Chapter 2: What is Biodiversity?
Levels of integration in biology

• **Species**
  – level of the *individual organism*
  – what determines a species?
    • group of actually or potentially interbreeding organisms
    • reproductively isolated
    • produce viable offspring
  – examples
Levels of integration in biology

• **Population**
  – group of organisms of the same species occupying a given place at a given time
  – generally referred to in terms of **density** and **distribution**
  – examples
Relationship between distribution and abundance

HIGH ABUNDANCE

MODERATE ABUNDANCE

NO ABUNDANCE = NO DISTRIBUTION
Levels of integration in biology

• **Community**
  – collection of populations occurring in a given area and linked together in a food web
  – has unique property of *species diversity*
  – examples
Levels of integration in biology

• **Ecosystem**
  – larger assemblage of communities linked by lines of energy transfer
  – examples
  – abiotic features
  – biotic features
Levels of integration in ecology
Ecosystem structure and function

- **Abiotic chemicals (carbon dioxide, oxygen, nitrogen, minerals)**
  - Solar energy
  - Heat

- **Producers (plants)**
  - Heat

- **Consumers (herbivores, carnivores)**
  - Heat

- **Decomposers (bacteria, fungus)**
  - Heat
Measuring biodiversity

- Inventory → **species richness** [Table 2.1]

<table>
<thead>
<tr>
<th>Ecosystem A</th>
<th>Ecosystem B</th>
<th>Ecosystem C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black oak</td>
<td>Black oak</td>
<td>Black oak</td>
</tr>
<tr>
<td>White pine</td>
<td>White pine</td>
<td>White pine</td>
</tr>
<tr>
<td>Red maple</td>
<td>Red maple</td>
<td>Red maple</td>
</tr>
<tr>
<td>Yellow birch</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ n = 4 \quad n = 3 \quad n = 3 \]
Measuring biodiversity

• **Species richness (s)**
  – number of different kinds of species present
  – does not account for commonness or rarity of the species present

• **Species diversity (H)**
  – number of species present (s) AND heterogeneity or evenness (E)
  – gives proper weight to common species
Measuring biodiversity

• Diversity and evenness [Table 2.2]

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black oak</td>
<td>40</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>White pine</td>
<td>30</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Red maple</td>
<td>20</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>Yellow birch</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total (N)</td>
<td>100</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Richness (s)</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Evenness (E)</td>
<td>0.92</td>
<td>0.88</td>
<td>0.99</td>
</tr>
<tr>
<td>Diversity (H)</td>
<td>0.56</td>
<td>0.39</td>
<td>0.47</td>
</tr>
</tbody>
</table>

\[ H = - \sum p_i \ln p_i, \] where \( p_i \) is a measure of the importance of the \( i^{th} \) species

Evenness = \( H / H_{\text{max}} \), where \( H_{\text{max}} \) is the maximum possible value of \( H \)
Mis-measuring biodiversity

- Diversity measures are **quantitative, not qualitative** – often the most important communities are not those with the highest diversity

<table>
<thead>
<tr>
<th>Forest</th>
<th>Marsh</th>
<th>Grassland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black oak</td>
<td>Reed-grass</td>
<td>White prairie-clover</td>
</tr>
<tr>
<td>Shagbark hickory</td>
<td>Painted turtle</td>
<td>Horned lark</td>
</tr>
<tr>
<td>Gray squirrel</td>
<td>Red-winged blackbird</td>
<td><strong>Black-footed ferret</strong></td>
</tr>
<tr>
<td>White-tailed deer</td>
<td>Muskrat</td>
<td></td>
</tr>
<tr>
<td>Raccoon</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13
Biodiversity and spatial scales

• **Extinction**
  – global extinctions
  – extirpations
    • regional extinction
    • local extinction

• **Endemic species**
  – found only in a defined geographic area, where they have had their entire evolutionary history
Biodiversity and spatial scales

- Risks of extinction at different spatial scales are key consideration for prioritizing endangered species
- The larger the scale at which an extinction is likely to occur, the more important it is to prevent it
Figure 2.2. Conservationists do not consider all species to be equally important. For example, the Iberian lynx, a species confined to southern Spain, is a higher priority for Spanish conservationists than the Eurasian lynx, which has a huge range that just reaches northern Spain.
Whittaker’s scales of diversity

- **Alpha diversity**: diversity that exists within an ecosystem

- **Beta diversity**: diversity that exists between ecosystems in the same region

- **Gamma diversity**: diversity that exists on a geographic scale
Figure 2.3. The distribution of four hypothetical lizard species showing alpha diversity (within an ecosystem, A plus B), beta diversity (among ecosystems, A/B plus C), and gamma diversity (geographic scale, A/B/C plus D).
Figure 2.4. Clear Lake in northern California used to be inhabited by 12 native species of fish until fisheries managers began introducing new fish species, 16 in all. These introductions decimated the native fish populations, but still produced a net increase in alpha diversity of 13 species. This increase came at the expense of global diversity because two of the original species, the Clear Lake splittail and the thicktail chub, are now globally extinct.
Biotic (biological) integrity

• Completeness of a biological system, including the presence of
  – all of the elements at appropriate densities (structure)
  – all of the processes at appropriate rates (function)

• Emphasizes overall balance and gives equal weight to functions and structure

• Focus is on condition of ecosystem in reference to what it would be in a natural state
Ecosystem integrity

• Ecosystem health or ecological health

• Encompasses the ecological and physical components of an ecosystem
  – soil erosion or sedimentation
  – energy flow through food webs
  – pollution impacts

• Evaluated in terms of function (overall processes or “services”) rather than structure (species present)
Ecosystem services

• **Pollination**
  
  – 30% of our food crops rely on pollination
    
    • e.g., apples, blueberries, cherries, chocolate, hay, alfalfa, etc.

  – pollinators: bees, butterflies, moths, birds, beetles, wasps, bats

  – pollinators threatened by
    
    • fragmented and degraded habitats
    • pesticides
    • introduction of diseases and non-native species
Ecosystem services

• **O₂ generation and CO₂ removal**
  – photosynthesis and nutrient cycling
  – purify air and water
  – regulate water vapor
  – regulate climate
    • forests reduce CO₂, greenhouse warming
    • oceans
      – algae take up CO₂ from water and atmosphere
      – currents and winds control world climate
Ecosystem services

• **Drought and flood control**
  – plant communities (especially forests and wetlands) help control floods
  – root systems hold soils in place, prevent erosion and mudslides
  – plants hold moisture in soils and reduce effect of droughts
  – coastal marshes act as storm surge buffers
Ecosystem services

• **Nutrient cycling**
  – soil organisms break down organic matter into nutrients that recycle into plants
  – in one pinch of soil
    • 30,000 protozoans
    • 50,000 algal cells
    • 400,000 fungal cells
    • billions of bacterial cells
  – other soil organisms: worms, insects, mites, springtails
Ecosystem services

• **Habitat**
  – natural populations and communities
  – endangered species
  – humans

• **Economic value**
<table>
<thead>
<tr>
<th>Ecosystem product / service</th>
<th>Estimated value ($US)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil bacterial services, such as converting N into usable form for crops, forests, pastures</td>
<td>$33 billion per year</td>
</tr>
<tr>
<td>Insect pollination of &gt;40 commercial crops in U.S.</td>
<td>$30 billion per year</td>
</tr>
<tr>
<td>&gt;350 million visitors to U.S. national parks, wildlife refuges and other public lands (fishing, hiking, hunting, whale watching, etc.)</td>
<td>&gt;400,000 jobs and $28 billion per year</td>
</tr>
<tr>
<td>Sales of prescription drugs containing ingredients derived from wild plants</td>
<td>&gt;$15 billion per year</td>
</tr>
<tr>
<td>Genetic trait from wild crop varieties introduced into domestic agricultural crops in the U.S.</td>
<td>$8 billion per year</td>
</tr>
<tr>
<td>Commercial and sport fishing revenue lost due to destruction of U.S. estuaries, 1954-1978</td>
<td>&gt;$200 million</td>
</tr>
<tr>
<td>Annual ocean fish catch worth to U.S. economy</td>
<td>$2.5 billion per year</td>
</tr>
<tr>
<td>Flood control services provided by marshlands near the Charles River in Boston, MA</td>
<td>$72,000 per acre of wetland</td>
</tr>
<tr>
<td>Products from natural and managed forests: timber, game, fruit, nuts, to U.S. economy</td>
<td>$3-8 billion per year</td>
</tr>
</tbody>
</table>
Sustainability

• Ability to maintain natural resources without diminishing them

• Intergenerational equity

• Sustainable natural resources
  – perpetual
  – nonrenewable
  – renewable
Major types of natural resources

**Resources**

- **Perpetual**
  - Direct solar energy
  - Winds, tides, flowing water

- **Nonrenewable**
  - Fossil fuels
  - Metallic minerals (Fe, Cu, Al)
  - Non-metallic minerals (clay, sand, PO₄)

- **Renewable**
  - Fresh air
  - Fresh water
  - Fertile soil
  - Plants and animals (biodiversity)
Chapter 3: Species Diversity
What is a species?

- Group of actually or potentially interbreeding natural populations, which is reproducively isolated from other such groups, and which produces viable offspring
What is a species?

• Problems with the classic definition
  – animal and plant hybrids (e.g., *Canis* species)
  – plants that exhibit asexual reproduction, self-fertilization or polyploidy
What is a species?

- **Problems with the classic definition**
  - *single-celled organisms* (bacteria, yeast, algae)
  - *prions* (self-reproducing proteins) and *viruses* that reproduce by using the cellular machinery of other cells
What is a species?

• Other proposed definitions
  – based on purpose for classification, e.g.,
    • evolutionary (ESUs or evolutionarily significant units)
    • phylogenetic*
    • ecological
    • cladistic
    • morphological
  – different definitions serve a purpose, none is more correct or better than others
  – fallback definition is that of a “competent taxonomist”
What is a species?

Figure 3.1. Hypothetical example illustrating the relationships between species A and B, Evolutionarily Significant Units (ESU), and populations as discussed in Box 3.1. The lengths of the lines joining species, ESUs, and populations are generally equivalent to the genetic distances among them. In this example all populations could be considered separate Management Units (MU) except populations 3 and 4, which are too closely related to be managed separately.
What is a species?
*Linnaean classification system*

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Humans</th>
<th>Asian tiger mosquito</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kingdom</td>
<td>Animalia</td>
<td>Animalia</td>
</tr>
<tr>
<td>Phylum</td>
<td>Chordata</td>
<td>Arthropoda</td>
</tr>
<tr>
<td>Class</td>
<td>Mammalia</td>
<td>Insecta</td>
</tr>
<tr>
<td>Order</td>
<td>Primates</td>
<td>Diptera</td>
</tr>
<tr>
<td>Family</td>
<td>Homidae</td>
<td>Culicidae</td>
</tr>
<tr>
<td>Genus</td>
<td>Homo</td>
<td>Aedes</td>
</tr>
<tr>
<td>species</td>
<td>sapiens</td>
<td>aegypti</td>
</tr>
</tbody>
</table>
How many species are there?

• Linnaeus (1758): 13,000
• Hammond (1995): 3.6 – 111.7 million
## How many species are there?

*Conservative estimates*

<table>
<thead>
<tr>
<th>Category</th>
<th>No. of identified species</th>
<th>Estimated total number of species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonvascular plants</td>
<td>150,000</td>
<td>200,000</td>
</tr>
<tr>
<td>Vascular plants</td>
<td>250,000</td>
<td>280,000</td>
</tr>
<tr>
<td>Invertebrates</td>
<td>1,300,000</td>
<td>4,400,000</td>
</tr>
<tr>
<td>Fishes</td>
<td>21,000</td>
<td>23,000</td>
</tr>
<tr>
<td>Amphibians</td>
<td>3,125</td>
<td>3,500</td>
</tr>
<tr>
<td>Reptiles</td>
<td>5,115</td>
<td>6,000</td>
</tr>
<tr>
<td>Birds</td>
<td>8,715</td>
<td>9,000</td>
</tr>
<tr>
<td>Mammals</td>
<td>4,170</td>
<td>4,300</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1,742,000</strong></td>
<td><strong>4,926,000</strong></td>
</tr>
</tbody>
</table>
Figure 3.2. Roughly 1.7 million species have been described by scientists; arthropods, primarily insects, constitute almost half this number. The estimated number of species is far greater, especially for smaller life-forms. (The data presented here are summarized from Table 3.1-2 of Heywood and Watson 1995. Redrawn from Hunter 1999.)
The total number of described species, by taxonomic group (after Hammond 1992, Stork 1993).
Using the relationship between number of species and their body size for larger organisms, it is possible to back-predict for the less known, smaller species to estimate the total number of species in the world (after May 1978, 1988).
The projected number of species for different taxa based on an estimated global total of 12.5 million species (after Hammond 1992, Stork 1993); shaded areas are the total number described species from Slide 11.
How many species are there?

- Tree fogging experiments by Terry Erwin (Smithsonian Institution) in 1980s: estimated 30 million insect species
  - based on 955 species of beetles collected by fogging 19 individuals of a single tree species in Panama
  - estimated that 13.5% of the beetles were monophagous; multiplied estimated total number of herbivores by the estimated number of total tree species
How many species are there?

- Tree fogging experiments by Terry Erwin
  - added in the fungivores, predators and other insects → 30 million total
  - most have not been described scientifically

- If there are 30 million species of insects, how many total species of organisms actually exist?
  - estimates over 100 million....
New species discovered in Colombia

Yariguies brush finch in 2006

Red-bearded titi monkey (*Callicebus caquetensis*) in 2010
52 new species discovered in Borneo since 2005!

Treefrog

New species of clouded leopard

Martin or civet?
Cryptic species

Figure 3.3. The depth of unexplored biodiversity is greatest among small species. Here are two examples. (a) An oribatid mite, *Gozmanyina majesta*, that lives in mosses and leaf litter in sphagnum bogs, where it feeds on fungi; it erects the large white setae on its back as a defense against predators. (Photo by Valerie Behan-Pelletier and Roy A. Norton.) (b) A tiny fungus, *Botryandromyces ornatus*, one of a diverse group, the Laboulbeniales, that live obligately on the integument of living arthropods; these specimens are growing on a beetle’s leg. (Photo from Alex Weir.)
**Figure 3.4.** These caterpillars represent **ten sibling species** of what was long thought to be a single butterfly species, the 2-barred flasher, *Astraptes fulgerator* (Hebert et al. 2004). The interim names reflect the primary larval food plant and, in some cases, a color character. (Photo from Dan Janzen; © 2004, National Academy of Sciences, USA.)
How many species are there?

• Do we really need to know?
  – the actual number of species in the world may not matter, but the estimates convey two fundamental ideas
    • the number of species that may ultimately be at risk is huge
    • there is still a lot about the world that we have yet to discover
Intrinsic value of species

- Conservation status
  - Governing bodies
    - World Conservation Union (IUCN Red List)
    - Convention on International Trade in Endangered Species (CITES)
  - Terms
    - rare
    - endangered
    - vulnerable
    - critically endangered
Intrinsic value of species

• **Rare** (versus endangered)
  - geographic range
    • found naturally only in a small geographic area
    • endemic
  - **habitat specificity**
    • occur only in specific, uncommon types of habitats
    • e.g., caves, desert springs
  - **local population size**
    • occur in low population densities where ever they are found
Instrumental value of species

• Economic values
  – food
    • domesticated varieties
    • importance of wild types
  – medicine
    • toxic secondary compounds
  – clothing, shelter, tools
  – fuel
  – recreation
  – services
Instrumental value of species

• Spiritual values
• Science and educational values
Instrumental value of species

• Ecological values
  – dominant species: numerically important
  – controller species: major roles in movement of energy and nutrients
**Instrumental value of species**

- **Ecological values**
  - *keystone species*: play a larger ecological role than their abundance would indicate

**Figure 3.10.** The ecological impacts of keystone species take many forms. The purple sea star is a keystone species because its predatory activities allow many species to coexist, while beavers (overleaf) shape entire communities because of flooding by their dams. (Sea star photo by Lindsay Seward.)
Innistrumental value of species

Mytilus monopolizes space and crowds out other species.
Instrumental value of species

- Strategic values
  - flagship species
Instrumental value of species

• **Strategic values**
  – umbrella species
Figure 3.11. Because jaguars range over a broad region and many different types of ecosystems, efforts to save them can benefit many other species, thus making jaguars an **umbrella species**. The map depicts both the range of ecosystems used by jaguars 100 years ago and the current range (in cross hatching). (From Sanderson et al. 2002b: Photo by M. Hunter.)
Instrumental value of species

• **Strategic values**
  – indicator species
    • positive indicators
    • negative indicators
Relative abundance of five species of tiger beetles along a disturbance gradient in Venezuela.
Chapter 4: Ecosystem Diversity
Biomes

• Groupings of plants and animals on a **regional scale** whose distribution patterns depend heavily on patterns of **climate**

• Identified by the **climax vegetation** or **community**

• A **climax community** forms in an undisturbed environment and continues to grow and perpetuate itself in the absence of further disturbance
Tundra

- Limited to the upper latitudes of the northern hemispheres; forms a belt around the arctic ocean
- Barren, treeless, low-lying shrubs, mosses and lichens
- Long winters, short growing season, little precipitation
- Little soil under permafrost
Taiga

- Coniferous trees extending in a giant arc from Alaska, North America and Canada, through Europe and Siberia
- Rainfall 15-20 inches annually; long severe winters
- Conical, needle leaf trees adapted to harsh winters
- Moose, elk, deer, snowshoe hare: predators whose coats become white in winter
Temperate broadleaf deciduous forest

- Located in western and central Europe, eastern Asia and eastern North America
- 20 to 60 inches of precipitation distributed evenly throughout the year
- Carnivores have been mostly eliminated by habitat destruction and hunting
- Nut-eaters such as squirrels and chipmunks; omnivores such as raccoons, skunks, black bear and opossum
Temperate evergreen forest

• Soil is poor, droughts and fires are frequent

• Predominant species tend to be evergreens

• Cool coastal climates where there is considerable rainfall or frequent heavy fogs may produce temperate rainforests (redwoods)
Chaparral

• Moderately dry climate

• Small (3-15 foot) shrubs with leathery leaves that contain aromatic and flammable substances
Temperate grasslands

- Prairies, steppes, veldt, pampas
- 10 to 20 inches of precipitation a year, much of which falls as snow
- Perennial grasses, forbs, and members of the sunflower and pea families
- Ground squirrels, prairie dogs, and pocket gophers
Tropical rainforest

- Average monthly temperatures above 17.8°C; no seasons
- Precipitation >100 inches per year
- ~50% of world’s plant and animals
- Importance of the canopy
Deserts

- Arid climates averaging less than 10 inches of precipitation a year
- Evaporation > precipitation
- Can reach temperatures higher than 37.8°C (100°F) on summer days and -6.7°C (20°F) at night
Conditions that create deserts

- Easterly winds keep moist air rising off the oceans from reaching the coast
- Near the 30° latitude, subtropical air descends in association with the Hadley cell, then compresses causing the formation of heat and dry, warm air
- Temperate deserts are generally located in areas known as rain shadows (Fig. 1-12)
- Located in the interiors of continents
Rain shadows

Moisture from the ocean cools and condenses to form rain on the windward side of the mountains.

Dry air falls on the leeward side. The air compresses as it falls, and so it warms and then absorbs moisture.