Biological Diversity and Ecosystem Integrity
Species Richness of Any Region

A balance between:

• Speciation and Immigration (adding species)

and

• Extinction and Emigration (subtracting species)
Modern and Historical Factors Determine Biodiversity

- Modern abiotic and biotic factors: climate, soils and substrate, elevation, topography, other species present (e.g., potential competitors, predators, diseases, mutualists)

- Historical factors: geological events (e.g., plate tectonics, mountain building and erosion), climate change, immigration (dispersal), splitting of ranges (vicariance), speciation, extinction
Figure 17. Major topographic features formed or shaped by Pleistocene seas. Illustration by Frank R. Rupert.
Florida Scrub
Liatris ohlingerae

Source: Pedro Quintana-Ascencio
Florida Scrub-Jay

Photo by Reed Noss
Gopherus polyphemus

Photo by Reed Noss
Biodiversity is not distributed randomly or uniformly across the landscape. Rather it tends to be concentrated in certain places: “hotspots”
From: Myers et al. (2000)
Bird species richness

Threatened bird species

Endemic bird species

From Orme et al. (2005)
Terrestrial vertebrate diversity by ecoregion (adjusted for ecoregion area):

(a) Species richness
(b) Species endemism

From: Lamoreux et al. (2006)
The Species-Area Relationship

“Islands only produce a greater or lesser number of species, as their circumference is more or less extensive”

- Johann Reinhold Forster (1772)
  (naturalist on Captain Cook’s second voyage around the world)
Amphibians and Reptiles in West Indies

(A)

Number of species

1000

100

10

1

Area (km²)

10

100

1000

10,000

100,000

Redonda

Montserrat

Jamaica

Puerto Rico

Hispaniola

Cuba
Birds in Sunda Islands, Philippines, and New Guinea

(B)

Number of species

Sunda Islands

Philippines

New Guinea

Area (km²)

1

10

100

1000

10,000

100,000

1000

100
Major Reason for the Species-Area Relationship:
Larger areas have more kinds of habitats (i.e., more heterogeneity)
Latitudinal Diversity Gradients

• Tropics are sources, high latitudes are sinks
• Extinction is lower in tropics, speciation is higher (positive feedback between number of species and rate of diversification)
• Low latitudes have higher primary productivity and more contiguous area
• Moisture is also important (i.e., hot wet places have highest species richness)
• Water explains most variation in species richness at low latitudes; energy (for animals) or water-energy (for plants) at high latitudes
Animal species richness is constrained by the interaction of energy and water.
Metabolic Theory of Biodiversity

- **Thermal kinetic energy**
  Temperature, $T$

- **Chemical potential energy**
  Net primary production (NPP)

- **Evolutionary rate per population**
  Function of $T$ and body size

- **Total number of populations**
  Function of metabolic rate and NPP

- **Overall speciation rate**
  Function of evolutionary rate per population and total number of populations

- **Overall extinction rate**
  Function of average abundance per species

- **Biological diversity**
  Function of overall speciation rate and overall extinction rate

*Gillooly and Allen (2007), Modified from Allen et al. (2007)*
Net Primary Production (Modis)

From: Running et al. (2004)
Latitudinal species richness in bivalve mollusks
C. Hart Merriam’s (1890, 1894) life zones (A) on San Francisco Peaks, Arizona, and (B) as latitudinal zones in North America (from Bailey 1996)
From Harris (1984)
Scales of Species Richness

- **Alpha**: richness within a local community
- **Beta**: turnover in species richness along an environmental gradient (from site to site)
- **Gamma**: total richness for a defined landscape or region
Model of the intermediate disturbance hypothesis

- Diversity
- Low
- High
- Disturbance frequency or intensity
Disturbance and Evolution

Species have evolved ways to:

• Avoid
• Tolerate
• Exploit

Disturbance…

Therefore, disturbances outside the range of variability that a species has experienced during its evolutionary history are likely to cause decline or extinction.
Stand-Replacing Fire vs. Stand-Maintaining Fire
Minimum Dynamic Area:

“the smallest area with a natural disturbance regime, which maintains internal recolonization sources and hence minimizes extinction”

Pickett and Thompson (1978)
Sizes of Natural Disturbances

- Gaps in old-growth mixed mesophytic forest: avg. = 31 m², 1.2%/year; largest 1500 m²
- Large windstorms in Rocky Mts: 15,000-20,000 acres
- April 3-4, 1974: Midwest tornadoes – combined path length = 2,598 miles
- Hurricane Hugo, 1989: 150 mile-wide swath across South Carolina, 1 billion bf of timber
- 4th of July 1999 blowdown: 500,000 acres in Minnesota, 288,000 acres in Ontario
- Yellowstone Fires, 1988: 1.2 million acres
- Largest recorded fire in Canada’s boreal forest: 3.5 million acres
Effects of an ancient cataclysm

The scenario is straight out of a science-fiction movie: Giant meteorite strikes earth, setting the planet afire. Volcanoes erupt, tsunamis crash into the continents. The sky grows dark for months, perhaps years. Unable to cope with the catastrophic changes in climate, countless species are wiped off the face of the planet.
Climate change typically is associated with mass extinctions and radiations.
Elevational shifts in vegetation in the eastern Cordillera of the Andes in Columbia from glacial maximum to the present (from Flenley 1979)
Reconstruction from fossil pollen of movement of two tree species northward since the last glacial maximum. Lines show the front of each species range in 1000-year intervals. The darker area is the present range. From Bernabo and Webb (1977).
Geographic range shifts of four rodent species from Pleistocene records (dots) to the present ranges (shading). From Graham (1986)
In the late Pleistocene, the diversity of large mammals in North America was unmatched. What are the ramifications of that scenario relative to today (e.g. plant and ecosystem diversity, etc.)?
Coincidence?
Jared Diamond: “man the exterminator.”
Passenger pigeon

Painting by John James Audubon
Proportion of U.S. and Canadian Species at Risk by Plant & Animal Group

- Freshwater mussels
- Snails (land & freshwater)
- Crayfishes
- Amphibians
- Stoneflies and mayflies
- Grasshoppers
- Freshwater fishes
- Flowering plants
- Mosses, Liverwort and Hornworts
- Ferns & fern allies
- Tiger beetles
- Butterflies & skippers
- Dragonflies & damselflies
- Reptiles, turtles, and crocodilians
- Mammals
- Lichens
- Conifers
- Birds

Legend:
- Yellow: Vulnerable (G3)
- Orange: Imperiled (G2)
- Red: Critically Imperiled (G1)
- Blue: Presumed/Possibly Extinct (GX/GH)
Figure 2. Areas of expansion, contraction, and persistence, based on historic and current species ranges for 17 species that experienced range contractions over more than 20% of their historic range. From: Laliberte and Ripple (2004)
Biodiversity Above and Below the Species Level

- Genetic diversity (within and among populations)
- Species diversity (richness, but also composition and abundances)
- Ecosystem diversity (structure, function, and composition)
Endangered Species Act

“To provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved...”

Implementation: largely species by species = ineffective
Latest Endangered Species: Natural Habitats of America

By WILLIAM K. STEVENS

In the first full review of the health of the American landscape, a new Federal study has concluded that vast stretches of formerly vibrant natural habitat, once amounting to at least half the area of the 48 contiguous states, have declined to the point of endangerment.

Although the plight of individual species has been the focus of public interest, the health of the larger interconnected community of plants, animals and microbes of which they are a part — the ecosystem, nature’s functional unit — is perhaps more important as a gauge of vitality. The new report finds that scores of ecosystems, of widely varying types and sizes, have declined on a grand but largely unappreciated scale. If the remnants should vanish, say the study’s authors, species adapted to them would probably vanish as well.

Thirty of the Imperiled ecosystems, including some that dominated and characterized whole regions before Europeans first landed in America, have declined over more than 98 percent of their area and are considered “critically endangered,” the study found. Decline was defined as destruction of a natural area, conversion of the area to other land uses — agriculture, for example — or “significant degradation” of ecological character or function.

“We’re not just losing single species here and there, we’re losing entire assemblages of species and their habitats,” said Dr. Reed F. Noss, one of three biologists who conducted the study for the National Biological Service, a research organization created within the Interior Department by Secretary Bruce Babbitt in 1993. The new study is to be issued by the agency as a technical report within a month.

“Our results indicate that more

Continued on Page B10, Column
Longleaf Pine Ecosystem

Photo by Reed Noss
LONGLEAF PINE FOREST
1936-1987
88% Decline in 50 Years

Source: Randy Kautz
As ecosystems become endangered, so do the species associated with them, and so do the “services” that ecosystems provide to human societies.
Ecosystem Services:
Benefits to People from Keeping Ecosystems Healthy

- Supporting services
- Provisioning services
- Regulating services
- Cultural services
From: Carpenter and Folke (2006)
Threats to Biodiversity and Ecosystem Integrity

Ultimate threats:
- human population growth
- economic growth and resource consumption

Proximate threats:
- habitat destruction, degradation, and fragmentation
- invasive non-native species
- global climate change (including sea-level rise)
- over-exploitation (especially marine)
Exponential Human Population Growth
Years 0-2100 A.D.

April 2008
6.7 billion
Exponential Population Growth Inevitably Ends in Population Collapse (and often ecosystem collapse)

(Deer Population in the Kaibab Plateau 1905 – 1940)
The annual population growth rate in Florida (which peaked at a net growth of nearly 1000 people per day) slowed recently, but will inevitably rise again. Housing construction has also slowed, after a long period of over-building, but habitat destruction continues at a rapid pace as developers anticipate another housing boom.
The Human Footprint, based on population density, land transformation, accessibility, and electrical power infrastructure
Agriculture Has Been Responsible for More Habitat Loss Than Any other Human Activity

Dark areas are where at least 30% of the landscape is cropland
The New Agricultural Threat: Biofuels

- Huge expansion of agricultural lands into natural habitat and formerly abandoned agricultural areas that could be restored to natural conditions
- Threat to world food supply
- Will likely cause much more harm than good
### Carbon emissions saved using biofuels instead of fossil fuels:

<table>
<thead>
<tr>
<th>Fuel Conversion</th>
<th>Carbon (metric tons/hectare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar cane to ethanol</td>
<td>50</td>
</tr>
<tr>
<td>Sugar beet to ethanol</td>
<td>30</td>
</tr>
<tr>
<td>Maize to ethanol</td>
<td>10</td>
</tr>
<tr>
<td>Rapeseed to biodiesel</td>
<td>20</td>
</tr>
<tr>
<td>Woody biomass to biodiesel</td>
<td>30</td>
</tr>
<tr>
<td>Palm oil to biodiesel</td>
<td>40</td>
</tr>
</tbody>
</table>

Over 30 years, the carbon sequestered by restoring forests is greater than the emissions avoided by using biofuels.

Redrawn from Righelato and Spracklen. *Science* 317:902 with supplementary data on palm oil (Righelato pers com)

### Carbon sequestered as a result of land conversion for restoration:

<table>
<thead>
<tr>
<th>Land Conversion</th>
<th>Carbon (metric tons/hectare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperate cropland to forest</td>
<td>100</td>
</tr>
<tr>
<td>Tropical cropland to forest</td>
<td>200</td>
</tr>
<tr>
<td>Temperate cropland to grassland</td>
<td>30</td>
</tr>
</tbody>
</table>

### Carbon released by clearcutting:

<table>
<thead>
<tr>
<th>Clearcutting Event</th>
<th>Carbon (metric tons/hectare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical forest to cropland</td>
<td>250</td>
</tr>
</tbody>
</table>

Adapted from Righelato and Spracklen (2007)
Livestock: A bigger threat to imperiled plant and animal species in the U.S. than all other nonnatives? (Gurevitch and Padilla 2004)

Parker et al. (2006): Native herbivores promote resistance to plant invasions, whereas exotic herbivores (to which native plants have not been selected to resist) facilitate invasions and trigger an “invasional meltdown”
Plant Diversity of Grasslands in Relation to Grazing Intensity

From: Milchunas et al. (1988)
Crested Caracara in “semi-improved” pasture, South-central Florida
A huge and increasing threat to the integrity of the oceans is acidification from CO$_2$ – which dissolves CaCO$_3$ and could destroy food webs.
The Gulf of Mexico Dead Zone

The “Dead Zone,” which varies in size but can cover up to 6,000-7,000 square miles, begins with excess N and P from agriculture in the Mississippi River watershed. In the Gulf, these nutrients lead to algal blooms and depletion of dissolved oxygen, creating hypoxic conditions and massive fish kills.

http://www.nasa.gov/vision/earth/environment/dead_zone.html
Ecosystems Can Absorb or Bounce Back from Stress – Up to a Point…

• Resilience – a modern concept of ecological stability

• Sometimes, the ability to resist stress and bounce back from disturbance are negatively correlated!
Ecosystem Stability and Biodiversity Go Together

• Functional Group – a group of species that plays a particular functional role in an ecosystem
• A high diversity of functional groups promotes stability in an ecosystem
• A high diversity (redundancy) of species within functional groups also contributes to stability
• Which is most important may vary – so, it makes sense to maintain both!
Common and Rare Species are Both Important to Ecosystem Function

- **Keystone Species** (including “Ecosystem Engineers”) – rare to relatively common species whose activities increase the biodiversity of the ecosystem

- **Foundation Species** – common or dominant species that determine the structure, function, and overall character of an ecosystem
Why Do We Care?

Conservation – and the science of conservation biology – rest on the value assumption that biodiversity is good and ought to be preserved.
The reasons for valuing biodiversity fall into two classes:

- Utilitarian (including ecosystem services)
- Non-utilitarian

We will discuss these reasons later!