Chapter 3

Where Is the World’s Biological Diversity Found?

Although the planet Earth has an abundance of biological diversity, certain ecosystems have far more species than others. Certain groups of organisms are also especially rich in species, and scientists are discovering entire new biological communities in previously unexplored places. In this chapter, we will examine the factors that determine the abundance and distribution of species throughout the world, which is one of the major components of biological diversity.

The most species-rich environments appear to be tropical rain forests and deciduous forests, coral reefs, large tropical lakes, and perhaps the deep sea (MEA 2005). Much of the diversity of tropical forests is due to their great abundance of insects, but they also have many species of birds, mammals, amphibians, and plants. In coral reefs and the deep sea, diversity is spread over a much broader range of phyla and classes. These marine systems contain representatives of 28 of the 35 animal phyla that exist today; one-third of these phyla exist only in the marine environment (Grassle 2001). In contrast, only one phylum is found exclusively in the terrestrial environment. Diversity in the ocean may be due to great age, enormous water volume, the degree of isolation of certain seas by intervening landmasses, the stability of the environment, and specialization.
on particular sediment types and water depths (adding a third dimension to the space occupied). However, the traditional view of the “unchanging” sea is being reevaluated as a result of evidence that shows decreased deep sea biodiversity during postglacial episodes and recent shifts in species distribution associated with global climate change. Diversity in large tropical lakes is accounted for by the rapid evolutionary radiation of fishes and other species in a series of isolated, productive habitats. High freshwater diversity is also found in complex river systems, with individual species having restricted distribution.

In temperate communities, great diversity is found among plant species in southwestern Australia, the Cape Region of South Africa, California, central Chile, and the Mediterranean basin, all of which are characterized by a Mediterranean climate of moist winters and hot, dry summers (Figure 3.1). The Mediterranean basin is the largest in area (2.1 million km²) and has the most plant species (22,500) (Caley 2008); the Cape Floristic Region of South Africa has an extraordinary concentration of unique plant species (9000) in a relatively small area (78,555 km²). The shrub and herb communities in these areas are apparently rich in species due to their combination of considerable geological age, complex site characteristics (such as topography and soils), and severe environmental conditions. The frequency of fire in these areas also may favor rapid speciation and prevent the domination of just a few species.

### Two of the Most Diverse Ecosystems on Earth

Species richness is greatest in tropical ecosystems. Tropical rain forests on land and coral reefs in marine systems are among the most biologically diverse ecosystems on Earth and have become the focus of popular attention.
**Tropical Rain Forests**

Even though the world’s tropical forests occupy only 7% of the land area, they contain over half the world’s species (Corlett and Primack 2010). This estimate is based on limited sampling of insects and other arthropods, groups that are thought to contain the majority of the world’s species. Reasonable estimates of the number of insect species in tropical forests range from 5 million to 10 million, though some estimates have been as high as 30 million species (Gaston and Spicer 2004). Such numbers suggest that insects found in tropical forests may constitute the majority of the world’s species. Information on other groups, such as plants and birds, is much more accurate. For flowering plants, gymnosperms, and ferns, about 40% of the world’s 275,000 species occur in the world’s tropical forest areas in the Americas, Africa, Madagascar, Southeast Asia, New Guinea, Australia, and various tropical islands.

About 30% of the world’s bird species—1300 species in the American tropics, 400 species in tropical Africa, and 900 in tropical Asia—depend on tropical forests. This figure is probably an underestimate, since it does not include species that are only partially dependent on tropical forests (such as migratory birds), nor does it reflect the high concentrations of tropical forest birds living in restricted habitats, such as islands, that may be more vulnerable to habitat loss. In forested islands such as New Guinea, 78% of the nonmarine birds depend on the tropical forest for their survival.

**Coral Reefs**

Colonies of tiny coral animals build the large coral reef ecosystems—the marine equivalent of tropical rain forests in both species richness and complexity (Knowlton and Jackson 2008) (Figure 3.2). One explanation for this richness is the high primary productivity of coral reefs, which produce 2500 grams of biomass per square meter per year, in comparison with 125 g/m²/yr in the open ocean. The clarity of the water in the reef ecosystem allows sunlight to penetrate deeply so that high levels of photosynthesis occur in the algae that live mutualistically inside the coral.

*FIGURE 3.2* Coral reefs are built up from the skeletons of billions of tiny individual animals. The intricate coral landscapes create a habitat for a diversity of other marine species, including many different kinds of fish. This reef is in the Maldives, an island nation in the equatorial Indian Ocean. (Photograph © Wolfgang Amri/istock.)
Extensive niche specialization among coral species and adaptations to varying levels of disturbance may also account for the high species richness found in coral reefs. The world’s largest coral reef is Australia’s Great Barrier Reef, with an area of 349,000 km². The Great Barrier Reef contains over 400 species of coral, 1500 species of fish, 4000 species of mollusks, and 6 species of turtles, and it provides breeding sites for some 252 species of birds. Although the Great Barrier Reef occupies only 0.1% of the ocean surface area, it contains about 8% of the world’s fish species. The Great Barrier Reef is part of the rich Indo–West Pacific region. The great diversity of species in this region is illustrated by the fact that more than 2000 fish species are found in the Philippine Islands, compared with 448 species found in the mid-Pacific Hawaiian Islands, and 500 species around the Bahama Islands. In comparison to tropical coral reefs, the number of marine fishes in temperate areas is low: the mid-Atlantic seaboard of North America has only 250 fish species, and the Mediterranean has fewer than 400 species.

Most of the animals inhabiting coral reefs are small in size and not yet studied; tens of thousands of species still await discovery and description. Scientists are also now beginning to learn about deep sea corals that live in deep, cold environments without light (Roark et al. 2006). These deep sea coral communities are still poorly known, but they appear to be rapidly declining due to destructive trawling practices.

One notable difference between the species of tropical forests and coral reefs is that, unlike many species of tropical forests that occur only in a specific part of the world, species of coral reefs are often widely dispersed, yet they occupy a tiny percentage of the ocean’s surface area. Only isolated islands, such as Hawaii, Fiji, and the Galápagos, have numerous restricted-range endemic species—species that are found in a particular location and nowhere else; fully 25% of Hawaiian coral species are endemic to the area (Pacific Whale Foundation 2003). Because most coral reef species are more widely distributed than rain forest species, they may be less prone to extinction by the destruction of a single locality. However, this assertion may be a taxonomic bias, because coral reef species are not as well known as terrestrial species. Recent research suggests that some widely distributed tropical marine species have genetically unique populations in certain geographical areas (Knutsen et al. 2009); eventually certain of these populations might be considered to be distinct species and warrant protection for that reason.

Patterns of Diversity

Patterns of diversity are known primarily through the efforts of taxonomists, who have methodically collected organisms from all areas of the world. These patterns, however, are known only in broad outline for many groups of organisms, because the great majority of species-rich groups, such as beetles, bacteria, and fungi, remain undescribed. It is clear that local variation in climate, environment, topography, and geological age are factors that affect patterns of species richness (Harrison et al. 2006).

Variation in Climate and Environment

In terrestrial communities, species richness tends to increase with decreasing elevation, increasing solar radiation, and increasing precipitation; that is, hot, rainy lowland areas have the most species. These factors act in combination; for example, deserts are species poor because of their low precipitation, even though they have high solar radiation. In some localities, species abundance is greatest at mid elevations. The lower richness of plants and animals in Africa, in comparison with South America and Asia, may be due to a combination of lower past and present rainfall, the smaller total area of rain forest, and a longer period of human impact in Africa (Corlett and Primack 2010). Even within tropical Africa itself, areas of low rainfall in the Sahel have fewer species than forested areas with higher rainfall to the south. However, the extensive savanna areas of east and central Africa have a richness and abundance of an-
telopes and other ungulate grazers not found on other continents. The greatest abundance of mammal species may occur at intermediate levels of precipitation rather than in the wettest or driest habitats. In the open ocean, species diversity reaches a peak at 2000 to 3000 m, with lower diversity closer to the surface and at greater depths.

**Variation in Topography, Geological Age, and Habitat Size**

Species richness can be greater where complex topography and great geological age provide more environmental variation, which allows genetic isolation, local adaptation, and speciation to occur. For example, a species able to colonize a series of isolated mountain peaks in the Andes during a period of favorable climate may eventually evolve into several different species, each adapted to its local mountain environment. A similar process could occur for fish and invertebrates occupying large drainage systems and lakes that become divided into several smaller systems. Examples include the Tennessee River system in the United States, the Mekong River in Southeast Asia, and Lake Baikal in Siberia. Geologically complex areas can produce a variety of soil conditions with very sharp boundaries between them, leading to multiple communities and species adapted to one specific soil type or another.

At various spatial scales, there are concentrations of species in particular places, and there is a rough correspondence in the distribution of species richness between different groups of organisms (Lamoreux et al. 2006; Xu et al. 2008). For example, in South America, concentrations of amphibians, birds, mammals, and plants are greatest in the western Amazon, with secondary concentrations in the highlands of the northeastern, and the Atlantic forests of southeastern, Brazil (Figure 3.3). In

![Figure 3.3](image-url)
North America, large-scale patterns of species richness are highly correlated for amphibians, birds, butterflies, mammals, reptiles, land snails, trees, all vascular plants, and tiger beetles; that is, a region with numerous species of one group will tend to have numerous species of the other groups (Ricketts et al. 1999). On a local scale, this relationship may break down; for example, amphibians may be most diverse in wet, shady habitats, whereas reptiles may be most diverse in drier, open habitats. At a global scale, each group of living organisms may reach its greatest species richness in a different part of the world because of historical circumstances or the suitability of the site to its needs.

Larger areas also can provide a greater range of habitats in which species can evolve and live. For example, coral species richness is several times greater in the southwestern Pacific Ocean than in the western Atlantic Ocean, which is much smaller in area (Figure 3.4). More than 50 genera of coral exist in many of the Indo-Pacific areas, but only about 20 genera occur in the reefs of the Caribbean Sea and the adjacent Atlantic Ocean.

Why Are There So Many Species in the Tropics?

Almost all groups of organisms show an increase in species diversity toward the tropics. For example, Thailand has 241 species of mammals, while France has only 104, despite the fact that both countries have roughly the same land area (Table 3.1). The contrast is particularly striking for trees and other flowering plants: 10 ha of forest in Amazonian Peru or Brazil might have 300 or more tree species, whereas an equivalent forest area in temperate Europe or the United States would probably contain 30 species or less. Within a given continent, the number of species increases toward the equator.

Patterns of diversity in terrestrial species are paralleled by patterns in marine species, again with an increase in species diversity toward the tropics. For example, the Great Barrier Reef off the eastern coast of Australia has 50 genera of reef-building coral at its northern end where it approaches the tropics, but it has only 10 genera at its southern end, farthest away from the tropics. These increases in rich-
ness of coastal species toward the tropics and in warmer waters are paralleled by increases in open ocean species, such as plankton and predatory fish (Rombouts et al. 2009), though there are some groups of species that are most diverse in temperate waters.

Many theories have been advanced to explain the greater diversity of species in the tropics (Pimm and Brown 2004). Following are some of the most reasonable theories:

1. Tropical regions receive more solar energy over the course of a year than temperate regions, and many of them also have abundant rainfall. As a result, many tropical communities have a higher rate of productivity than temperate communities, in terms of the number of kilograms of living material (biomass) produced each year per hectare of habitat. This high productivity results in a greater resource base that can support a wider range of species.

2. Species of tropical communities have had longer periods of stability than species of temperate communities, which have had to disperse in response to periods of glaciation. This greater stability has allowed the processes of evolution and speciation to occur uninterrupted in tropical communities in response to local conditions. In temperate areas, the scouring actions of glaciers and the frigid climate destroyed many local species that might have evolved, and it favored those species able to disperse long distances. Thus, a relatively more stable climate has allowed a greater degree of evolutionary specialization and local adaptation to occur in tropical areas.

3. The warm temperatures and high humidity in many tropical areas provide favorable conditions for the growth and survival of many species. Entire communities of species can also develop in the tree canopies. In contrast, species living in temperate zones must have physiological mechanisms that allow them to tolerate cold and freezing conditions. These species may also have specialized behaviors, such as dormancy, hibernation, burrowing into the ground, or migration, to help them survive the winter. The inability of many groups of plants and animals to live outside the tropics suggests that adaptations to cold do not evolve easily or quickly.

### TABLE 3.1 Number of Native Mammal Species in Selected Tropical and Temperate Countries Paired for Comparable Size

<table>
<thead>
<tr>
<th>Tropical Area (1000 km²)</th>
<th>Number of Mammal Species</th>
<th>Temperate Area (1000 km²)</th>
<th>Number of Mammal Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil 8456</td>
<td>604</td>
<td>Canada 9220</td>
<td>207</td>
</tr>
<tr>
<td>DRC 2268</td>
<td>425</td>
<td>Argentina 2737</td>
<td>378</td>
</tr>
<tr>
<td>Mexico 1909</td>
<td>529</td>
<td>Algeria 2382</td>
<td>84</td>
</tr>
<tr>
<td>Indonesia 1812</td>
<td>471</td>
<td>Iran 1636</td>
<td>150</td>
</tr>
<tr>
<td>Colombia 1039</td>
<td>443</td>
<td>South Africa 1221</td>
<td>278</td>
</tr>
<tr>
<td>Venezuela 882</td>
<td>363</td>
<td>Chile 748</td>
<td>147</td>
</tr>
<tr>
<td>Thailand 511</td>
<td>241</td>
<td>France 550</td>
<td>104</td>
</tr>
<tr>
<td>Philippines 298</td>
<td>180</td>
<td>United Kingdom 242</td>
<td>75</td>
</tr>
<tr>
<td>Rwanda 25</td>
<td>111</td>
<td>Belgium 30</td>
<td>71</td>
</tr>
</tbody>
</table>

Source: Data from IUCN Red List 2009.

DRC = Democratic Republic of the Congo.

High species diversity in the tropics may be due to greater productivity and stability, warmer temperatures, and more niche specialization, allowing many species to flourish and co-exist.
4. Due to a predictable environment, species interactions in the tropics are more intense, leading initially to greater competition among species and later to niche specialization. Also, tropical species may face greater pressure from parasites and disease because there is no freezing weather in winter to reduce pest populations. Ever-present populations of these parasites prevent any single species or group of species from dominating communities, creating an opportunity for numerous species to coexist at low individual densities. For example, tree seedlings are often killed by fungi and insects when they grow near other trees of the same species, often leading to wide spaces between adult trees of the same species. In many ways, the biology of the tropics is the biology of rare species. In contrast, temperate zone species may face reduced parasite pressure because the winter cold suppresses parasite populations, allowing one or a few competitively superior species of plants and animals to dominate the community and exclude many other, less competitive species.

5. The large geographical area of the tropics, in comparison with the temperate zone, may account for the greater rates of speciation and lower rates of extinction in the tropics (Chown and Gaston 2000). This follows from the fact that the tropical areas north and south of the equator are next to each other, while the temperate areas outside the tropics are divided in two by the tropics themselves.

How Many Species Exist Worldwide?

At present, about 1.5 million species have been described. At least two to three times this number of species (primarily insects and other arthropods in the tropics) remain undescribed (Figure 3.5A). Our knowledge of species numbers is imprecise because inconspicuous species have not received their proper share of taxonomic attention. For example, spiders, nematodes, and fungi living in the soil and insects living in the tropical forest canopy are small and difficult to study. These poorly known groups could number in the hundreds of thousands, or even millions, of species. Our best estimate is that there are between 5 and 10 million species (Gaston and Spicer 2004).

New Species Are Being Discovered All the Time

Amazingly, about 20,000 new species are described each year. While certain groups of organisms such as birds, mammals, and temperate flowering plants are relatively well known, a small but steady number of new species in these groups are being discovered each year (Peres 2005). Even among a group as well studied as primates, ten new monkey species have been found in Brazil over the past 20 years, and three new species of lemurs have been discovered in Madagascar. Every decade, 500 to 600 new species of amphibians are described.

In groups such as insects, spiders, mites, nematodes, and fungi, the number of described species is still increasing at the rate of 1%–2% per year (Donoghue and Alverson 2000). Huge numbers of species in these groups, mostly in tropical areas but also in the temperate zone, have yet to be discovered and described (Figure 3.5B). Compounding the problem is the fact that, though most of the world’s remaining undescribed species are probably insects and other invertebrates, only one-third of the world’s 5000 taxonomists are now studying these groups.

Species are typically discovered when taxonomists collect specimens while on field trips but are unable to identify them despite looking at all available published descriptions. Taxonomists will then make a description of each new species and give it a new scientific name. New species are also discovered when further research,
often involving the techniques of molecular systematics and DNA analysis, reveals that what was originally thought to be a single species with a number of geographically distinct populations is really two or more species.

Sometimes new species are discovered as “living fossils”—species known only from the fossil record and believed to be extinct until living examples are found in modern times. In 1938, ichthyologists throughout the world were stunned by the report of a strange fish caught in the Indian Ocean. This fish, subsequently named *Latimeria chalumnae*, belonged to a group of marine fish known as coelacanths that were common in ancient seas but were thought to have gone extinct 65 million years.

![Figure 3.5](image-url)

**Figure 3.5** (A) Approximately 1.5 million species have been identified and described by scientists; the majority of these are insects and plants. (B) For several groups estimated to contain over 100,000 species, the numbers of described species are indicated by the blue portions of the bars; the green portions are estimates of the number of undescribed species. The vertebrates are included for comparison. The number of undescribed species is particularly speculative for the microorganisms (viruses, bacteria, protists). Estimates of the possible number of identifiable species range from 5 million to 30 million. (A, data from Wilson 1992; B, after Hammond 1992.)
Coelacanths are of particular interest to evolutionary biologists because they show certain features of muscles and bones in their fins that are comparable to the limbs of the first vertebrates that crawled onto land. Biologists searched the Indian Ocean for 14 years before another coelacanth was found, off Grand Comore Island between Madagascar and the African coast. Subsequent investigation has shown that there is a single population of about 300 individuals living in underwater caves just offshore of Grand Comore (Fricke and Hissmann 1990). In recent years, the Union of the Comores implemented a conservation plan to protect the coelacanths, including a ban on catching and selling the fish. In a remarkable footnote to this story, in 1997 a marine biologist working in Indonesia was astonished to see a dead coelacanth for sale in a local fish market. Subsequent investigations demonstrated that this was a new species of coelacanth (Inoue et al. 2005) unknown to science but well known to the local fishermen, with a population estimated to be about 10,000, illustrating how much is still waiting to be discovered in the world’s oceans.

In 2002, scientists exploring in the remote Brandberg Mountains of Namibia in southwestern Africa discovered insects in an entirely new order, distantly related to grasshoppers, stick insects, and praying mantids, subsequently named the Mantophasmatodea and given the new common name of “gladiator insects” (Klass et al. 2002). The last time a new order of insects had been described was in 1915. Further searches in other African countries have found additional species in this order.

New species may be discovered in unexpected places, as members of an international research team found when they noticed an unusual entrée on the grill in a Laotian food market. Natives called it “kha-nyou”; although clearly a rodent, it was not an animal known to any of the researchers. In 2006, after several years of studying skeletons and dead specimens, taxonomists deemed kha-nyou to be a heretofore unknown species belonging to a rodent family thought to have been extinct for 11 million years (Dawson et al. 2006). The newly discovered species was given the scientific name Laonastes aenigmamus, or “rock-dwelling, enigmatic mouse.” More commonly called the Laotian rock rat or rock squirrel, this rodent is neither a mouse nor a rat nor a squirrel, but a unique species (Figure 3.6).

Recently Discovered Communities

In addition to new species, entire biological communities continue to be discovered, often in extremely remote and inaccessible localities. These communities often consist of inconspicuous species, such as bacteria, protists, and small invertebrates, that have escaped the attention of earlier taxonomists. Specialized exploration techniques have aided in these discoveries, particularly in the deep sea and in the forest canopy. Some recently discovered communities include the following:
• Diverse communities of animals, particularly insects, are adapted to living in the canopies of tropical trees and rarely, if ever, descend to the ground (Lowman et al. 2006). Technical climbing equipment, canopy towers and walkways, tall cranes, and even dirigibles are being used to open up this habitat to exploration (Figure 3.7).

• The floor of the deep sea has unique communities of bacteria and animals that grow around geothermal vents (Box 3.1). Undescribed, active bacteria unrelated to any known species have even been found in marine sediments at depths of up to 6.5 km (4 mi.), where they undoubtedly play a major chemical and energetic role in this vast ecosystem (Li et al. 1999; Scheckenback et al. 2010). Drilling projects have shown that diverse bacterial communities exist even 2.8 km deep in the Earth’s crust, at densities ranging from 100 to 100 million bacteria per gram of solid rock. These bacterial communities in extreme environments are being actively investigated as a source of novel chemicals, for their potential usefulness in degrading toxic chemicals, and for insight into whether life could exist on other planets.

• Using DNA technology to investigate the interior of leaves of healthy tropical trees has revealed an extraordinarily rich group of fungi, consisting of thousands of undescribed species (Arnold and Lutzoni 2007). These fungi appear to aid the plant in excluding harmful bacteria and fungi, in exchange for receiving a place to live and perhaps some carbohydrates.

• The human body is populated by millions of viruses, bacteria, fungi, and mites. The density of bacteria growing in our armpits may reach 10 million cells per cm². One study of six people discovered that there were 182 distinct species of bacteria living on their arms. Some of these bacteria may play a beneficial role in secreting antimicrobial compounds that control harmful bacteria. We might also expect to find comparable levels of microbial abundance and diversity on other animals.
Diversity Surveys: Collecting and Counting Species

Describing the diversity of major groups of organisms represents an enormous undertaking. Large institutions and teams of scientists often undertake biological surveys of entire countries or regions, which may involve decades—such work includes specimen collection in the field, identification of known species, descriptions of new species, and finally, publication of the results so that others can use the information. Two such examples are the massive Flora of North America project, based at the Missouri Botanical Garden, and the Flora Malesiana in the Indo–Pacific region, organized by the Rijksherbarium in the Netherlands.

In conducting such surveys, scientists determine the identity and numbers of species present in an area by means of a thorough collection of specimens that has been compiled over an extended period of time. The collection is then carefully sorted and classified by specialists, often at museums. For example, a team from the Natural History Museum in London collected over 1 million beetles from a 500 ha lowland rain forest in the Dumoga Bone National Park on Sulawesi, Indonesia, in 1985. This effort led to an initial list of 3488 species, large numbers of which were previously unknown to science. Subsequent museum work allowed the identification of new species and the publication of new taxonomic books, which are now used as standard references for the region.

Hydrothermal vents are temporary underwater openings in the Earth’s crust. Extremely hot water (in excess of 150°C), sulfides, and other dissolved minerals escape from these vents and support a profusion of species in the deepest parts of the ocean. Specialized chemosynthetic bacteria are the primary producers of the vent community, using the minerals as an energy source. Communities of large animals such as clams, crabs, fishes, and 2 m long tube worms (also known as pogonophorans) in turn feed on the bacteria directly, or the bacteria live symbiotically inside their bodies. The vents themselves are short-lived, spanning a few decades at most; however, the ecosystems supported by these vents are thought to have evolved over the past 200 million years or more. Until deep sea submersibles were developed in the 1970s, scientists were completely unaware of the communities that live around the vents. Since 1979, however, when the submersible Alvin was first used to examine the vents around the Galápagos rift in the Pacific Ocean, 150 new species, 50 new genera, and 20 new families and subfamilies of animals—not including microorganisms—have been described. As investigation of deep sea vents continues, more families will certainly be discovered, encompassing many new genera and species.

Like many terrestrial ecosystems, hydrothermal ecosystems vary according to differences in their local environment. Distribution of hydrothermal ecosystems is dependent upon the character of the vents, including the temperature, chemical composition, and flow pattern of hydrothermal fluid issuing from the vents. Scientists studying hydrothermal species may work for decades yet acquire only minimal knowledge of the dynamics of these ecosystems, because of the unique nature of the study sites: the vents are ephemeral, sometimes existing for only a few years, and inaccessible—they can be reached only with the use of expensive, specialized equipment. Work is just starting on the genetics of these species to determine their ability to disperse and colonize new vents.

**BOX 3.1 Conserving a World Unknown: Hydrothermal Vents and Oil Plumes**

- Biologists are aware that many species exist that have not been adequately studied and described, a fact that frequently hampers conservation. In recent years, it has become apparent that there are entire ecosystems that remain undiscovered in the more remote parts of the Earth. It is clear from the example of deep sea hydrothermal vents that species, genera, and even families of organisms exist about which scientists know nothing and in places where little life was predicted to occur. The biota of these vents were investigated in detail only in the last 30 years with the invention of technology that enables scientists to photograph and collect specimens from depths of over 2000 meters (German et al. 2008). Such organisms pose a significant problem for conservationists: How does one go about conserving undiscovered or barely known species and ecosystems?

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Scientists continue to make remarkable discoveries in nature. Conservation strategies, such as reducing pollution, sometimes need to be implemented even when little is known about the species or ecosystem in question.
which are similar to those that comprise hydrothermal communities. Some of the same species that congregate around hydrothermal and petroleum-seep vents may also colonize the carcasses of large fish and marine mammals, such as whales, that sink to the bottom of the ocean floor (Little 2010). These unpredictable bonanzas of organic matter may provide crucial stepping-stones for organisms to disperse among widely scattered hydrothermal vents and petroleum seeps.

Despite the inaccessibility of the sites and the cost of investigation, biologists nevertheless need to think ahead to conservation problems that might face these unique marine ecosystems in the future. Water pollution and trawling, for example, have damaged ocean species in shallower waters and in theory could harm these ecosystems as well. Is it possible to develop conservation programs for such deep sea ecosystems despite our lack of information? At this stage, there is only one definitive statement that can address these dilemmas: we know that restricting and regulating pollution, degradation from trawling, and other damaging human activities have broadly positive effects on natural ecosystems, so programs that protect the marine environment may offer the best conservation strategy in these situations, even when the ecosystems themselves are not thoroughly understood.

Estimating the Number of Species

Worldwide, the most diverse group of organisms appears to be the insects, with about 750,000 species described already—about half the world’s total species (see Figure 3.6A). If we assume the number of insect species can be accurately estimated in tropical forests where they are most abundant, then it may be possible to estimate the total number of species in the world. Various entomologists have attempted this by sampling entire insect communities in tropical forests, using insecticidal fogging of whole trees and intensive hand collection (Figure 3.8) (Ødegaard 2000; Novotny et al. 2002; Gering et al. 2007). These studies have revealed an extremely rich and largely undescribed insect fauna in the tree canopies. Using the results of such intensive collecting, these entomologists have attempted to calculate the number of insect species. In one approach, they began with the fact that there are 55,000 categorization of 1000 more species, with as many as 2000 species remaining to be identified over the coming years and decades. The goal of many such surveys is to keep sampling until most of the species have been collected. Even careful surveys miss many species, particularly when they are rare or inconspicuous, or if they only occur in the soil.
species of tropical trees and woody vines (lianas). Based on detailed field sampling, entomologists estimated that there are on average 9 species of specialized beetle feeding on each distinct plant species, leading to an estimated 400,000–500,000 species of canopy beetles. Canopy beetles represent about 44% of all beetle species, yielding an estimate of about 1 million beetle species. Because beetles are about 20% of all insects, it can be estimated that there are about 5 million insects in tropical forests. Such calculations give values comparable to earlier estimates of 5 to 10 million species for the entire Earth (Gaston and Spicer 2004).

Such “rules” can be used to determine how many species are involved in other biological relationships (Schmit et al. 2005). For example, in Britain and Europe, where species have been extensively studied, there are about six times more fungus species than plant species. If this general ratio is applicable throughout the world, there may be as many as 1.5 million fungus species, in addition to the estimated 250,000 plant species worldwide. Since only 69,000 fungus species have been described so far, it is possible that there are over 1.4 million fungus species waiting to be discovered, most of them in the tropics. If it turns out that fungal diversity increases more rapidly toward the equator, as some scientists have suggested (Frohlich and Hyde 1999), there may be as many as 9 million undescribed fungus species.

Yet another approach is to assume that each species of plant and insect, which together form the majority of currently known species, has at least one species of specialized bacteria, protist, and nematode (roundworm); hence the estimate of the number of total species worldwide should be multiplied by 4—bringing it to 20 million, using the figure of 5 million species as the starting point, or to 40 million if 10 million species is the starting point. Developing such preliminary approaches al-

Many scientists are working to determine the number of species in the world. The best estimate is that there are about 5–10 million species, with about half of them being insects.
lows estimates to be made of the numbers of species in communities while more rigorous sampling and identification is being performed.

UNDERREPRESENTED SPECIES The difficulty of making estimates of species numbers is exacerbated by the fact that inconspicuous species have not received their proper share of taxonomic attention. Since inconspicuous species constitute the majority of species on Earth, the difficulty of finding and cataloging them delays a thorough understanding of the full extent of the planet’s biological diversity (Caron 2009).

Inconspicuous organisms, including small rodents, most insects, and microorganisms, are much less likely to be observed by chance outside their natural habitats, as the coelacanth was, or even within their native environments (Wilson 2010). For example, mites in the soil, soft-bodied insects such as bark lice, and nematodes in both soil and water are small and hard to study. If properly studied, these groups could be found to number in the hundreds of thousands of species, or even millions. Since demonstrating the role of nematode species as root parasites of agricultural plants, scientists have dramatically increased their efforts to collect and describe these minute roundworms. Consequently, the catalog of this one group of organisms has grown from the 80 species known in 1860 to about 20,000 species known today; some experts estimate that there may be millions more species waiting to be described (Boucher and Lambshead 1995). As is the case with so many other taxonomic groups, the number of trained specialists is the limiting factor in unlocking the diversity of this enormous group of species.

Bacteria are also very poorly known (Azam and Worden 2004) and thus underrepresented in estimates of the total species on Earth. Yet, at the densities at which they occur, they must have an important role to play in ecosystem functioning. For example, the density of bacteria in seawater is astonishing; upward of 100 million cells per liter can exist, with a large diversity of species. Only about 5000 species of bacteria are currently recognized by microbiologists, because they are difficult to grow and identify. However, work analyzing bacterial DNA indicates that there may be from 6400 to 38,000 species in a single gram of soil and 160 species in a liter of seawater (Nee 2003). Such high diversity in small samples suggests that there could be tens of thousands or even millions of undescribed bacteria species. Many of these unknown bacteria are probably very common and of major environmental importance. In the ancient kingdom of Archaea, which has been less studied in the past, even new bacteria phyla continue to be discovered.

Many inconspicuous species that live in remote habitats will not be found and cataloged unless biologists search for them. A lack of collecting, especially, has hampered our knowledge of the species richness of the marine environment—a great frontier of biological diversity, with huge numbers of species and even entire communities still unknown—at least in part because it poses challenges for study (Brandt et al. 2007). Marine invertebrate animals such as polychaete worms, for instance, are not well studied because they make the ocean bottom their home. Additionally, an entirely new animal phylum, the Loricifera, was described in 1983 based on specimens from the deep sea (Kristensen et al. 2007), and another new phylum, the Cycliophora, was first described in 1995 based on tiny, ciliate creatures found on the mouthparts of the Norway lobster (Figure 3.9) (Funch and Kristensen 1995). Undoubtedly, more species, genera, families, orders, classes, and phyla (and perhaps even kingdoms!) are waiting to be discovered.

Considering that about 20,000 new animal species are described each year and perhaps 5 million more are waiting to be identified, the task of describing the world’s
species will not be completed for over 250 years if continued at the present rate! This underlines the absolutely critical need for more taxonomists.

The Need for More Taxonomists

A major problem the scientific community faces in describing and cataloging the biological diversity of the world is the lack of trained taxonomists able to take on the job. At the present time, there are only about 5000 taxonomists in the world, and only about 1500 of them are competent to work with tropical species, plus many of them are based in temperate countries. Unfortunately, this number is declining rather than increasing. When academic taxonomists retire, universities have a tendency to either close the position due to financial difficulties or replace the retiring biologist with a nontaxonomist. Many members of the younger generation of taxonomists are so preoccupied with the technology of molecular systematics and associated data analysis that they are neither interested in nor capable of continuing the great tradition of discovering and cataloging the world’s biological treasures. A substantial increase in the number of field taxonomists focused primarily on describing and identifying tropical and marine species is needed to complete the task of describing the world’s biological diversity. Much of this effort should be directed to lesser-known groups, such as fungi, bacteria, and invertebrates. And where possible, these taxonomists need to be based in tropical countries where this

FIGURE 3.9 A new phylum, the Cycliophora, was first described in 1995. The phylum contains one vase-shaped species, *Symbion pandora* (about 40 of which are shown in the inset). The individuals attach themselves to the mouthparts of the Norway lobster, *Nephrops norvegicus*. (Photographs courtesy of Reinhardt Kristensen, University of Copenhagen.)
diversity is located. Natural history societies and clubs that combine professional and amateur naturalists also can play a valuable role in assisting these efforts and in exposing the general public and student groups to the issues and excitement of biological diversity and encouraging people to become taxonomists.

Summary

1. In general, species richness is greatest in tropical rain forests, coral reefs, tropical lakes, the deep sea, and shrublands with a Mediterranean climate. In terrestrial habitats, species richness tends to be greatest at lower elevations and in warmer areas with abundant rainfall. Areas that are geologically old and topographically complex also tend to have more species.

2. Tropical rain forests occupy only 7% of the Earth’s land area, yet they are estimated to contain most of the Earth’s species. The great majority of these species are insects not yet described by scientists. Coral reef communities are also rich in species, with many of the species widely distributed. The deep sea also appears to be rich in species but is still not adequately explored.

3. About 1.5 million species have been described, and more than twice that number remain to be described. Intensive collecting of insects in tropical forest has yielded estimates of species numbers ranging from 5 to 10 million, but it could be higher.

4. While conspicuous groups, such as flowering plants, mammals, and birds, are reasonably well known to science, other inconspicuous groups, particularly insects, bacteria, and fungi, have not been thoroughly studied. New biological communities are still being discovered, especially in the deep sea and the forest canopy. For example, spectacular communities that occupy deep sea hydrothermal vents are major, recent discoveries.

5. There is a vital need for more taxonomists and field biologists to study, collect, classify, and help protect the world’s biological diversity before it is lost.

For Discussion

1. What are the factors promoting species richness? Why is biological diversity diminished in particular environments? Why aren’t species able to overcome these limitations and undergo the process of speciation?

2. Develop arguments for both low and high estimates of the total number of species in particular groups, such as bacteria, fungi, or nematodes. Read more about groups that you don’t know well. Why is it important to identify and name all the species in a particular group?

3. If taxonomists are so important to documenting and protecting biological diversity, why are their numbers declining instead of increasing? How could societal and scientific priorities be readjusted to reverse this trend? Is the ability to identify and classify species a skill that every conservation biologist should possess?

4. Some scientists have argued that life may have existed on Mars, and recent drilling demonstrates that bacteria actually flourish in rocks deep under the Earth’s surface. Speculate, as wildly as you can, about where to search for previously unsuspected species, communities, or novel life forms.
Suggested Readings


Lowman, M. D., E. Burgess, and J. Burgess. 2006. *It’s a Jungle Up There: More Tales from the Treetops*. Yale University Press, New Haven, CT. Anecdotes and adventures while exploring the diversity of the tropical forest canopy.


Schechenbach, F., K. Hausmann, C. Wylezich, M. Weitere, and H. Arndt. 2010. Large-scale patterns in biodiversity of microbial eukaryotes from the abyssal sea floor. *Proceedings of the National Academy of Sciences USA* 107: 115–120. Large numbers of mostly unknown species are found at depths of 5000 m.