What is Biodiversity

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CONNEXIONS

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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/>.

5.3 Level 1: Sorting and Classifying a Spider Collection and Assessing its Comprehensiveness

Obtain a paper copy of the spider collection for forest patch "1." The spiders were captured by a biologist traveling along transects through the patch and striking a random series of 100 tree branches. All spiders dislodged that fell onto an outstretched sheet were collected and preserved in alcohol. They have since been spread out on a tray for you to examine. The spider collection is hypothetical but the species pictured are actual spiders that occur in central Africa (illustrations used are from *Berland 1955*[9]).

The next task is for you to sort and identify the spiders. To do this you have to identify all the specimens in the collection. To classify the spiders look for external characters that all members of a particular group of spiders have in common but that are not shared by other groups of spiders. For example, leg length, hairiness, relative size of body segments, or abdomen patterning and abdomen shape all might be useful characters. Look for groups of morphologically indistinguishable spiders, and describe briefly the set of characters unique to each group. These operational taxonomic units that you define will be considered separate species. To assist you in classifying these organisms, a diagram of key external morphological characters of beetles is provided (Figure 5.1). Note that most spider identification depends on close examination of spider genitalia. For this exercise, however, we will be examining gross external characteristics of morphologically dissimilar species.

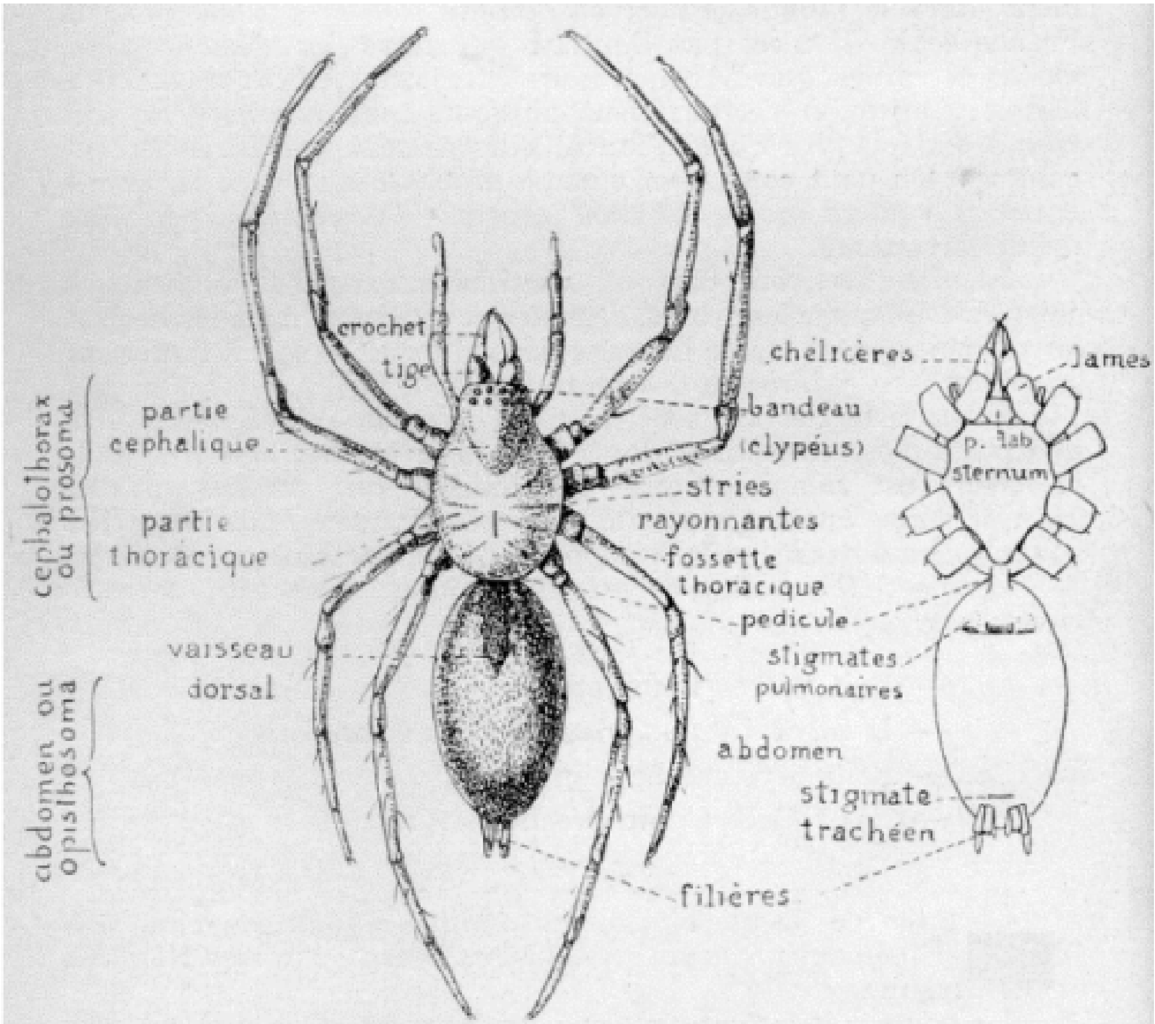

Figure 5.1: Basic external characteristics of spiders useful for identifying individuals to species.

Assign each species a working name, preferably something descriptive. For example, you might call a particular species "spotted abdomen, very hairy" or "short legs, spiky abdomen" Just remember that the more useful names will be those that signify to you something unique about the species. Construct a table listing each species, its distinguishing characteristics, the name you have applied to it, and the number of occurrences of the species in the collection (Figure 5.2).

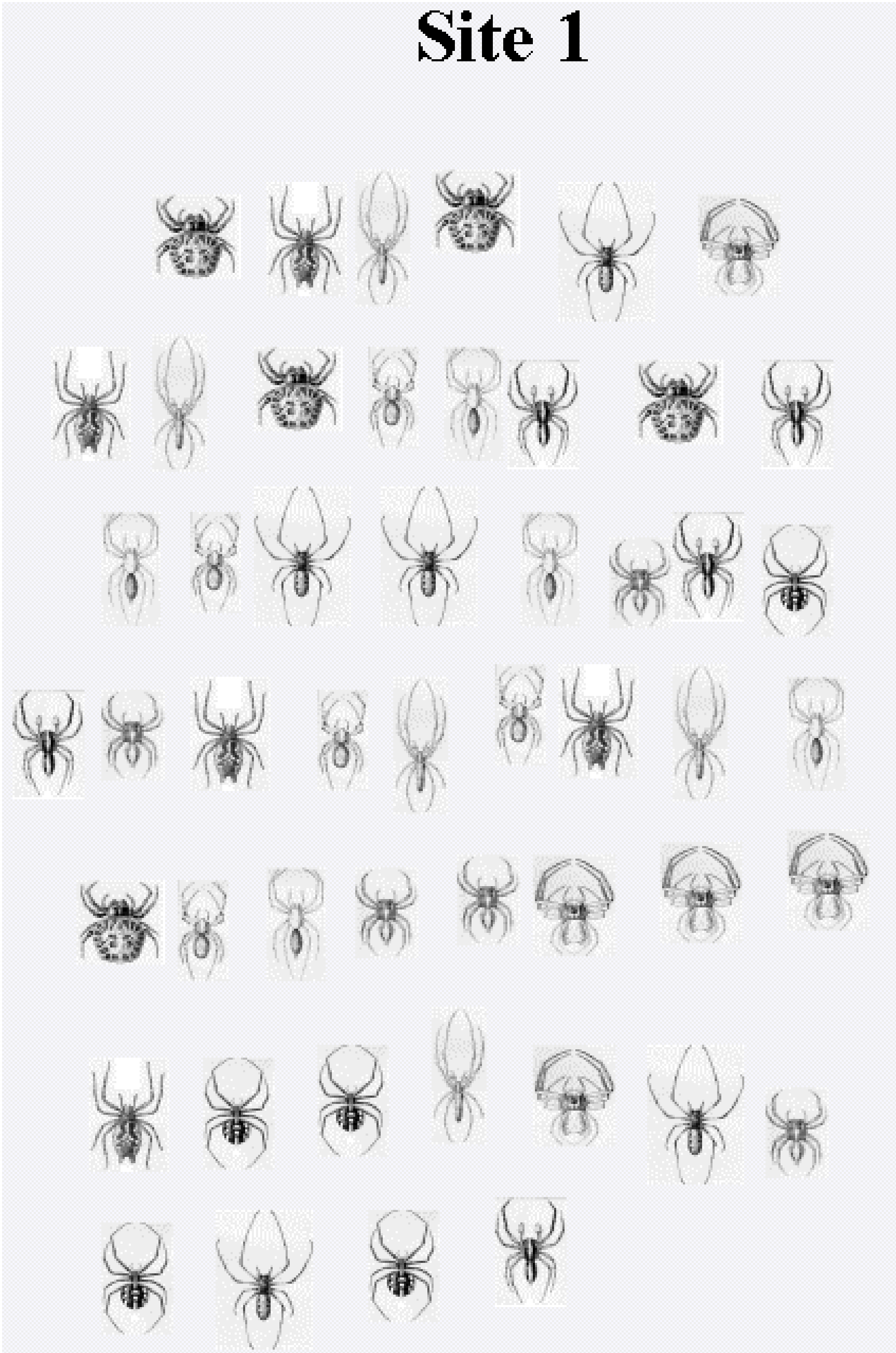

Figure 5.2

Last, ask whether this collection adequately represents the true diversity of spiders in the forest patch at the time of collection. Were most of the species present sampled or were many likely missed? This is always an important question to ask to ensure that the sample was adequate and hence can be legitimately contrasted among sites to, for example, assign areas as low versus high diversity sites.

To do this you will perform a simple but informative analysis that is standard practice for conservation biologists who do biodiversity surveys. This analysis involves constructing a so-called **collector's curve** (*Colwell and Coddington 1994*[18]). These plot the cumulative number of species observed (y-axis) against the cumulative number of individuals classified (x-axis). The collector's curve is an increasing function with a slope that will decrease as more individuals are classified and as fewer species remain to be identified (Figure 5.3). If sampling stops while the collector's curve is still rapidly increasing, sampling is incomplete and many species likely remain undetected. Alternatively, if the slope of the collector's curve reaches zero (flattens out), sampling is likely more than adequate as few to no new species remain undetected.

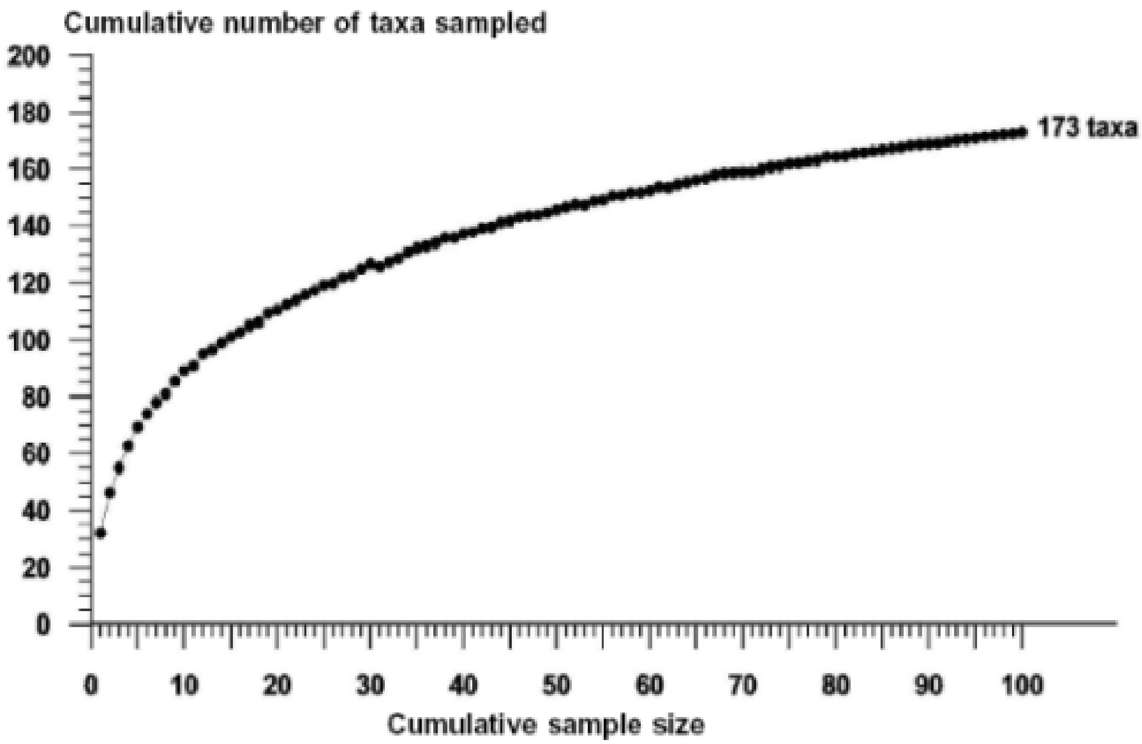

Figure 5.3: An example of a collectors curve. Cumulative sample size represents the number of individuals classified. The cumulative number of taxa sampled refers to the number of new species detected.

To construct the collector's curve for this spider collection, choose a specimen within the collection at random. This will be your first data point, such that $X = 1$ and $Y = 1$ because after examining the first individual you have also identified one new species! Next move consistently in any direction to a new specimen and record whether it is a member of a new species. In this next step, $X = 2$, but Y may remain as 1 if the next individual is not of a new species or it may change to 2 if the individual represents a new species different from individual 1. Repeat this process until you have proceeded through all 50 specimens and construct the collector's curve from the data obtained (just plot Y versus X). Does the curve flatten out? If so, after how many individual spiders have been collected? If not, is the curve still increasing? What can you conclude from the shape of your collector's curve as to whether the sample of spiders is an adequate characterization of spider diversity at the site?

5.4 Level 2: Contrasting spider diversity among sites to provide a basis for prioritizing conservation efforts

In this part of the exercise you are provided with spider collections from 4 other forest patches. The forest patches have resulted from fragmentation of a once much larger, continuous forest. You will use the spider diversity information to prioritize efforts for the five different forest patches (including the data from the first patch which you have already classified). Here are the additional spider collections: (See Figure 5.4, Figure 5.5, Figure 5.6, and Figure 5.7)

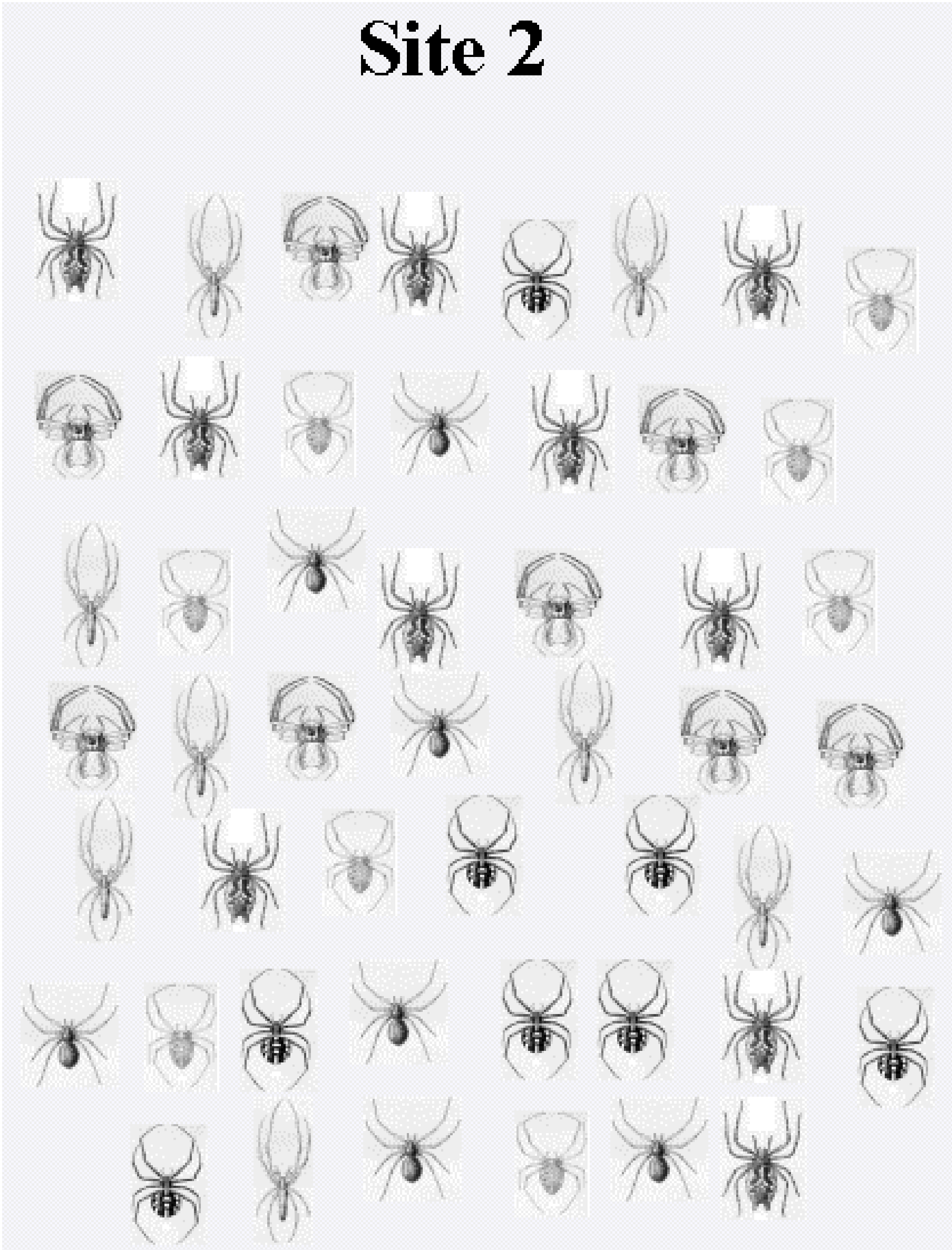

Figure 5.4

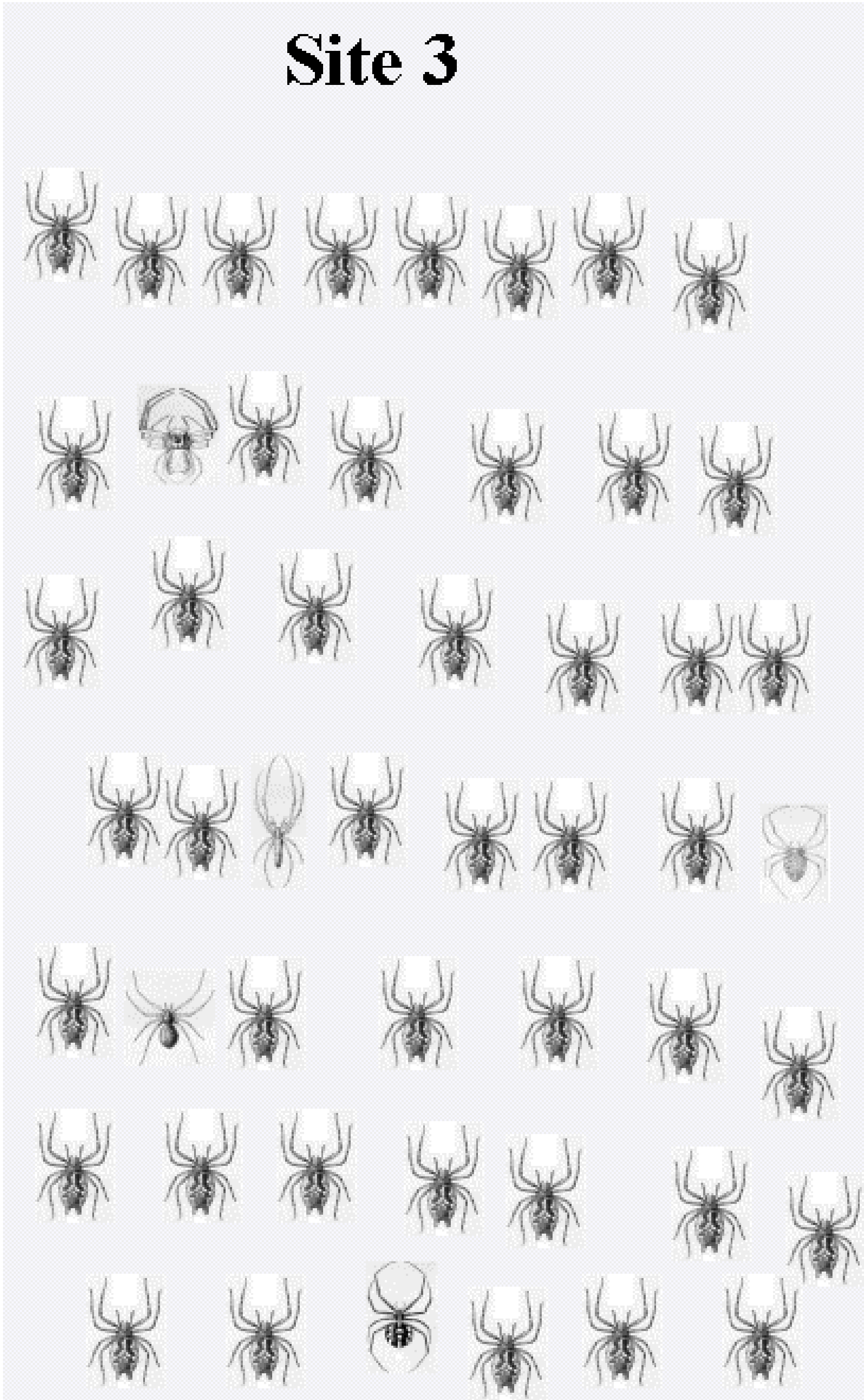

Figure 5.5

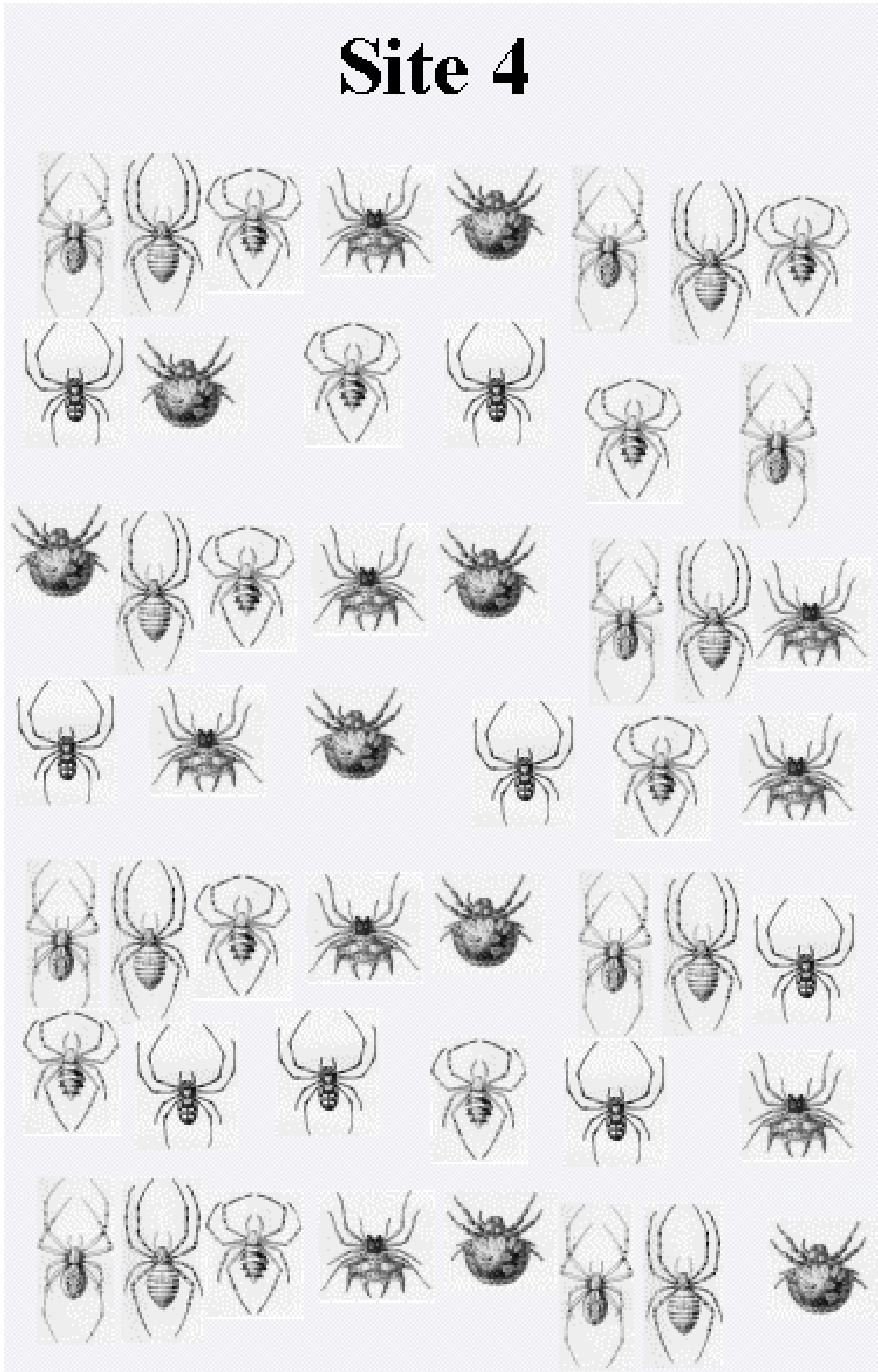

Figure 5.6

Figure 5.7

Again, tally how many individuals belonging to each species occur in each site's spider collection (use your classification of spiders completed for Site 1 (Figure 5.2) during Level 1 of the exercise). Specifically, construct a table of species (rows) by site (columns). In the table's cells put the number of individuals of each species you found in the collection from the island. You can then analyze these data to generate different measures of community characteristics to help you to decide how to prioritize protection of the forest patches. Recall that you need to rank the patches in terms of where protection efforts should be applied, and you need to provide a rationale for your ranking.

You will find it most useful to base your decisions on three community characteristics: species richness and species diversity within each forest patch, and the similarity of spider communities between patches. Species richness is simply the tally of different spider species that were collected in a forest patch. Species diversity is a more complex concept. We will use a standard index called Simpson Reciprocal Index, $\frac{1}{D}$ where D is calculated as follows:

$$D = \sum \left({p_i}^2\right)$$

where p_i = the fractional abundance of the i^{th} species on an island. For example, if you had a sample of two species with five individuals each, $D = \frac{1}{0.5^2+0.5^2} = 2$. The higher the value, the greater the diversity. The maximum value is the number of species in the sample, which occurs when all species contain an equal number of individuals. Because this index not only reflects the number of species present but also the relative distribution of individuals among species within a community it can reflect how balanced communities are in terms of how individuals are distributed across species. As a result, two communities may have precisely the same number of species, and hence species richness, but substantially different diversity measures if individuals in one community are skewed toward a few of the species whereas individuals are distributed more evenly in the other community.

Diversity is one thing, distinctiveness is quite another. Thus another important perspective in ranking sites is how different the communities are from one another. We will use the simplest available measure of community similarity, that is, the Jaccard coefficient of community similarity, to contrast community distinctiveness between all possible pairs of sites:

$$\mathrm{CC}_j = \frac{c}{S}$$

where c is the number of species common to both communities and S is the total number of species present in the two communities. For example, if one site contains only 2 species and the other site 2 species, one of which is held in common by both sites, the total number of species present is 3 and the number shared is 1, so $1/3 = 33\%$. This index ranges from 0 (when no species are found in common between communities) to 1 (when all species are found in both communities). Calculate this index to compare each pair of sites separately, that is, compare Site 1 (Figure 5.2) with Site 2 (Figure 5.4), Site 1 (Figure 5.2) with Site 3 (Figure 5.5), ..., Site 4 (Figure 5.6) with Site 5 (Figure 5.7) for 10 total comparisons. You might find it useful to determine the average similarity of one community to all the others, by averaging the CC_j values across each comparison a particular site is included.

Once you have made these calculations of diversity (species richness and Simpson's Reciprocal Index) you can tackle the primary question of the exercise: How should you rank these sites for protection and why? Making an informed decision requires reconciling your analysis with concepts of biological diversity as it pertains to diversity and distinctiveness. What do you recommend?

5.5 Level 3: Considering evolutionary distinctiveness

When contrasting patterns of species diversity and community distinctiveness, we typically treat each species as equally important, yet are they? What if a species-poor area actually is quite evolutionarily distinct from others? Similarly, what if your most species-rich site is comprised of a swarm of species that have only recently diverged from one another and are quite similar to species present at another site? These questions allude to issues of biological diversity at higher taxonomic levels. Only by looking at the underlying evolutionary relationships among species can we gain this additional perspective. We have provided in Figure 5.8 a phylogeny of the spider families that occur in your collections (a genuine phylogeny for these families based in large part on *Coddington and Levi 1991*[17]). In brief, the more closely related families (and species therein) are located on more proximal branches within the phylogeny. Based on the evolutionary relationships among these families, will you modify any of the conclusions you made on prioritizing forest patches for protection based on patterns of species diversity alone? If so, why?

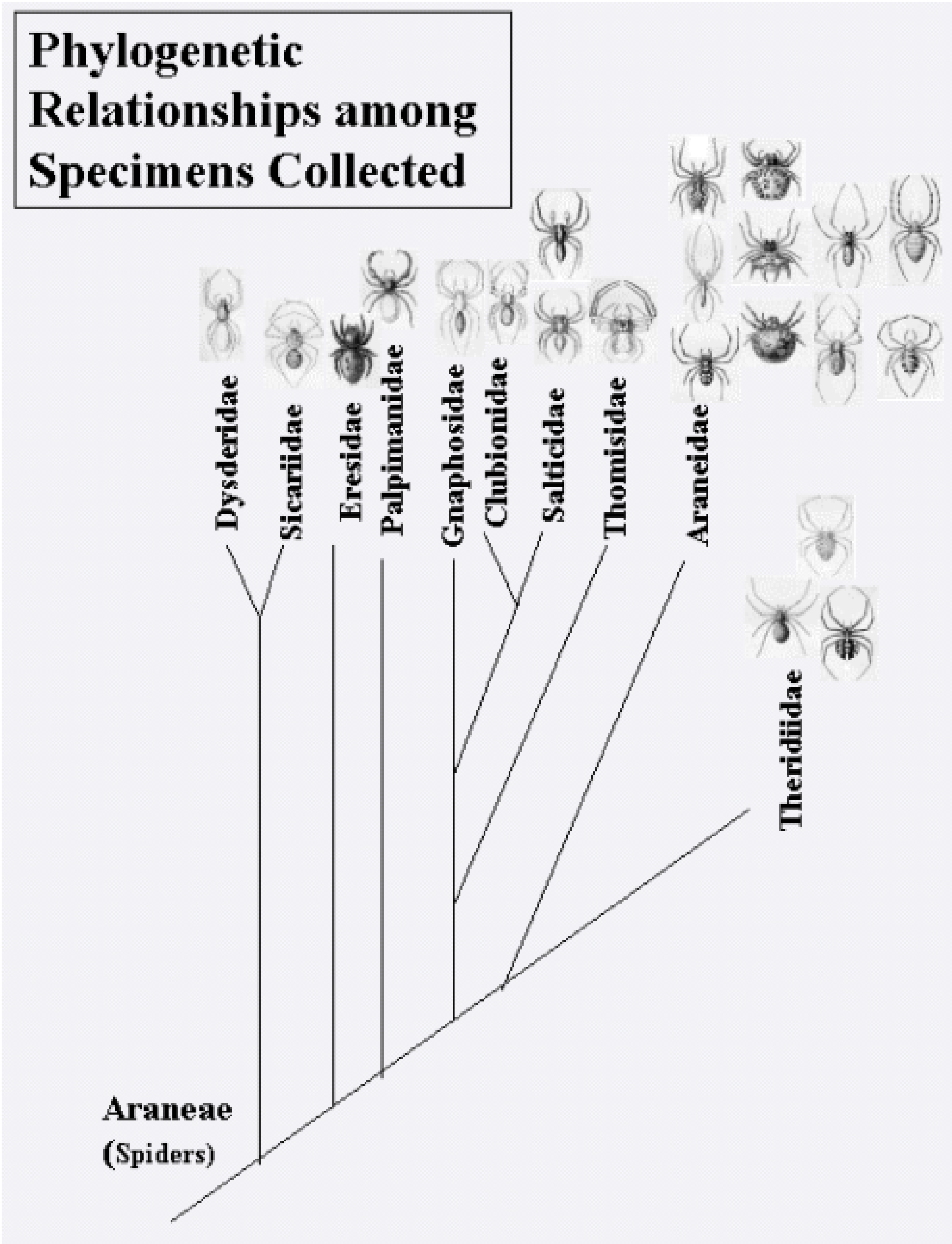
Phylogenetic
Relationships among
Specimens Collected
Dysderidae
Sicariidae
Eresidae
Palpimanidae
Gnaphosidae
Clubionidae
Salticidae
Thomisidae
Araneidae
Theridiidae
Araneae
(Spiders)

Figure 5.8

Chapter 6

Species Diversity[1]

Strictly speaking, **species diversity** is the number of different species in a particular area (**species richness**) weighted by some measure of abundance such as number of individuals or biomass. However, it is common for conservation biologists to speak of species diversity even when they are actually referring to species richness.

Another measure of species diversity is the **species evenness**, which is the relative abundance with which each species is represented in an area. An **ecosystem** where all the species are represented by the same number of individuals has high species evenness. An ecosystem where some species are represented by many individuals, and other species are represented by very few individuals has a low species evenness. Table 6.1: Estimated Numbers of Described Species, Based on Lecointre and Guyader (2001) shows the abundance of species (number of individuals per hectare) in three ecosystems and gives the measures of species richness (S), evenness (E), and the Shannon diversity index (H).

Shannon's diversity index $H = -\left(\sum \left(\rho_i \ln \rho_i\right)\right)$

- ρ_i is the proportion of the total number of specimens i expressed as a proportion of the total number of species for all species in the ecosystem. The product of $\rho_i \ln \rho_i$ for each species in the ecosystem is summed, and multiplied by -1 to give H. The species evenness index (E) is calculated as $E = \frac{H}{H_{\max}}$.
- $H_{\max}$ is the maximum possible value of H, and is equivalent to $\ln S$. Thus $E = \frac{H}{\ln S}$

See *Gibbs et al., 1998: p157*[35] and *Beals et al. (2000)*[8] for discussion and examples. *Magurran (1988)*[61] also gives discussion of the methods of quantifying diversity.

In Table 6.1: Estimated Numbers of Described Species, Based on Lecointre and Guyader (2001), ecosystem A shows the greatest diversity in terms of species richness. However, ecosystem B could be described as being **richer** insofar as most species present are more evenly represented by numbers of individuals; thus the species evenness (E) value is larger. This example also illustrates a condition that is often seen in tropical ecosystems, where disturbance of the ecosystem causes uncommon species to become even less common, and common species to become even more common. Disturbance of ecosystem B may produce ecosystem C, where the uncommon species 3 has become less common, and the relatively common species 1 has become more common. There may even be an increase in the number of species in some disturbed ecosystems but, as noted above, this may occur with a concomitant reduction in the abundance of individuals or local extinction of the rarer species.

Species richness and species evenness are probably the most frequently used measures of the total biodiversity of a region. Species diversity is also described in terms of the **phylogenetic diversity**, or evolutionary relatedness, of the species present in an area. For example, some areas may be rich in closely related taxa, having evolved from a common ancestor that was also found in that same area, whereas other areas may have an array of less closely related species descended from different ancestors (see further comments in the section on Species diversity as a surrogate for global biodiversity (p. 27)).

[1]This content is available online at <http://cnx.org/content/m12174/1.3/>.

To count the number of species, we must define what constitutes a species. There are several competing theories, or "species concepts" (*Mayden, 1997*[62]). The most widely accepted are the morphological species concept, the biological species concept, and the phylogenetic species concept.

Although the **morphological species concept** (MSC) is largely outdated as a theoretical definition, it is still widely used. According to this concept:

> *species are the smallest groups that are consistently and persistently distinct, and distinguishable by ordinary means. (- **Cronquist, 1978**[?]).*

In other words, **morphological species concept** states that "a species is a community, or a number of related communities, whose distinctive morphological characters are, in the opinion of a competent systematist, sufficiently definite to entitle it, or them, to a specific name" (*Regan, 1926: 75*[80]).

The **biological species concept** (BSC), as described by *Mayr and Ashlock (1991)*[64], states that

> *"a species is a group of interbreeding natural populations that is reproductively isolated from other such groups".*

According to the **phylogenetic species concept** (PSC), as defined by *Cracraft (1983)*[19], a species :

> *"is the smallest diagnosable cluster of individual organism [that is, the cluster of organisms are identifiably distinct from other clusters] within which there is a parental pattern of ancestry and descent".*

These concepts are not congruent, and considerable debate exists about the advantages and disadvantages of all existing species concepts (for further discussion, see the module on Macroevolution: essentials of systematics and taxonomy).

In practice, systematists usually group specimens together according to shared features (genetic, morphological, physiological). When two or more groups show different sets of shared characters, and the shared characters for each group allow all the members of that group to be distinguished relatively easily and consistently from the members of another group, then the groups are considered different species. This approach relies on the objectivity of the phylogenetic species concept (*i.e.*, the use of intrinsic, shared, characters to define or diagnose a species) and applies it to the practicality of the morphological species concept, in terms of sorting specimens into groups (*Kottelat, 1995*[52], *1997*[53]).

Despite their differences, all species concepts are based on the understanding that there are parameters that make a species a discrete and identifiable evolutionary entity. If populations of a species become isolated, either through differences in their distribution (*i.e.*, geographic isolation) or through differences in their reproductive biology (*i.e.*, reproductive isolation), they can diverge, ultimately resulting in speciation. During this process, we expect to see distinct populations representing **incipient species** - species in the process of formation. Some researchers may describe these as subspecies or some other sub-category, according to the species concept used by these researchers. However, it is very difficult to decide when a population is sufficiently different from other populations to merit its ranking as a subspecies. For these reasons, subspecific and infrasubspecific ranks may become extremely subjective decisions of the degree of distinctiveness between groups of organisms (*Kottelat, 1997*[53]).

An **evolutionary significant unit** (ESU) is defined, in conservation biology, as a group of organisms that has undergone significant genetic divergence from other groups of the same species. According to *Ryder, 1986*[84] identification of ESUs requires the use of natural history information, range and distribution data, and results from analyses of morphometrics, cytogenetics, allozymes and nuclear and mitochondrial DNA. In practice, many ESUs are based on only a subset of these data sources. Nevertheless, it is necessary to compare data from different sources (*e.g.*, analyses of distribution, morphometrics, and DNA) when establishing the status of ESUs. If the ESUs are based on populations that are **sympatric** or **parapatric** then it is particularly important to give evidence of significant genetic distance between those populations.

ESUs are important for conservation management because they can be used to identify discrete components of the evolutionary legacy of a species that warrant conservation action. Nevertheless, in evolutionary terms and hence in many systematic studies, species are recognized as the minimum identifiable unit of biodiversity above the level of a single organism (*Kottelat, 1997*[53]). Thus there is generally more systematic information available for species diversity than for subspecific categories and for ESUs. Consequently, estimates of species diversity are used more frequently as the standard measure of overall biodiversity of a region.

6.1 Species Diversity as a Surrogate for Global Biodiversity

Global biodiversity is frequently expressed as the total number of species currently living on Earth, *i.e.*, its species richness. Between about 1.5 and 1.75 million species have been discovered and scientifically described thus far (*LeCointre and Guyader, 2001*[58]; *Cracraft, 2002*[20]). Estimates for the number of scientifically valid species vary partly because of differing opinions on the definition of a species.For example, the phylogenetic species concept recognizes more species than the biological species concept. Also, some scientific descriptions of species appear in old, obscure, or poorly circulated publications. In these cases, scientists may accidentally overlook certain species when preparing inventories of biota, causing them to describe and name an already known species.

More significantly, some species are very difficult to identify. For example, taxonomically "cryptic species" look very similar to other species and may be misidentified (and hence overlooked as being a different species). Thus, several different, but similar-looking species, identified as a single species by one scientist, are identified as completely different species by another scientist. For further discussion of cryptic species, with specific examples of cryptic frogs from Vietnam, see *Inger (1999)*[45] and *Bain et al., (in press)*[7].

Scientists expect that the scientifically described species represent only a small fraction of the total number of species on Earth today. Many additional species have yet to be discovered, or are known to scientists but have not been formally described. Scientists estimate that the total number of species on Earth could range from about 3.6 million up to 117.7 million, with 13 to 20 million being the most frequently cited range (*Hammond, 1995*[37]; *Cracraft, 2002*[20]).

The estimation of total number of species is based on extrapolations from what we already know about certain groups of species. For example, we can extrapolate using the ratio of scientifically described species to undescribed species of a particular group of organisms collected from a prescribed area. However, we know so little about some groups of organisms, such as bacteria and some types of fungi, that we do not have suitable baseline data from which we can extrapolate our estimated total number of species on Earth. Additionally, some groups of organisms have not been comprehensively collected from areas where their species richness is likely to be richest (for example, insects in tropical rainforests). These factors, and the fact that different people have used different techniques and data sets to extrapolate the total number of species, explain the large range between the lower and upper figures of 3.6 million and 117.7 million, respectively.

While it is important to know the total number of species of Earth, it is also informative to have some measure of the proportional representation of different groups of related species (*e.g.* bacteria, flowering plants, insects, birds, mammals). This is usually referred to as the taxonomic or phylogenetic diversity. Species are grouped together according to shared characteristics (genetic, anatomical, biochemical, physiological, or behavioral) and this gives us a classification of the species based on their phylogenetic, or apparent evolutionary relationships. We can then use this information to assess the proportion of related species among the total number of species on Earth. Table 6.1: Estimated Numbers of Described Species, Based on Lecointre and Guyader (2001) contains a selection of well-known taxa.

Estimated Numbers of Described Species, Based on Lecointre and Guyader (2001)

Taxon	**Taxon Common Name**	**Number of species described***	**N as percentage of total number of described species***
Bacteria	true bacteria	9021	0.5
Archaea	archaebacteria	259	0.01
Bryophyta	mosses	15000	0.9
Lycopodiophyta	clubmosses	1275	0.07
Filicophyta	ferns	9500	0.5
Coniferophyta	conifers	601	0.03
Magnoliophyta	flowering plants	233885	13.4
Fungi	fungi	100800	5.8
"Porifera"	sponges	10000	0.6
Cnidaria	cnidarians	9000	0.5
Rotifera	rotifers	1800	0.1
Platyhelminthes	flatworms	13780	0.8
Mollusca	mollusks	117495	6.7
Annelida	annelid worms	14360	0.8
Nematoda	nematode worms	20000	1.1
Arachnida	arachnids	74445	4.3
Crustacea	crustaceans	38839	2.2
Insecta	insects	827875	47.4
Echinodermata	echinoderms	6000	0.3
Chondrichthyes	cartilaginous fishes	846	0.05
Actinopterygii	ray-finned bony fishes	23712	1.4
Lissamphibia	living amphibians	4975	0.3
Mammalia	mammals	4496	0.3
Chelonia	living turtles	290	0.02
Squamata	lizards and snakes	6850	0.4

continued on next page

Aves	birds	9672	0.6
Other		193075	11.0

Table 6.1: * The total number of described species is assumed to be 1,747,851. This figure, and the numbers of species for taxa are taken from *LeCointre and Guyader (2001)*[58].

Most public attention is focused on the biology and ecology of large, charismatic species such as mammals, birds, and certain species of trees (*e.g.*, mahogany, sequoia). However, the greater part of Earth's species diversity is found in other, generally overlooked groups, such as mollusks, insects, and groups of flowering plants.

Chapter 7

Alpha, Beta, and Gamma Diversity[1]

Whittaker (1972)[108] described three terms for measuring biodiversity over spatial scales: alpha, beta, and gamma diversity. **Alpha diversity** refers to the diversity within a particular area or ecosystem, and is usually expressed by the number of species (*i.e.*, **species richness**) in that ecosystem. For example, if we are monitoring the effect that British farming practices have on the diversity of native birds in a particular region of the country, then we might want to compare species diversity within different **ecosystems**, such as an undisturbed deciduous wood, a well-established hedgerow bordering a small pasture, and a large arable field. We can walk a transect in each of these three ecosystems and count the number of species we see; this gives us the alpha diversity for each ecosystem; see Table 7.1: Alpha, beta and gamma diversity for hypothetical species of birds in three different ecosystems (this example is based on the hypothetical example given by *Meffe et al., 2002; Table 6.1*[66]).

If we examine the change in species diversity between these ecosystems then we are measuring the **beta diversity**. We are counting the total number of species that are unique to each of the ecosystems being compared. For example, the beta diversity between the woodland and the hedgerow habitats is 7 (representing the 5 species found in the woodland but not the hedgerow, plus the 2 species found in the hedgerow but not the woodland). Thus, beta diversity allows us to compare diversity between ecosystems.

Gamma diversity is a measure of the overall diversity for the different ecosystems within a region. *Hunter (2002: 448) ([42])* defines gamma diversity as "geographic-scale species diversity". In the example in Table 7.1: Alpha, beta and gamma diversity for hypothetical species of birds in three different ecosystems, the total number of species for the three ecosystems 14, which represent the gamma diversity.

Alpha, beta and gamma diversity for hypothetical species of birds in three different ecosystems

Hypothetical species	Woodland habitat	Hedgerow habitat	Open field habitat
A	X		
B	X		
C	X		
			continued on next page

[1] This content is available online at <http://cnx.org/content/m12147/1.2/>.

D	X		
E	X		
F	X	X	
G	X	X	
H	X	X	
I	X	X	
J	X	X	
K		X	
L		X	X
M			X
N			X
Alpha diversity	**10**	**7**	**3**
Beta diversity	**Woodland vs. hedgerow: 7**	**Hedgerow vs. open field: 8**	**Woodland vs. open field: 13**
Gamma diversity	**14**		

Table 7.1

Chapter 8

Introduction to Utilitarian Valuation of Biodiversity[1]

Determining the value or worth of biodiversity is complex. Economists typically subdivide utilitarian or use values of biodiversity into **direct use value** for those goods that are consumed directly, such as food or timber, and **indirect use value** for those services that support the items that are consumed, including ecosystem functions like nutrient cycling.

There are several less tangible values that are sometimes called **non-use or passive values**, for things that we don't use but would consider as a loss if they were to disappear; these include **existence value**, the value of knowing something exists even if you will never use it or see it, and **bequest value**, the value of knowing something will be there for future generations (*Moran and Pearce 1994*[69]). **Potential or Option value** refers to the use that something may have in the future; sometimes this is included as a use value, we have chosen to include it within the passive values here based on its abstract nature. The components included within the category of "utilitarian" values vary somewhat in the literature. For example, some authors classify spiritual, cultural, and aesthetic values as indirect use values, whiles others consider them to be non-use values, differentiated from indirect use values – such as nutrient cycling – because spiritual, cultural, and aesthetic values for biodiversity are not essential to human survival. Still others consider these values as separate categories entirely. (See also, *Callicott 1997*[15], *Hunter 2002*[44], *Moran and Pearce 1994*[69], *Perlman and Adelson 1997*[74], *Primack 2002*[77], *Van Dyke 2003*[102]). In this module, we include spiritual, cultural and aesthetic values as a subset of indirect values or services, as they provide a service by enriching our lives (Table 8.1: Categories of Values of Biodiversity).

Categories of Values of Biodiversity

Direct Use Value (Goods)	**Indirect Use Value (Services)**	**Non-Use Values**	
Food, medicine, building material, fiber, fuel	Atmospheric and climate regulation, pollination, nutrient recycling	Potential (or Option) Value	Future value either as a good or a service
			continued on next page

[1]This content is available online at <http://cnx.org/content/m12164/1.2/>.

	Cultural, Spiritual, and Aesthetic	Existence Value	Value of knowing something exists
		Bequest Value	Value of knowing that something will be there for future generations

Table 8.1

NOTE: Some authors choose to differentiate Cultural, Spiritual, Aesthetic, and Non-Use Values from those services that provide basic survival needs such as the air we breathe.

Chapter 9

Biodiversity over Time[1]

The history of life on Earth is described in various publications and web sites (*e.g.*, *Speer, B.R. and A.G. Collins. 2000*[92]; *Tudge, 2000*[97]; *Lecointre and Guyader, 2001*[59]; *Maddison, 2001*[60] *Eldredge, 2002*[24]); it is also discussed in the module on Macroevolution: essentials of systematics and taxonomy. For the current purpose of understanding what is biodiversity, it is only necessary to note that that the diversity of species, ecosystems and landscapes that surround us today are the product of perhaps 3.7 billion (*i.e.*, 3.7×10^9) to 3.85 billion years of evolution of life on Earth (*Mojzsis et al., 1996*[67]; *Fedo and Whitehouse, 2002*[26]).

Thus, the evolutionary history of Earth has physically and biologically shaped our contemporary environment. As noted in the section on Biogeography (Chapter 13), plate tectonics and the evolution of continents and ocean basins have been instrumental in directing the evolution and distribution of the Earth's biota. However, the physical environment has also been extensively modified by these biota. Many existing landscapes are based on the remains of earlier life forms. For example, some existing large rock formations are the remains of ancient reefs formed 360 to 440 million years ago by communities of algae and invertebrates (*Veron, 2000*[47]). Very old communities of subterranean bacteria may have been responsible for shaping many geological processes during the history of the Earth, such as the conversion of minerals from one form to another, and the erosion of rocks (*Fredrickson and Onstott, 1996*[30]). The evolution of photosynthetic bacteria, sometime between 3.5 and 2.75 million years ago *Schopf, 1993*[88]; *Brasier et al., 2002*[12]; *Hayes, 2002*[38]), played an important role in the evolution of the Earth's atmosphere. These bacteria released oxygen into the atmosphere, changing it's composition from the former composition of mainly carbon dioxide, with other gases such as nitrogen, carbon monoxide, methane, hydrogen and sulphur gases present in smaller quantities. It probably took over 2 billion years for the oxygen concentration to reach the level it is today (*Hayes, 2002*[38]), but the process of oxygenation of the atmosphere led to important evolutionary changes in organisms so that they could utilize oxygen for metabolism. The rise of animal and plant life on land was associated with the development of an oxygen rich atmosphere.

[1]This content is available online at <http://cnx.org/content/m12148/1.2/>.

Chapter 10

A Brief History of Life on Earth[1]

The diversity of species, ecosystems and landscapes that surround us today are the product of perhaps 3.7 billion (*i.e.*, 3.7×10^9) to 3.85 billion years of evolution of life on Earth (*Mojzsis et al., 1996*[68]; *Fedo and Whitehouse, 2002*[**?**]). Life may have first evolved under harsh conditions, perhaps comparable to the deep-sea thermal vents where chemo-autotrophic bacteria are currently found (these are organisms that obtain their energy only from inorganic, chemical sources).

A subterranean evolution of life has also been suggested. Rock layers deep below the continents and ocean floors, that were previously thought to be too poor in nutrients to sustain life, have now been found to support thousands of strains of microorganisms. Types of bacteria have been collected from rock samples almost 2 miles below the surface, at temperatures up to 75 degrees Celsius. These chemo-autotrophic microorganisms derive their nutrients from chemicals such as carbon, hydrogen, iron and sulphur. Deep subterranean communities could have evolved underground or originated on the surface and become buried or otherwise transported down into subsurface rock strata, where they have subsequently evolved in isolation. Either way, these appear to be very old communities, and it is possible that these subterranean bacteria may have been responsible for shaping many geological processes during the history of the Earth (*e.g.*, the conversion of minerals from one form to another, and the erosion of rocks) (*Fredrickson and Onstott, 1996*[31]).

The earliest evidence for photosynthetic bacteria - suspected to be cyanobacteria - is dated at sometime between 3.5 and 2.75 billion years ago (*Schopf, 1993*[**?**]; *Brasier et al., 2002*[**?**]; *Hayes, 2002*[**?**]). These first photosynthetic organisms would have been responsible for releasing oxygen into the atmosphere. (**Photosynthesis** is the formation of carbohydrates from carbon dioxide and water, through the action of light energy on a light-sensitive pigment, such as chlorophyll, and usually resulting in the production of oxygen). Prior to this, the atmosphere was mainly composed of carbon dioxide, with other gases such as nitrogen, carbon monoxide, methane, hydrogen and sulphur gases present in smaller quantities.

It probably took over 2 billion years, from the initial advent of photosynthesis for the oxygen concentration in the atmosphere to reach the level it is at today (*Hayes, 2002*[**?**]). As oxygen levels rose, some of the early anaerobic species probably became extinct, and others probably became restricted to habitats that remained free of oxygen. Some assumed a lifestyle permanently lodged inside aerobic cells. The anaerobic cells might, initially, have been incorporated into the aerobic cells after those aerobes had engulfed them as food. Alternatively, the anaerobes might have invaded the aerobic hosts and become parasites within them. Either way, a more intimate symbiotic relationship subsequently evolved between these aerobic and anaerobic cells. In these cases the survival of each cell was dependent on the function of the other cell.

The evolution of this symbiotic relationship was an extremely important step in the evolution of more complex cells that have a nucleus, which is a characteristic of the Eucarya or eucaryotes (eu = good, or true; and karyon = kernel, or nucleus). Recent studies of rocks from Western Australia have suggested that the earliest forms of single-celled eucaryotes might be at least 2.7 billion years old (*Anon, 2001*[3]). According

[1] This content is available online at <http://cnx.org/content/m12146/1.2/>.

to contemporary theories, there has been sufficient time, over those 2.7 billion years, for some of the genes of the invading anaerobe to have been lost, or even transferred to the nucleus of the host aerobe cell. As a result, the genomes of the ancestral invader and ancestral host have become mingled and the two entities can now be considered as one from a genetic standpoint.

The evolutionary history of the Eucarya is described in various standard references and so is not covered in detail here. Briefly, eucaryotes constitute three well known groups - the Viridiplantae or green plants, the Fungi, and the Metazoa or animals. There are also many basal groups of eucaryotes that are extremely diverse - and many of which are evolutionarily ancient. For example, the Rhodophyta, or red algae, which might be the sister-group to the Viridiplantae, includes fossil representatives dating from the Precambrian, 1025 billion years ago. The Stramenopiles includes small, single-celled organisms such as diatoms, fungus-like species of water moulds and downy mildews, and extremely large, multicellular brown seaweeds such as kelps.

The earliest known green plants are green algae, dating from the Cambrian, at least 500 million years ago. By the end of the Devonian, 360 million years ago, plants had become quite diverse and included representatives similar to modern plants. Green plants have been extremely important in shaping the environment. Fueled by sunlight, they are the primary producers of carbohydrates, sugars that are essential food resources for herbivores that are then prey to predatory carnivores. The evolution and ecology of pollinating insects is closely associated with the evolution of the Angiosperms, or flowering plants, since the Jurassic and Cretaceous periods.

Fungi, which date back to the Precambrian times about 650 to 540 million years ago, are also important in shaping and sustaining biodiversity. By breaking down dead organic material and using this for their growth, they recycle nutrients back through ecosystems. Fungi are also responsible for causing several plant and animal diseases. Fungi also form symbiotic relationships with tree species, often in nutrient-poor soils such as are found in the humid tropics, allowing their symbiont trees the ability to flourish in what would otherwise be a difficult environment.

Metazoa, which date to over 500 million years ago have also been responsible for shaping many ecosystems, from the specialized tubeworms of deep sea, hydrothermal vent communities of the ocean floor, to the birds living in the high altitudes of the Himalayas, such as the impeyan pheasant and Tibetan snow cock. Many species of animals are parasitic on other species and can significantly affect the behavior and life-cycles of their hosts.

Thus, the evolutionary history of Earth has physically and biologically shaped our contemporary environment. Many existing landscapes are based on the remains of earlier life forms. For example, some existing large rock formations are the remains of ancient reefs formed 360 to 440 million years ago by communities of algae and invertebrates (*Veron, 2000*[48]).

Chapter 11

Ecosystem Diversity[1]

An **ecosystem** is a community plus the physical environment that it occupies at a given time. An ecosystem can exist at any scale, for example, from the size of a small tide pool up to the size of the entire biosphere. However, lakes, marshes, and forest stands represent more typical examples of the areas that are compared in discussions of ecosystem diversity.

Broadly speaking, the diversity of an ecosystem is dependent on the physical characteristics of the environment, the diversity of species present, and the interactions that the species have with each other and with the environment. Therefore, the functional complexity of an ecosystem can be expected to increase with the number and taxonomic diversity of the species present, and the vertical and horizontal complexity of the physical environment. However, one should note that some ecosystems (such as submarine black smokers, or hot springs) that do not appear to be physically complex, and that are not especially rich in species, may be considered to be functionally complex. This is because they include species that have remarkable biochemical specializations for surviving in the harsh environment and obtaining their energy from inorganic chemical sources (*e.g.*, see discussions of *Rothschild and Mancinelli, 2001*[83]).

The physical characteristics of an environment that affect ecosystem diversity are themselves quite complex (as previously noted for community diversity (Chapter 14)). These characteristics include, for example, the temperature, precipitation, and topography of the ecosystem. Therefore, there is a general trend for warm tropical ecosystems to be richer in species than cold temperate ecosystems (see "Spatial gradients in biodiversity (Chapter 3)"). Also, the energy flux in the environment can significantly affect the ecosystem. An exposed coastline with high wave energy will have a considerably different type of ecosystem than a low-energy environment such as a sheltered salt marsh. Similarly, an exposed hilltop or mountainside is likely to have stunted vegetation and low species diversity compared to more prolific vegetation and high species diversity in sheltered valleys (see *Walter, 1985*[106], and *Smith, 1990*[91] for general discussions on factors affecting ecosystems, and comparative ecosystem ecology).

Environmental disturbance on a variety of temporal and spatial scales can affect the species richness and, consequently, the diversity of an ecosystem. For example, river systems in the North Island of New Zealand have been affected by volcanic disturbance several times over the last 25,000 years. Ash-laden floods running down the rivers would have extirpated most of the fish fauna in the rivers, and recolonization has been possible only by a limited number of diadromous species (*i.e.*, species, like eels and salmons, that migrate between freshwater and seawater at fixed times during their life cycle). Once the disturbed rivers had recovered, the diadromous species would have been able to recolonize the rivers by dispersal through the sea from other unaffected rivers (*McDowall, 1996*[65]).

Nevertheless, moderate levels of occasional disturbance can also increase the species richness of an ecosystem by creating spatial heterogeneity in the ecosystem, and also by preventing certain species from dominating the ecosystem. (See the module on Organizing Principles of the Natural World for further discussion).

Ecosystems may be classified according to the dominant type of environment, or dominant type of

[1]This content is available online at <http://cnx.org/content/m12156/1.2/>.

species present; for example, a salt marsh ecosystem, a rocky shore intertidal ecosystem, a mangrove swamp ecosystem. Because temperature is an important aspect in shaping ecosystem diversity, it is also used in ecosystem classification (*e.g.*, cold winter deserts, versus warm deserts) (*Udvardy, 1975*[99]).

While the physical characteristics of an area will significantly influence the diversity of the species within a community, the organisms can also modify the physical characteristics of the ecosystem. For example, stony corals (Scleractinia) are responsible for building the extensive calcareous structures that are the basis for coral reef ecosystems that can extend thousands of kilometers (*e.g.* Great Barrier Reef). There are less extensive ways in which organisms can modify their ecosystems. For example, trees can modify the microclimate and the structure and chemical composition of the soil around them. For discussion of the geomorphic influences of various invertebrates and vertebrates see (*Butler, 1995*[14]) and, for further discussion of ecosystem diversity see the module on Processes and functions of ecological systems .

Chapter 12

Population Diversity[1]

A **population** is a group of individuals of the same species that share aspects of their genetics or **demography** more closely with each other than with other groups of individuals of that species (where demography is the statistical characteristic of the population such as size, density, birth and death rates, distribution, and movement of migration).

Population diversity may be measured in terms of the variation in genetic and morphological features that define the different populations. The diversity may also be measured in terms of the populations' demographics, such as numbers of individuals present, and the proportional representation of different age classes and sexes. However, it can be difficult to measure demography and genetics (*e.g.*, allele frequencies) for all species. Therefore, a more practical way of defining a population, and measuring its diversity, is by the space it occupies. Accordingly, a **population** is a group of individuals of the same species occupying a defined area at the same time (*Hunter, 2002: 144*[42]). The area occupied by a population is most effectively defined by the ecological boundaries that are important to the population (for example, a particular region and type of vegetation for a population of beetles, or a particular pond for a population of fish).

The geographic range and distribution of populations (*i.e.*, their spatial structure) represent key factors in analyzing population diversity because they give an indication of likelihood of movement of organisms between populations and subsequent genetic and demographic interchange. Similarly, an estimate of the overall population size provides a measure of the potential genetic diversity within the population; large populations usually represent larger gene pools and hence greater potential diversity (see Genetic diversity[2]).

Isolated populations, with very low levels of interchange, show high levels of genetic divergence (*Hunter, 2002: 145*[42]), and exhibit unique adaptations to the biotic and abiotic characteristics of their habitat. The genetic diversity of some groups that generally do not disperse well - such as amphibians, mollusks, and some herbaceous plants - may be mostly restricted to local populations (*Avise, 1994*[4]). For this reason, range retractions of species can lead to loss of local populations and the genetic diversity they hold. Loss of isolated populations along with their unique component of genetic variation is considered by some scientists to be one of the greatest but most overlooked tragedies of the biodiversity crisis (*Ehrlich & Raven 1969*[23]).

Populations can be categorized according to the level of divergence between them. Isolated and genetically distinct populations of a single species may be referred to as subspecies according to some (but not all) species concepts. Populations that show less genetic divergence might be recognized as **variants** or **races.** However, the distinctions between subspecies and other categories can be somewhat arbitrary (see Species diversity (Chapter 6)).

A species that is ecologically linked to a specialized, patchy habitat may likely assume the patchy distribution of the habitat itself, with several different populations distributed at different distances from each other. This is the case, for example, for species that live in wetlands, alpine zones on mountaintops, particular soil types or forest types, springs, and many other comparable situations. Individual organisms may

[1] This content is available online at <http://cnx.org/content/m12171/1.2/>.
[2] "Genetic Diversity" <http://cnx.org/content/m12158/latest/>

periodically disperse from one population to another, facilitating genetic exchange between the populations. This group of different but interlinked populations, with each different population located in its own, discrete patch of habitat, is called a **metapopulation**.

There may be quite different levels of dispersal between the constituent populations of a metapopulation. For example, a large or overcrowded population patch is unlikely to be able to support much immigration from neighboring populations; it can, however, act as a **source** of dispersing individuals that will move away to join other populations or create new ones. In contrast, a small population is unlikely to have a high degree of emigration; instead, it can receive a high degree of immigration. A population that requires net immigration in order to sustain itself acts as a **sink**. The extent of genetic exchange between source and sink populations depends, therefore, on the size of the populations, the carrying capacity of the habitats where the populations are found, and the ability of individuals to move between habitats. Consequently, understanding how the patches and their constituent populations are arranged within the metapopulation, and the ease with which individuals are able to move among them is key to describing the population diversity and conserving the species. For more discussion, see the module on Metapopulations.

Chapter 13

Biogeographic Diversity[1]

Biogeography is "the study of the distribution of organisms in space and through time". Analyses of the patterns of biogeography can be divided into the two fields of historical biogeography and ecological biogeography (*Wiley, 1981*[109]).

Historical biogeography examines past events in the geological history of the Earth and uses these to explain patterns in the spatial and temporal distributions of organisms (usually species or higher taxonomic ranks). For example, an explanation of the distribution of closely related groups of organisms in Africa and South America is based on the understanding that these two land masses were formerly connected as part of a single land mass (Gondwana). The ancestors of those related species which are now found in Africa and South America are assumed to have had a cosmopolitan distribution across both continents when they were connected. Following the separation of the continents by the process of plate tectonics, the isolated populations are assumed to have undergone **allopatric speciation** (*i.e.*, speciation achieved between populations that are completely geographically separate). This separation resulted in the closely related groups of species on the now separate continents. Clearly, an understanding of the systematics of the groups of organisms (*i.e.*, the evolutionary relationships that exists between the species) is an integral part of these historical biogeographic analyses.

The same historical biogeographic hypotheses can be applied to the spatial and temporal distributions of marine biota. For example, the biogeography of fishes from different ocean basins has been shown to be associated with the geological evolution of these ocean basins (see *Stiassny and Harrison, 2000*[95] for examples with references). However, we cannot assume that all existing distribution patterns are solely the product of these past geological processes. It is evident, for example, that the existing marine fauna of the Mediterranean is a product of the complex geological history of this marine basin, involving separation from the Indian and Atlantic Oceans, periods of extensive desiccation followed by flooding and recolonization from the Atlantic (*Por, 1989*[76]). However, there is also good evidence that the eastern end of the Mediterranean has been colonized more recently by species that have dispersed from the Red Sea via the Suez canal.

Thus, the field of **ecological biogeography** first examines the dispersal of organisms (usually individuals or populations) and the mechanisms that influence this dispersal, and then uses this information to explain the spatial distribution patterns of these organisms. For further discussion see the module on "Biogeography" and see *Wiley, 1981*[109], and *Humphries and Parenti, 1999*[39].

[1]This content is available online at <http://cnx.org/content/m12149/1.2/>.

Chapter 14

Community Diversity[1]

A **community** comprises the populations of different species that naturally occur and interact in a particular environment. Some communities are relatively small in scale and may have well-defined boundaries. Some examples are: species found in or around a desert spring, the collection of species associated with ripening figs in a tropical forest, those clustered around a hydrothermal vent on the ocean floor, those in the spray zone of a waterfall, or under warm stones in the alpine zone on a mountaintop. Other communities are larger, more complex, and may be less clearly defined, such as old-growth forests of the northwest coast of North America, lowland fen communities of the British Isles, or the community of freshwater species of Lake Baikal.

Sometimes biologists apply the term "community" to a subset of organisms within a larger community. For example, some biologists may refer to the "community" of species specialized for living and feeding entirely in the forest canopy, whereas other biologists may refer to this as part of a larger forest community. This larger forest community includes those species living in the canopy, those on the forest floor, and those moving between these two habitats, as well as the functional interrelationships between all of these. Similarly, some biologists working on ecosystem management might distinguish between the community of species that are endemic to an area (*e.g.* species that are endemic to an island) as well as those "exotic" species that have been introduced to that area. The introduced species form part of the larger, modified community of the area, but might not be considered as part of the regions original and distinctive community.

Communities are frequently classified by their overall appearance, or **physiognomy**. For example, coral reef communities are classified according to the appearance of the reefs where they are located, *i.e.*, fringing reef communities, barrier reef communities, and atoll communities. Similarly, different stream communities may be classified by the physical characteristics of that part of the stream where the community is located, such as riffle zone communities and pool communities. However, one of the easiest, and hence most frequent methods of community classification is based on the dominant types of species present for example, intertidal mussel bed communities, Ponderosa pine forest communities of the Pacific northwest region of the U.S., or Mediterranean scrubland communities. Multivariate statistics provide more complex methods for diagnosing communities, for example, by arranging species on coordinate axes (*e.g.*, x-y axes) that represent gradients in environmental factors such as temperature or humidity. For more information, see the module on "Natural communities in space and time."

The factors that determine the diversity of a community are extremely complex. There are many theories on what these factors are and how they determine community and ecosystem diversity. Environmental factors, such as temperature, precipitation, sunlight, and the availability of inorganic and organic nutrients are very important in shaping communities and **ecosystems**. *Hunter (2002: 81)*[43] notes that, generally speaking, organisms can persist and evolve in places where there are sufficient environmental resources for the organisms to channel energy into growth and reproduction rather than simply the metabolic requirements for survival. In other words, organisms are less likely to thrive in a harsh environment with low energy

[1]This content is available online at <http://cnx.org/content/m12150/1.2/>.

resources. One way of measuring community diversity is to examine the energy flow through food webs that unite the species within the community; the extent of community diversity can be measured by the number of links in the food web. However, in practice, it can be very difficult to quantify the functional interactions between the species within a community. It is easier to measure the genetic diversity of the populations in the community, and to count the numbers of species present, and use these measures of genetic diversity and species richness as proxies for describing the functional diversity of the community. The evolutionary or taxonomic diversity of the species present is another way of measuring the diversity of a community, for application to conservation biology.

Chapter 15

Ecoregions[1]

Since the 1980s, there has been an increasing tendency to map biodiversity over "ecosystem regions" or "ecoregions". An **ecoregion** is "a relatively large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions" (*WWF, 1999*[28]); thus, the ecosystems within an ecoregion have certain distinct characters in common (*Bailey, 1998a*[6]). Several standard methods of classifying ecoregions have been developed, with climate, altitude, and predominant vegetation being important criteria (*Stein et al., 2000*[93]). Bailey's (1983, 1998a, b) classification is one of the most widely adopted. It is a hierarchical system with four levels: domains, divisions, provinces and sections.

Domains are the largest geographic levels and are defined by climate, *e.g.*, polar domain, dry domain, or humid tropical domain. Domains are split into smaller divisions that are defined according climate and vegetation, and the divisions are split into smaller provinces that are usually defined by their major plant formations. Some divisions also include varieties of "mountain provinces". These generally have a similar climatic regime to the neighboring lowlands but show some altitudinal zonation, and they are defined according to the types of zonation present. Provinces are divided into sections, which are defined by the landforms present.

Because ecoregions are defined by their shared biotic and abiotic characteristics, they represent practical units on which to base conservation planning. Moreover, the hierarchical nature of Bailey's ecoregion classification allows for conservation management to be planned and implemented at a variety of geographical levels, from small scale programs focused on discrete sections, to much larger national or international projects that target divisions. Olson and Dinerstein (*2002*[72]) identified 238 terrestrial or aquatic ecoregions called the "Global 200" that they considered to be priorities for global conservation. These ecoregions were selected because they harbor exceptional biodiversity and are representative of the variety of Earths ecosystems. For further discussion of ecoregions see the modules on Landscape ecology and Conservation planning on a regional scale.

[1]This content is available online at <http://cnx.org/content/m12155/1.2/>.

Chapter 16

Extinction[1]

Extinction (the complete disappearance of a species from Earth) is an important part of the evolution of life on Earth. The current diversity of species is a product of the processes of extinction and speciation throughout the previous 3.8 billion year history of life. Raup (*1991*[78]) assumed that there might be 40 million species alive today, but between 5 and 50 billion species have lived at some time during the history of the Earth. Therefore, Raup estimated that 99.9% of all the life that has existed on Earth is now **extinct**); a species is assumed to be extinct when there is no reasonable doubt that the last individual has died (*IUCN, 2002*[29]). However, extinction has not occurred at a constant pace through the Earth's history. There have been at least five periods when there has been a sudden increase in the rate of extinction, such that the rate has at least doubled, and the extinctions have included representatives from many different taxonomic groups of plants and animals; these events are called **mass extinctions**. The timing of these mass extinctions is shown in Figure 16.1.

[1] This content is available online at <http://cnx.org/content/m12157/1.2/>.

THE MAJOR EXTINCTION EVENTS

Era	Period	Epoch	Approximate duration of Era, Period, or Epoch (millions of years before present)	Major extinction events*
CENOZOIC	Quaternary	Holocene	present-0.01	← 6th major extinction ?
		Pleistocene	0.01-1.6	
	Tertiary	Pliocene	1.6-5.3	
		Miocene	5.3-24	
		Oligocene	24-37	
		Eocene	37-58	
		Paleocene	58-65	
MESOZOIC	Cretaceous		65-144	← 5th major extinction (end of Cretaceous; K-T boundary)
	Jurassic		144-208	
	Triassic		208-245	← 4th major extinction (end of Triassic)
PALEOZOIC	Permian		245-286	← 3rd major extinction (end of Permian)
	(Carboniferous) Pennsylvanian		286-325	
	(Carboniferous) Mississippian		325-360	
	Devonian		360-408	← 2nd major extinction (late Devonian)
	Silurian		408-440	
	Ordovician		440-505	← 1st major extinction (end of Ordovician)
	Cambrian		505-570	
PRECAMBRIAN			570-4500	

* Many smaller extinction events are not indicated; see Raup (1991: fig. 4-1 for examples).

Figure 16.1

Each of the first five mass extinctions shown in Figure 16.1 represents a significant loss of biodiversity - but recovery has been good on a geologic time scale. Mass extinctions are apparently followed by a sudden burst of evolutionary diversification on the part of the remaining species, presumably because the surviving species started using habitats and resources that were previously "occupied" by more competitively successful species that went extinct. However, this does not mean that the recoveries from mass extinction have been rapid; they have usually required some tens of millions of years (*Jablonski, 1995*[49]).

It is hypothesized that we are currently on the brink of a "sixth mass extinction," but one that differs from previous events. The five other mass extinctions predated humans and were probably the ultimate products of some physical process (*e.g.* climate change through meteor impacts), rather than the direct consequence of the action of some other species. In contrast, the sixth mass extinction is the product of human activity over the last several hundred, or even several thousand years. These mass extinctions, and their historic and modern consequences are discussed in more detail in the modules on Historical perspectives on extinction and the current biodiversity crisis, and Ecological consequences of extinctions..

Chapter 17

Landscape Diversity[1]

A **landscape** is "a mosaic of heterogeneous land forms, vegetation types, and land uses" (*Urban et al., 1987*[101]). Therefore, assemblages of different ecosystems (the physical environments and the species that inhabit them, including humans) create landscapes on Earth. Although there is no standard definition of the size of a landscape, they are usually in the hundred or thousands of square miles.

Species composition and population viability are often affected by the structure of the landscape; for example, the size, shape, and connectivity of individual patches of ecosystems within the landscape (*Noss, 1990*[71]). Conservation management should be directed at whole landscapes to ensure the survival of species that range widely across different ecosystems (*e.g.*, jaguars, quetzals, species of plants that have widely dispersed pollen and seeds) (*Hunter, 2002: 83-85, 268-270 ([42])*).

Diversity within and between landscapes depends on local and regional variations in environmental conditions, as well as the species supported by those environments. Landscape diversity is often incorporated into descriptions "ecoregions (Chapter 15),"

[1]This content is available online at <http://cnx.org/content/m12165/1.2/>.

Chapter 18

Ecological Value[1]

Natural communities are finely-tuned systems, where each species has an **ecological value** to the other species that are part of that ecosystem. Species diversity increases an ecosystem's stability and resilience, in particular its ability to adapt and respond to changing environmental conditions. If a certain amount, or type (such as a keystone species) of species are lost, eventually it leads to the loss of ecosystem function. Many ecosystems though have built-in redundancies so that two or more species' functions may overlap. Because of these redundancies, several changes in the number or type of species may not impact an ecosystem. However, not all species within an ecosystem are of the same importance. Species that are important due to their sheer numbers are often called **dominant species**. These species make up the most biomass of an ecosystem. Species that have important ecological roles that are greater than one would expect based on their abundance are called **keystone species**. These species are often central to the structure of an ecosystem, removal of one or several keystone species may have consequences immediately, or decades or centuries later (*Jackson et al. 2001*[**?**]). Ecosystems are complex and difficult to study, thus it is often difficult to predict which species are keystone species. The impact of removing an individual or several keystone species from kelp forests in the Pacific is examined in Example 18.1 (Northern Pacific Kelp Forests).

Example 18.1: Northern Pacific Kelp Forests

Kelp forests, as their name suggests, are dominated by kelp, a brown seaweed of the family Laminariales. They are found in shallow, rocky habitats from temperate to subarctic regions, and are important ecosystems for many commercially valuable fish and invertebrates.

Vast forests of kelp and other marine plants existed in the northern Pacific Ocean prior to the 18th century. The kelp was eaten by herbivores such as sea urchins (Family Strongylocentrotidae), which in turn were preyed upon by predators such as sea otters (*Enhydra lutris*). Hunting during the 18th and 19th centuries brought sea otters to the brink of extinction. In the absence of sea otters, sea urchin populations burgeoned and grazed down the kelp forests, at the extreme creating "urchin barrens," where the kelp was completely eradicated. Other species dependent on kelp (such as red abalone *Haliotis rufescens*) were affected too. Legal protection of sea otters in the 20th century led to partial recovery of the system.

More recently sea otter populations in Alaska seem to be threatened by increased predation from killer whales (*Orcinus orca*) (*Estes et al. 1998*[**?**]). It appears that whales may have shifted their diet to sea otters when populations of their preferred prey, Stellar sea lions (*Arctocephalus townsendi*) and Harbor seals (*Phoca vitulina*) declined. The exact reason for the decline in the sea lion and seal populations is still unclear, but appears to be due to declines in their prey in combination with increased fishing and higher ocean temperatures. As a result of the loss of sea otters, increased sea urchin populations are grazing down kelp beds again.

[1]This content is available online at <http://cnx.org/content/m12154/1.2/>.

Example 18.2: Southern Californian Kelp Forests

Interestingly, a similar scenario in kelp forests in Southern California did not show immediate effects after the disappearance of sea otters from the ecosystem. This is because the system was more diverse initially. Other predators (California sheephead fish, *Semicossyphus pulcher*, and spiny lobsters, *Panulirus interruptus*) and competitors (abalone **Haliotis spp**) of the sea urchin helped maintain the system. However, when these predators and competitors were over-harvested as well in the 1950s, the kelp forests declined drastically as sea urchin populations boomed.

In the 1970s and 1980s, a sea urchin fishery developed which then enabled the kelp forest to recover. However, it left a system with little diversity. The interrelationships among these species and the changes that reverberate through systems as species are removed are mirrored in other ecosystems on the planet, both aquatic and terrestrial.

As this example illustrates, biodiversity is incredibly complex and conservation efforts cannot focus on just one species or even on events of the recent past.

Glossary

A

albedo
: the amount of solar radiation reflected by a surface

allopatric speciation
: speciation achieved between populations that are completely geographically separated (their ranges do not overlap or are not contiguous).

Alpha diversity
: the diversity within a particular area or ecosystem; usually expressed by the number of species (*i.e.*, species richness) in that ecosystem

Area of endemism
: an areas which has a high proportion of endemic species (*i.e.*, species with distributions that are naturally restricted to that region)

B

bequest value
: the value of knowing something will be there for future generations

Beta diversity
: a comparison of of diversity between ecosystems, usually measured as the amount of species change between the ecosystems

Biodiversity coldspots
: areas that have relatively low biological diversity but are also experiencing a high rate of habitat loss

Biodiversity hotspots
: in general terms these are areas that have high levels of endemism (and hence diversity) but which are also experiencing a high rate of loss of habitat. This concept was originally developed for terrestrial ecosystems. A terrestrial biodiversity hotspot is an area that has at least 0.5%, or 1,500 of the worlds ca. 300,000 species of green plants (*Viridiplantae*), and that has lost at least 70% of its primary vegetation (*Myers et al., 2000*[?]). Marine biodiversity hotspots have been defined for coral reefs, 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*[?])

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

biogeography
: the study of the distribution of organisms in space and through time

Biological species concept
: a species is a group of interbreeding natural populations unable to successfully mate or reproduce with other such groups, and which occupies a specific niche in nature (Mayr, 1982; Bisby and Coddington, 1995).

C

Community
: the populations of different species that naturally occur and interact in a particular environment

Community
: the populations of different species that naturally occur and interact in a particular environment.

D

Demography
: the statistical characteristics of the population such as size, density, birth and death rates, distribution, and movement or migration.

direct use value

refers to products or goods which are consumed directly such as food or timber

dominant species

species that are important due to their sheer numbers in an ecosystem

E **Ecological biogeography:**

the study of the dispersal of organisms (usually individuals or populations) and the mechanisms that influence this dispersal, and the use of this information to explain spatial distribution patterns

ecological value

the values that each species has as part of an ecosystem

Ecoregion

a relatively large unit of land or water containing a geographically distinct assemblage of species, natural communites, and environmental conditions (*WWF, 1999*[**?**])

Ecoregions

a relatively large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions (*WWF, 1999*[**?**]). The ecosystems within an ecoregion have certain distinct characters in common (*Bailey, 1998a*[**?**]).

Ecosystem

a community plus the physical environment that it occupies at a given time

ecosystem

a community plus the physical environment that it occupies at a given time.

Ecosystem

Endemic species

those species whose distributions are naturally restricted to a defined region

evapotranspiration

is the process whereby water is absorbed from soil by vegetation and then released back into the atmosphere

Evolutionary significant unit

a group of organisms that has undergone significant genetic divergence from other groups of the same species. Identification of ESUs is based on natural history information, range and distribution data, and results from analyses of morphometrics, cytogenetics, allozymes and nuclear and mitochondrial DNA. Concordance of those data, and the indication of significant genetic distance between sympatric groups of organisms, are critical for establishing an ESU.

existence value

the value of knowing something exists even if you will never use it or see it

Extinct

a species is assumed to be extinct when there is no reasonable doubt that the last individual has died (*IUCN, 2002*[**?**])

Extinction

the complete disappearance of a species from Earth

G **Gamma diversity**

a measure of the overall diversity within a large region. Geographic-scale species diversity according to *Hunter (2002: 448) ([42])*

Genetic Diversity

refers to any variation in the nucleotides, genes, chromosomes, or whole genomes of organisms.

H **Historical biogeography**

the study of events in the geological history of the Earth and their use to explain patterns in the spatial and temporal distributions of organisms (usually species or higher taxonomic ranks)

I **indirect use value**

refers to the services that support the products that are consumed, this includes ecosystems functions like nutrient cycling

K **keystone species**

species that have important ecological roles that are greater than one would expect based on their abundance

L

Landscape

a mosaic of heterogeneous land forms, vegetation types, and land uses (*Urban et al., 1987*[?])

Landscapes

a mosaic of heterogeneous land forms, vegetation types, and land uses (*Urban et al., 1987*[?]).

M

Marine Biodiversity hotspots

Mass extinction

a period when there is a sudden increase in the rate of extinction, such that the rate at least doubles, and the extinctions include representatives from many different taxonomic groups of plants and animals

Metapopulation

a group of different but interlinked populations, with each different population located in its own, discrete patch of habitat

Morphological species concept

species are the smallest natural populations permanently separated from each other by a distinct discontinuity in the series of biotype (Du Rietz, 1930; Bisby and Coddington, 1995).

N

non use or passive value

refers to the value for things that we don't use but would feel a loss if they were to disappear

O

Orobiome

a mountainous environment or landscape with its constituent ecosystems

Orogenesis

the process of mountain building.

P

Parapatric

occupying contiguous but not overlapping ranges.

Photosynthesis

the formation of carbohydrates from carbon dioxide and water, through the action of light energy on a light-sensitive pigment, such as chlorophyll, and usually resulting in the production of oxygen

Phylogenetic diversity

the evolutionary relatedness of the species present in an area.

Phylogenetic species concept

a species is the smallest group of organisms that is diagnosably [that is, identifiably] distinct from other such clusters and within which there is a parental pattern of ancestry and descent (Cracraft, 1983; Bisby and Coddington, 1995).

Plate Tectonics

the forces acting on the large, mobile pieces (or "plates") of the Earth's lithosphere (the upper part of the mantle and crust of the Earth where the rocks are rigid compared to those deeper below the Earth's surface) and the movement of those "plates".

Population

1. a group of individuals of the same species that share aspects of their demography or genetics more closely with each other than with other groups of individuals of that species
2. A population may also be defined as a group of individuals of the same species occupying a defined area at the same time (*Hunter, 2002: 144*[?])

potential or option value

refers to the use that something may have in the future

S

Sink

a population patch, in a metpopulation that does not have a high degree of emigration outside its boundaries but, instead, requires net immigration in order to sustain itself

Source

a population patch, in a metapopulation, from which individuals disperse to other population patches or create new ones

Species diversity

the number of different species in a particular area (*i.e.*, species richness) weighted by some measure of abundance such as number of individuals or biomass.

Species evenness

the relative abundance with which each species are represented in an area.

Species richness

the number of different species in a particular area

Species richness

the number of different species in a particular area.

surface roughness

the average vertical relief and small-scale irregularities of a surface

Sympatric

occupying the same geographic area.

T

Terrestrial Biodiversity hotspots

W

watersheds

land areas drained by a river and its tributaries

wetlands

areas where water is 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 where the vegetation is adapted to these conditions

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What is Biodiversity

This collection provides an overview of what is meant by the term 'biodiversity,' and how we measure it. The collection reviews the different levels of biodiversity, or the 'biodiversity hierarchy' including: genetic and phenotypic diversity; population diversity; species diversity; community diversity; ecosystem diversity; landscape diversity; and historical and ecological biogeographic diversity. Brief definitions of populations, species, communities, and ecosystems are provided, with some introductory discussion of different types of 'species concepts.' The collection defines the terms 'species richness' and 'species evenness' as methods for measuring species diversity, and it discusses the use of species richness as a surrogate for describing overall global biodiversity. The collection reviews the distribution of biodiversity in space, explaining the definitions of alpha, beta and gamma diversity for measuring diversity within and between ecosystems. The environmental factors that affect these patterns of spatial diversity are briefly discussed. The collection also includes a brief review of the different ways by which assessments of spatial diversity are used for conservation planning and management (e.g., based on ecoregions, or biodiversity hotspots and coldspots). The collection concludes with a brief discussion of diversity over geological time.