dioxide in the atmosphere, but it is doubtful that either the earth's oceans or its forests can absorb the entirety of the extra carbon released by human activity (*Falkowski et al. 2000*[25]).

[1] This content is available online at <http://cnx.org/content/m12159/1.1/>.

1.2 Land Use Change and Climate Regulation

The energy source that ultimately drives the earth's climate is the sun. The amount of solar radiation absorbed by the earth depends primarily on the characteristics of the surface. Although the link between solar absorption, thermodynamics, and ultimately climate is very complex, newer studies indicate that vegetation cover and seasonal variation in vegetation cover affects climate on both global and local scales. New generations of atmospheric circulation models are increasingly able to incorporate more complex data related to these parameters (*Sellers et al. 1997*[90]). Besides regulating the atmosphere's composition, the extent and distribution of different types of vegetation over the globe modifies climate in three main ways:

- affecting the reflectance of sunlight (**radiation balance**);
- regulating the release of water vapor (**evapotranspiration**); and
- changing wind patterns and moisture loss (**surface roughness**).

The amount of solar radiation reflected by a surface is known as its **albedo**; surfaces with low albedo reflect a small amount of sunlight, those with high albedo reflect a large amount. Different types of vegetation have different albedos; forests typically have low albedo, whereas deserts have high albedo. Deciduous forests are a good example of the seasonal relationship between vegetation and radiation balance. In the summer, the leaves in deciduous forests absorb solar radiation through photosynthesis; in winter, after their leaves have fallen, deciduous forests tend to reflect more radiation. These seasonal changes in vegetation modify climate in complex ways, by changing evapotranspiration rates and albedo (*IPCC 2001*[73]).

Vegetation absorbs water from the soil and releases it back into the atmosphere through **evapotranspiration**, which is the major pathway by which water moves from the soil to the atmosphere. This release of water from vegetation cools the air temperature. In the Amazon region, vegetation and climate is tightly coupled; evapotranspiration of plants is believed to contribute an estimated fifty percent of the annual rainfall (*Salati 1987*[85]). Deforestation in this region leads to a complex feedback mechanism, reducing evapotranspiration rates, which leads to decreased rainfall and increased vulnerability to fire (*Laurance and Williamson 2001*[56]).

Deforestation also influences the climate of cloud forests in the mountains of Costa Rica. The Monteverde Cloud Forest harbors a rich diversity of organisms, many of which are found nowhere else in the world. However, deforestation in lower-lying lands, even regions over 50 kilometers way, is changing the local climate, leaving the "cloud" forest cloudless (*Lawton et al. 2001*[57]). As winds pass over deforested lowlands, clouds are lifted higher, often above the mountaintops, reducing the ability for cloud forests to form. Removing the clouds from a cloud forest dries the forest, so it can no longer support the same vegetation or provide appropriate habitat for many of the species originally found there. Similar patterns may be occurring in other, less studied montane cloud forests around the world.

Different vegetation types and topographies have varying **surface roughness**, which change the flow of winds in the lower atmosphere and in turn influences climate. Lower surface roughness also tends to reduce surface moisture and increase evaporation. Farmers apply this knowledge when they plant trees to create windbreaks (*Johnson et al. 2003*[50]). Windbreaks reduce wind speed and change the microclimate, increase surface roughness, reduce soil erosion, and modify temperature and humidity. For many field crops, windbreaks increase yields and production efficiency. They also minimize stress on livestock from cold winds.

1.3 Soil and Water Conservation

Biodiversity is also important for global soil and water protection. Terrestrial vegetation in forests and other upland habitats maintain water quality and quantity, and controls soil erosion.

In **watersheds** where vegetation has been removed, flooding prevails in the wet season and drought in the dry season. Soil erosion is also more intense and rapid, causing a double effect: removing nutrient-rich topsoil and leading to siltation in downstream riverine and ultimately oceanic environments. This siltation harms riverine and coastal fisheries as well as damaging coral reefs (*Turner and Rabalais 1994*[98]; *van Katwijk et al. 1993*[103]).

One of the most productive ecosystems on earth, **wetlands** have water present at or near the surface of the soil or within the root zone, all year or for a period of time during the year, and the vegetation there is adapted to these conditions. Wetlands are instrumental for the maintenance of clean water and erosion control. Microbes and plants in wetlands absorb nutrients and in the process filter and purify water of pollutants before they can enter coastal or other aquatic ecosystems.

Wetlands also reduce flood, wave, and wind damage. They retard the flow of floodwaters and accumulate sediments that would otherwise be carried downstream or into coastal areas. Wetlands also serve as breeding grounds and nurseries for fish and support thousands of bird and other animal species.

1.4 Nutrient Cycling

Nutrient cycling is yet another critical service provided by biodiversity – particularly by microorganisms. Fungi and other microorganisms in soil help break down dead plants and animals, eventually converting this organic matter into nutrients that enrich the soil (*Pimentel et al. 1995*[75]).

Nitrogen is essential for plant growth, and an insufficient quantity of it limits plant production in both natural and agricultural ecosystems. While nitrogen is abundant in the atmosphere, only a few organisms (commonly known as nitrogen-fixing bacteria) can use it in this form. Nitrogen-fixing bacteria extract nitrogen from the air, and transform it into ammonia, then other bacteria further break down this ammonia into nitrogenous compounds that can be absorbed and used by most plants. In addition to their role in decomposition and hence nutrient cycling, microorganisms also help detoxify waste, changing waste products into forms less harmful to humans.

1.5 Pollination and Seed Dispersal

An estimated 90 percent of flowering plants depend on pollinators such as wasps, birds, bats, and bees, to reproduce. Plants and their pollinators are increasingly threatened around the world (*Buchmann and Nabhan 1995*[13]; *Kremen and Ricketts 2000*[54]). Pollination is critical to most major crops and virtually impossible to replace. For instance, imagine how costly fruit would be (and how little would be available) if its natural pollinators no longer existed and each developing flower had to be fertilized by hand.

Many animal species are important dispersers of plant seeds. It has been hypothesized that the loss of a seed disperser could cause a plant to become extinct. At present, there is no example where this has occurred. A famous example that has often been cited previously is the case of the dodo (*Raphus cucullatus*) and the tambalacoque (*Sideroxylon grandiflorum*). The dodo, a large flightless bird that inhabited the island of Mauritius in the Indian Ocean, became extinct due to overhunting in the late seventeenth century. It was once thought that the tambalacoque, a now endangered tree, depended upon the dodo to germinate its hard-cased seeds (*Temple 1977*[96]). In the 1970s, only 13 trees remained and it was thought the tree had not reproduced for 300 years. The seeds of the tree have a very hard coat, as an experiment they were fed to a turkey; after passing through its gizzard the seeds were viable and germinated. This experiment led scientists to believe that the extinction of the dodo was coupled to the tambalacoque's inability to reproduce. However, this hypothesis has not stood up to further scrutiny, as there were several other species (including three now extinct species, a large-billed parrot, a giant tortoise, and a giant lizard) that were also capable of cracking the seed (*Witmar and Cheke 1991*[111]; *Catling 2001*[16]). Thus many factors, including the loss of the dodo, could have contributed to the decline of the tambalacoque. (For further details of causes of extinction see Historical Perspectives on Extinction and the Current Biodiversity Crisis). Unfortunately, declines and/or extinctions of species are often unobserved and thus it is difficult to tease out the cause of the end result, as multiple factors are often operating simultaneously. Similar problems exist today in understanding current population declines. For example, in a given species, population declines may be caused by loss of habitat, loss in prey species or loss of predators, a combination of these factors, or possibly some other yet unidentified cause, such as disease.

In the pine forests of western North America, corvids (including jays, magpies, and crows), squirrels, and bears play a role in seed dispersal. The Clark's nutcracker (*Nucifraga columbiana*) is particularly well adapted to dispersal of whitebark pine (*Pinus albicaulis*) seeds (*Lanner 1996*[55]). The nutcracker removes the wingless seeds from the cones, which otherwise would not open on their own. Nutcrackers hide the seeds in clumps. When the uneaten seeds eventually grow, they are clustered, accounting for the typical distribution pattern of whitebark pine in the forest.

In tropical areas, large mammals and frugivorous birds play a key role in dispersing the seeds of trees and maintaining tree diversity over large areas. For example, three-wattled bellbirds (*Procnias tricarunculata*) are important dispersers of tree seeds of members of the Lauraceae family in Costa Rica. Because bellbirds return again and again to one or more favorite perches, they take the fruit and its seeds away from the parent tree, spreading Lauraceae trees throughout the forest (*Wenny and Levy 1998*[107]).

Chapter 2

Definition of Biodiversity[1]

Biodiversity, a contraction of the phrase "biological diversity," is a complex topic, covering many aspects of biological variation. In popular usage, the word **biodiversity** is often used to describe all the species living in a particular area. If we consider this area at its largest scale - the entire world - then biodiversity can be summarized as "life on earth." However, scientists use a broader definition of biodiversity, designed to include not only living organisms and their complex interactions, but also interactions with the abiotic (non-living) aspects of their environment. Definitions emphasizing one aspect or another of this biological variation can be found throughout the scientific and lay literature (see *Gaston, 1996: Table 1.1*[32]). For the purposes of this module, **biodiversity** is defined as:

> *the variety of life on Earth at all its levels, from genes to ecosystems, and the ecological and evolutionary processes that sustain it.*

Genetic diversity is the "fundamental currency of diversity" (*Williams and Humphires, 1996*[110]) that is responsible for variation between individuals, populations and species. Therefore, it is an important aspect of any discussion of biodiversity. The interactions between the individual organisms (*e.g.*, reproductive behavior, predation, parasitism) of a population or community, and their specializations for their environment (including ways in which they might modify the environment itself) are important functional aspects of biodiversity. These functional aspects can determine the diversity of different communities and ecosystems.

There is also an important spatial component to biodiversity. The structure of communities and ecosystems (*e.g.* the number of individuals and species present) can vary in different parts of the world. Similarly, the function of these communities and ecosystems (*i.e.* the interactions between the organisms present) can vary from one place to another. Different assemblages of ecosystems can characterize quite diverse landscapes, covering large areas. These spatial patterns of biodiversity are affected by climate, geology, and physiography (*Redford and Richter, 1999*[79]).

The structural, functional, and spatial aspects of biodiversity can vary over time; therefore there is a temporal component to the analysis of biodiversity. For example, there can be daily, seasonal, or annual changes in the species and number of organisms present in an ecosystem and how they interact. Some ecosystems change in size or structure over time (*e.g.* forest ecosystems may change in size and structure because of the effects of natural fires, wetlands gradually silt up and decrease in size). Biodiversity also changes over a longer-term, evolutionary, time-scale. Geological processes (*e.g.*, **plate tectonics**, **orogenesis**, erosion), changes in sea-level (marine transgressions and regressions), and changes in climate cause significant, long-term changes to the structural and spatial characteristics of global biodiversity. The processes of natural selection and species evolution, which may often be associated with the geological processes, also result in changes to local and global flora and fauna.

Many people consider humans to be a part of nature, and therefore a part of biodiversity. On the other hand, some people (*e.g.*, *Redford and Richter, 1999* [79]) confine biodiversity to natural variety and variability,

[1] This content is available online at <http://cnx.org/content/m12151/1.2/>.

excluding biotic patterns and ecosystems that result from human activity, even though it is difficult to assess the "naturalness" of an ecosystem because human influence is so pervasive and varied (*Hunter, 1996*[40]; *Angermeier, 2000*[2]; *Sanderson et al.,2002*[86]). If one takes humans as part of nature, then cultural diversity of human populations and the ways that these populations use or otherwise interact with habitats and other species on Earth are a component of biodiversity too. Other people make a compromise between totally including or excluding human activities as a part of biodiversity. These biologists do not accept all aspects of human activity and culture as part of biodiversity, but they do recognize that the ecological and evolutionary diversity of domestic species, and the species composition and ecology of agricultural ecosystems are part of biodiversity. (For further discussion see the modules on Human evolution and Cultural Diversity; in preparation.)

Chapter 3

Spatial Gradients in Biodiversity[1]

Generally speaking, warm tropical ecosystems are richer in species than cold temperate ecosystems at high latitudes (see *Gaston and Williams, 1996*[34], for general discussion). A similar pattern is seen for higher taxonomic groups (genera, families). Various hypotheses (*e.g.*, environmental patchiness, solar energy, productivity; see *Blackburn and Gaston, 1996*[11]) have been raised to explain these patterns. For example, it is assumed that warm, moist, tropical environments, with long day-lengths provide organisms with more resources for growth and reproduction than harsh environments with low energy resources (*Hunter, 2002*[41]). When environmental conditions favor the growth and reproduction of primary producers (*e.g.*, aquatic algae, corals, terrestrial flora) then these may support large numbers of secondary consumers, such as small herbivores, which also support a more numerous and diverse fauna of predators. In contrast, the development of primary producers in colder temperate ecosystems is constrained by seasonal changes in sunlight and temperature. Consequently, these ecosystems may support a less diverse biota of secondary consumers and predators.

Recently, (*Allen et al. 2002*[1]) developed a model for the effect of ambient temperature on metabolism, and hence generation time and speciation rates, and used this model to explain the latitudinal gradient in biodiversity. However, these authors also noted that the principles that underlie these spatial pattern of biodiversity are still not well understood.

Species and ecosystem diversity is also known to vary with altitude *Walter (1985)*[105] and *Gaston and Williams (1996: 214-215)*[34]. Mountainous environments, also called **orobiomes**, are subdivided vertically into altitudinal belts, such as montane, alpine and nival, that have quite different **ecosystems**. Climatic conditions at higher elevations (*e.g.*, low temperatures, high aridity) can create environments where relatively few species can survive. Similarly, in oceans and freshwaters there are usually fewer species as one moves to increasing depths below the surface. However, in the oceans there may be a rise in species richness close to the seabed, which is associated with an increase in ecosystem heterogeneity.

By mapping spatial gradients in biodiversity we can also identify areas of special conservation interest. Conservation biologists are interested in areas that have a high proportion of **endemic species**, *i.e.*, species whose distributions are naturally restricted to a limited area. It is obviously important to conserve these areas because much of their flora and fauna, and therefore the ecosystems so-formed, are found nowhere else. Areas of high endemism are also often associated with high **species richness** (see *Gaston and Spicer, 1998*[33] for references).

Some conservation biologists have focused their attention on areas that have high levels of endemism (and hence diversity) that are also experiencing a high rate of loss of ecosystems; these regions are **biodiversity hotspots**. Because biodiversity hotspots are characterized by localized concentrations of biodiversity under threat, they represent priorities for conservation action (*Sechrest et al., 2002*[89]). A **terrestrial biodiversity hotspot** is defined quantitatively as an area that has at least 0.5%, or 1,500 of the world's ca. 300,000 species of green plants (*Viridiplantae*), and that has lost at least 70% of its primary vegetation (*Myers et*

[1] This content is available online at <http://cnx.org/content/m12173/1.2/>.

al., 2000[70]; *Conservation International, 2002*[46]). **Marine biodiversity hotspots** are quantitatively defined based on measurements of relative endemism of multiple taxa (species of corals, snails, lobsters, fishes) within a region and the relative level of threat to that region (*Roberts et al., 2002*[81]). According to this approach, the Philippine archipelago and the islands of Bioko, Sao Tome, Principe and Annobon in the eastern Atlantic Gulf of Guinea are ranked as two of the most threatened marine biodiversity hotspot regions.

Conservation biologists may also be interested in **biodiversity coldspots**; these are areas that have relatively low biological diversity but also include threatened ecosystems (*Kareiva and Marvier, 2003*[51]). Although a biodiversity coldspot is low in species richness, it can also be important to conserve, as it may be the only location where a rare species is found. Extreme physical environments (low or high temperatures or pressures, or unusual chemical composition) inhabited by just one or two specially adapted species are coldspots that warrant conservation because they represent unique environments that are biologically and physically interesting. For further discussion on spatial gradients in biodiversity and associated conservation practices see the related modules on "Where is the world's biodiversity?" and "Conservation Planning at a Regional Scale."

Chapter 4

Introduction to the Biodiversity Hierarchy[1]

To effectively conserve biodiversity, we need to be able to define what we want to conserve, determine where it currently occurs, identify strategies to help conserve it, and track over time whether or not these strategies are working. The first of these items, defining what we want to conserve, is complicated by the remarkable diversity of the organisms themselves. This is a product of the **genetic diversity** of the organisms, that is, variation in the DNA (deoxyribonucleic acid) that makes up the genes of the organisms.

Genetic diversity among organisms exists at the following different levels:

- within a single individual;
- between different individuals of a single population;
- between different populations of a single species (**population diversity**);
- between different species (**species diversity**).

It can be difficult, in some cases, to establish the boundaries between these levels of diversity. For example, it may be difficult to interpret whether variation between groups of individuals represents diversity between different species, or represents diversity only between different populations of the same species. Nevertheless, in general terms, these levels of genetic diversity form a convenient hierarchy for describing the overall diversity of organisms on Earth.

Similarly, the functional and spatial aspects of biodiversity can also be discussed at a number of different levels; for example, diversity within or between **communities**, **ecosystems**, **landscapes**, biogeographical regions, and **ecoregions**.

[1]This content is available online at <http://cnx.org/content/m12162/1.2/>.

Chapter 5

What is Biodiversity? A comparison of spider communities[1]

5.1 Objectives

To explore through classification of life forms the concept of biological diversity as it occurs at various taxonomic levels.

5.2 Procedures

Spiders are a highly species rich group of invertebrates that exploit a wide variety of niches in virtually all the earth's biomes. Some species of spiders build elaborate webs that passively trap their prey whereas others are active predators that ambush or pursue their prey. Given spiders' taxonomic diversity as well as the variety of ecological niches breadth along with the ease of catching them, spiders can represent useful, fairly easily measured indicators of environmental change and community level diversity.

This exercise focuses on classifying and analyzing spider communities to explore the concept of biological diversity and experience its application to decision making in biological conservation. The exercise can be undertaken in three parts, depending on your interest level.

- **Level (1)** - You will gain experience in classifying organisms by sorting a hypothetical collection of spiders from a forest patch and determining if the spider collection is adequate to accurately represent the overall diversity of spiders present in the forest patch.
- **Level (2)** - If you wish to explore further, you can sort spider collections made at four other forest patches in the same region and contrast spider communities in terms of their species richness, species diversity, and community similarity. You will apply this information to make decisions about the priority that should be given to protecting each forest patch in order to conserve the regional pool of spider diversity.
- **Level (3)** - If you wish to explore the concepts of biodiversity yet further, you will next take into account the evolutionary relationships among the families of spiders collected. This phylogenetic perspective will augment your decision making about priorities for patch protection by accounting for evolutionary distinctiveness in addition to diversity and distinctiveness at the community level.

Once you have worked through these concepts and analyses you will have a much enhanced familiarity with the subtleties of what biological diversity is.

[1] This content is available online at <http://cnx.org/content/m12179/1.1/>.