Human Uses of the Biosphere and Impacts on Earth Systems Ecosystems

IPOL 8512

Ecosystem Productivity

- **Productivity** or **production** = the rate of generation of biomass in an ecosystem. It can be expressed in units of mass per unit surface area per unit time, e.g. grams per square meter per year. The mass unit may relate to dry matter or to the mass of carbon generated.

Primary Productivity

- **Primary productivity** = the productivity of autotrophs, such as plants on land and algae in water.
  - It involves the synthesis of new organic material from inorganic molecules, such as H_2O and CO_2. It is dominated by the process of **photosynthesis**, which uses sunlight to synthesize organic molecules, such as sugars. A simplified reaction is

$$CO_2 + H_2O + \textit{light} \rightarrow CH_2O + O_2$$

  - **Chemosynthesis**, the biological conversion of one or more carbon molecules (usually carbon dioxide or methane) and nutrients into organic matter using the oxidation of inorganic molecules (e.g. hydrogen gas, hydrogen sulfide) or methane as a source of energy, represents a small fraction of primary production. A simplified sample reaction is

$$CO_2 + O_2 + 4\ H_2S \rightarrow CH_2O + 4\ S + 3\ H_2O$$

Gross Primary Production, GPP

- Autotrophs

  $CO_2 + H_2O \rightarrow$ organic molecules, e.g. $C_6H_{12}O_6$

  Radiant energy $\rightarrow$ chemical potential energy
- Energy stored in organic molecules supplies energy needs of both autotrophs and heterotrophs.
- Because there are lots of different organic molecules, the rate of formation of these molecules (mass of substances per time) can be described in terms of the mass of carbon in the substances formed per time, e.g. Gt(C)/y.
- The total rate of formation of these substances is called the gross primary production, GPP.

Net Primary Production, NPP

- The autotrophs convert some of the organic molecules that are part of the GPP back into CO_2 and H_2O in plant respiration to provide energy to run the autotroph (plant respiration).

- The portion that remains is available for autotroph growth and for the energy needs of heterotrophs. This is the net primary production, NPP, which is the difference between the rate at which the plants in an ecosystem produce useful chemical energy (GPP) and the rate at which they use some of that energy during autotroph respiration.

  NPP = GPP - respiration [by plants]

- Both gross and net primary production can be expressed in units of mass/area/time, e.g. Gt(C)/m^2/y, or mass/time, Gt(C)/y.

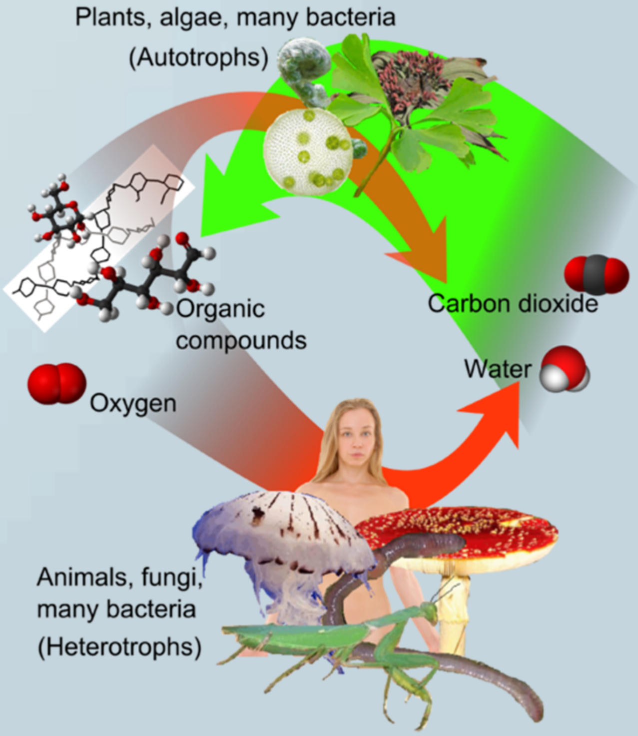
GPP and NPP

$CO_2 + H_2O$ + radiant energy $\rightarrow$ higher energy organic molecules, e.g. $C_6H_{12}O_6 \rightarrow$ GPP

GPP = NPP + autotroph respiration (R)

rate at which
higher energy organic molecules, e.g. $C_6H_{12}O_6 \rightarrow CO_2 + H_2O$ + energy

Rate of formation of more complex molecules that are available to provide energy for autotroph growth and heterotroph growth and respiration



Secondary Productivity

- **Secondary productivity** = the generation of biomass of heterotrophic (consumer) organisms in a system. It represents the quantity of new tissue created through the use of assimilated food.
  - Secondary productivity is sometimes defined to only include consumption of primary producers by herbivorous consumers (with tertiary production referring to carnivorous consumers), but is more commonly defined to include all biomass generation by heterotrophs.
  - Organisms responsible for secondary production include animals, fungi, and many bacteria.

Conversion of Solar Energy to Biomass

Simplified photosynthesis:

$$CO_2 + H_2O + \text{energy} \rightarrow CH_2O + O_2$$

(Actual typical photosynthate: $C_{1480}H_{2960}O_{1480}N_{160}P_{18}S_{10}$)

Simplified respiration or combustion:

$$CH_2O + O_2 \rightarrow CO_2 + H_2O + \text{energy}$$

"Fixing" 1 g of organic C requires about 40 kJ of energy.

"Burning" 1 g of organic C releases about 40 kJ of energy.

Global Estimates of GPP and NPP

- Global GPP ≈ 200 Gt C/y (± large uncertainty)
- Global NPP ≈ 100 Gt C/y ± 25 Gt C/y
  - Estimate has gone up since Cow published: 75 → 100
- Terrestrial NPP ≈ 60 Gt C/y
  - Varies widely by biome type; see *Cow* Appendix XII (old estimates)
- Ocean NPP ≈ 50 Gt C/y ± 10 Gt C/y (hard to measure)

Problem:

- Calculate the joules of energy per year derived from the NPP of 100 Gt C/yr.

Annual Energy from Global NPP

- Calculate the joules of energy per year derived from the NPP of 100 Gt C/yr.

$$\frac{?\,\mathrm{J}}{1\ \mathrm{yr}} = \frac{100\ \cancel{\mathrm{Gt}}\ \cancel{\mathrm{C}}}{1\ \cancel{\mathrm{yr}}}\left(\frac{10^9\ \cancel{\mathrm{t}}}{1\ \cancel{\mathrm{Gt}}}\right)\left(\frac{10^6\ \cancel{\mathrm{g}}}{1\ \cancel{\mathrm{t}}}\right)\left(\frac{40\ \cancel{\mathrm{kJ}}}{1\ \cancel{\mathrm{g}}\ \cancel{\mathrm{C}}}\right)\left(\frac{10^3\ \cancel{\mathrm{J}}}{1\ \cancel{\mathrm{kJ}}}\right) \approx \mathbf{4.0 \times 10^{21}\ J/yr}$$

NPP Percentage of Total Solar Radiation

- Calculate the power in TW derived from 100 Gt C/yr. What percentage of the total solar radiation (100,000 TW) is this?

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$$\left(\frac{1 \cancel{\text{yr}}}{365 \cancel{\text{day}}}\right)\left(\frac{1 \cancel{\text{day}}}{24 \cancel{\text{hr}}}\right)\left(\frac{1 \cancel{\text{hr}}}{60 \cancel{\text{min}}}\right)\left(\frac{1 \cancel{\text{min}}}{60 \cancel{\text{s}}}\right) \approx \mathbf{130\ TW}$$

$$\frac{? \text{ TW NPP}}{\text{TW solar}} \times 100 = \frac{130 \text{ TW NPP}}{100{,}000 \text{ TW solar}} \times 100 = \mathbf{0.13\%}$$

- In a sense, this is the efficiency with which the planet uses solar energy.

Conversion Between Mass Carbon and Mass Biota

- We can approximate the chemical composition of living things as CH_2O and water. A better approximation is $H_{2960}O_{1480}C_{1480}N_{160}P_{18}S_{10}$. It is useful to be able to convert between mass of CH_2O and mass of carbon or between mass of $H_{2960}O_{1480}C_{1480}N_{160}P_{18}S_{10}$ and mass of carbon. Calculate the conversion factors that will make these conversions.

Carbon to Biomass Ratio

$$\text{if } CH_2O \approx \text{biomass}$$

$$\frac{?\text{ g C}}{\text{g } CH_2O} = \frac{1\ \cancel{\text{mol C}}}{1\ \cancel{\text{mol } CH_2O}}\left(\frac{12.011\text{ g C}}{1\ \cancel{\text{mol C}}}\right)\left(\frac{1\ \cancel{\text{mol } CH_2O}}{30.0263\text{ g } CH_2O}\right)$$

$$= \frac{0.40002\text{ g C}}{1\text{ g } CH_2O} \approx \frac{0.40002\text{ g C}}{1\text{ g biomass}}$$

$$\text{if } H_{2960}O_{1480}C_{1480}N_{160}P_{18}S_{10} \approx \text{biomass}$$

$$\frac{?\text{ g C}}{\text{g biomass}} = \frac{1480\ \cancel{\text{mol C}}}{1\ \cancel{\text{mol biomass}}}\left(\frac{12.011\text{ g C}}{1\ \cancel{\text{mol C}}}\right)\left(\frac{1\ \cancel{\text{mol biomass}}}{47558.155\text{ g biomass}}\right)$$

$$= \frac{0.37378\text{ g C}}{1\text{ g biomass}}$$

Mass of Living Things

- It has been estimated that there are about 700 Gt C in living biota. If we approximate the chemical composition of living things as CH_2O and water, what is the approximate *dry* mass in metric tons of Earth's living things? If we use $H_{2960}O_{1480}C_{1480}N_{160}P_{18}S_{10}$ as the formula for dry biomass, what is the approximate *dry* mass in metric tons of Earth's living things?

Mass of Living Things

$$? \text{ Gt CH}_2\text{O} = 700 \cancel{\text{Gt C}} \left(\frac{1 \text{ Gt CH}_2\text{O}}{0.40002 \cancel{\text{Gt C}}} \right) \approx \mathbf{1700\ Gt\ biomass}$$

$$? \text{ Gt H}_{2960}\text{O}_{1480}\text{C}_{\cancel{1480}}\text{N}_{160}\text{P}_{18}\text{S}_{10} = 700 \text{ Gt C} \left(\frac{1 \text{ Gt H}_{2960}\text{O}_{1480}\text{C}_{1480}\text{N}_{160}\text{P}_{18}\text{S}_{10}}{0.37378 \cancel{\text{Gt C}}} \right)$$

$$\approx \mathbf{1900\ Gt\ biomass}$$

- Most Earths biomass is in terrestrial plants – trees, shrubs, and grasses. The woody parts of terrestrial plants are about 50% free water, the leafy parts about 75%. As a rough estimate of the average, assume living things altogether are 2/3 water and 1/3 dry organic matter (DOM).
- What is the approximate wet mass of living matter?

Wet Mass of Living Things

$$? \text{ Gt biota} = 1900 \cancel{\text{ Gt DOM}} \left(\frac{3 \text{ Gt biota}}{1 \cancel{\text{ Gt DOM}}} \right) \approx \mathbf{6000 \text{ Gt biota}}$$

- Biota have mass 1,000 times less than atmosphere, but contain a similar amount of carbon.

COW – The Greens We Eat

- The human population is about 6.8 billion people. The average human energy consumption is about 2500 Calories per day. Using the NPP given on page 16 of COW of 7.5×10^{16} g(C)/yr, calculate fraction of the total annual plant growth on Earth that is eaten by humans?

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$$\frac{?\,\text{J}}{\text{yr}} = 6.8 \times 10^{9}\ \cancel{\text{pers.}} \left(\frac{2500\ \cancel{\text{Cal}}}{1\ \cancel{\text{day}} \bullet \cancel{\text{pers.}}}\right)\left(\frac{4184\,\text{J}}{1\ \cancel{\text{Cal}}}\right)\left(\frac{365\ \cancel{\text{day}}}{1\ \text{yr}}\right)$$

$$= 2.6 \times 10^{19}\,\text{J/yr}$$

$$\frac{?\,\text{g C}}{\text{g } C_6H_{12}O_6} = \frac{12.011\,\text{g C}}{1\ \cancel{\text{mol C}}}\left(\frac{6\ \cancel{\text{mol C}}}{1\ \cancel{\text{mol } C_6H_{12}O_6}}\right)\left(\frac{1\ \cancel{\text{mol } C_6H_{12}O_6}}{180.158\,\text{g } C_6H_{12}O_6}\right)$$

$$= \frac{0.40002\,\text{g C}}{1\,\text{g } C_6H_{12}O_6} \approx \frac{0.40002\,\text{g C}}{1\,\text{g biomass}}$$

$$\frac{?\,\text{kJ total}}{\text{yr}} = \frac{7.5 \times 10^{16}\ \cancel{\text{g C}}}{1\ \text{yr}}\left(\frac{1\ \cancel{\text{g biomass}}}{0.40002\ \cancel{\text{g C}}}\right)\left(\frac{1.6 \times 10^{4}\,\text{J}}{1\ \cancel{\text{g biomass}}}\right)$$

$$= 3.0 \times 10^{21}\,\text{kJ/yr}$$

$$\frac{?\,\text{J/yr pers}}{\text{J/yr total}} = \frac{2.6 \times 10^{19}\,\text{J/yr}}{3.0 \times 10^{21}\,\text{J/yr}} = \mathbf{0.0086 \text{ or } 0.86\%}$$

Land Cover

- Earth's land area =
  30% land • 500×10^6 km^2 total = **150×10^6 km^2**
- Quick rule of thumb:
  (see *Cow* Appendix XII for more precise figures)

  Forest = 50×10^6 km^2

  Other Productive Land = 50×10^6 km^2

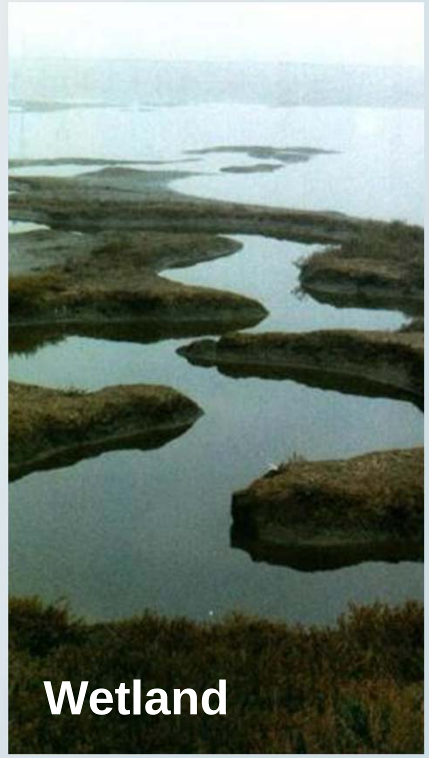
  "Wasteland" = 50×10^6 km^2

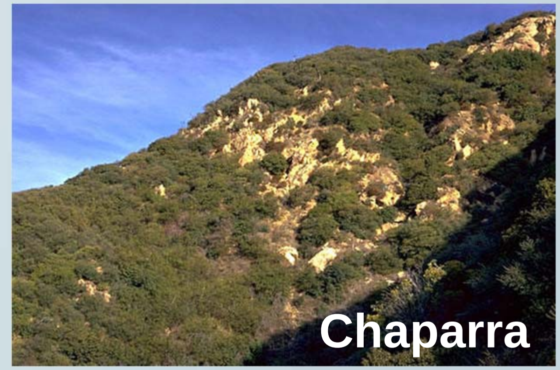
Earth’s Biomes

- NPP differs greatly between different biomes.
- **Biome** = A major regional or global biotic community, such as a grassland or desert, characterized chiefly by the dominant forms of plant life and the prevailing climate.
- Biomes can be classified in different ways, but there are about a dozen major types.

Biomes


Taiga


Wetland


Chaparra
l

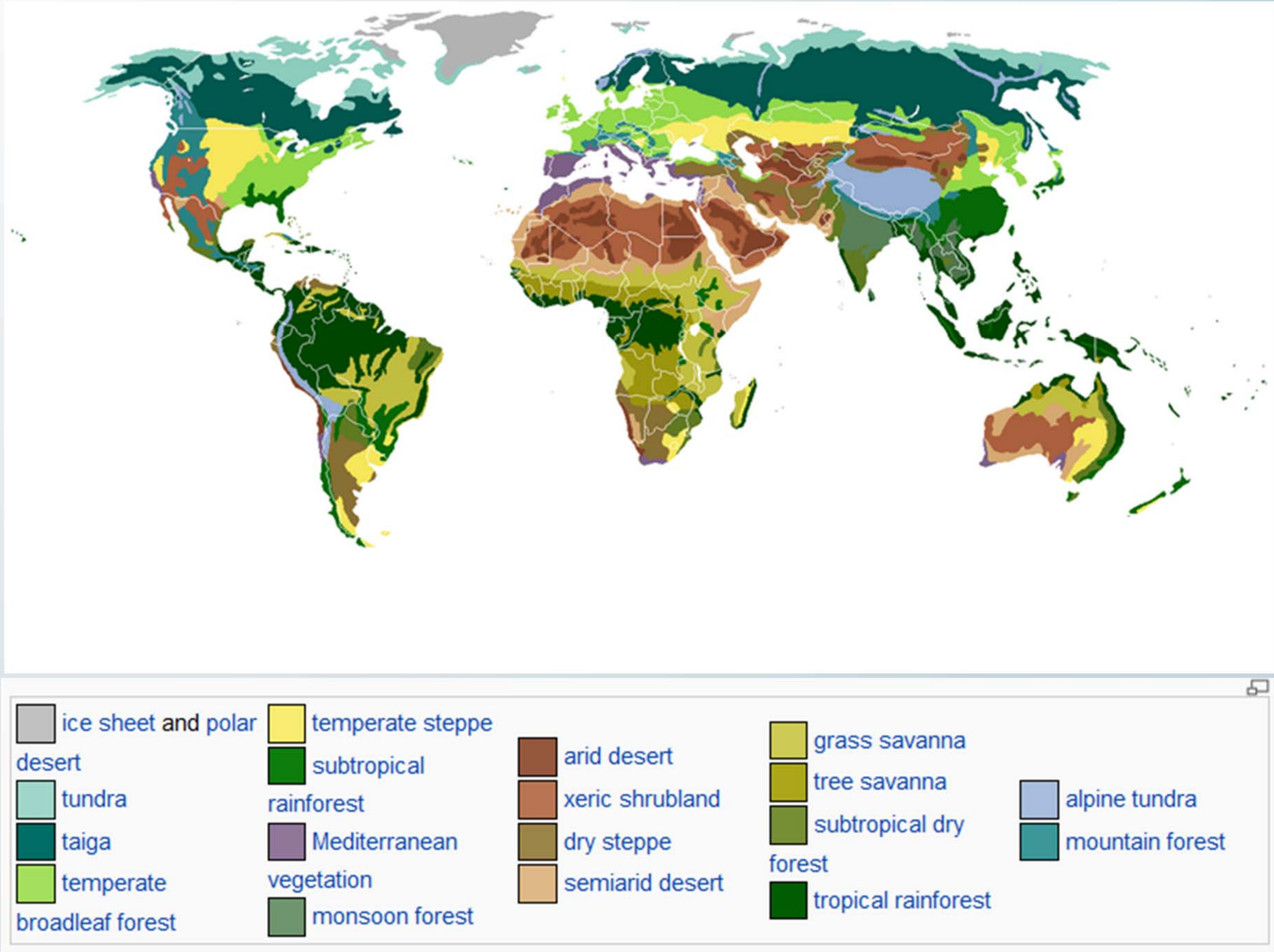

Tropical
rainforest


Desert

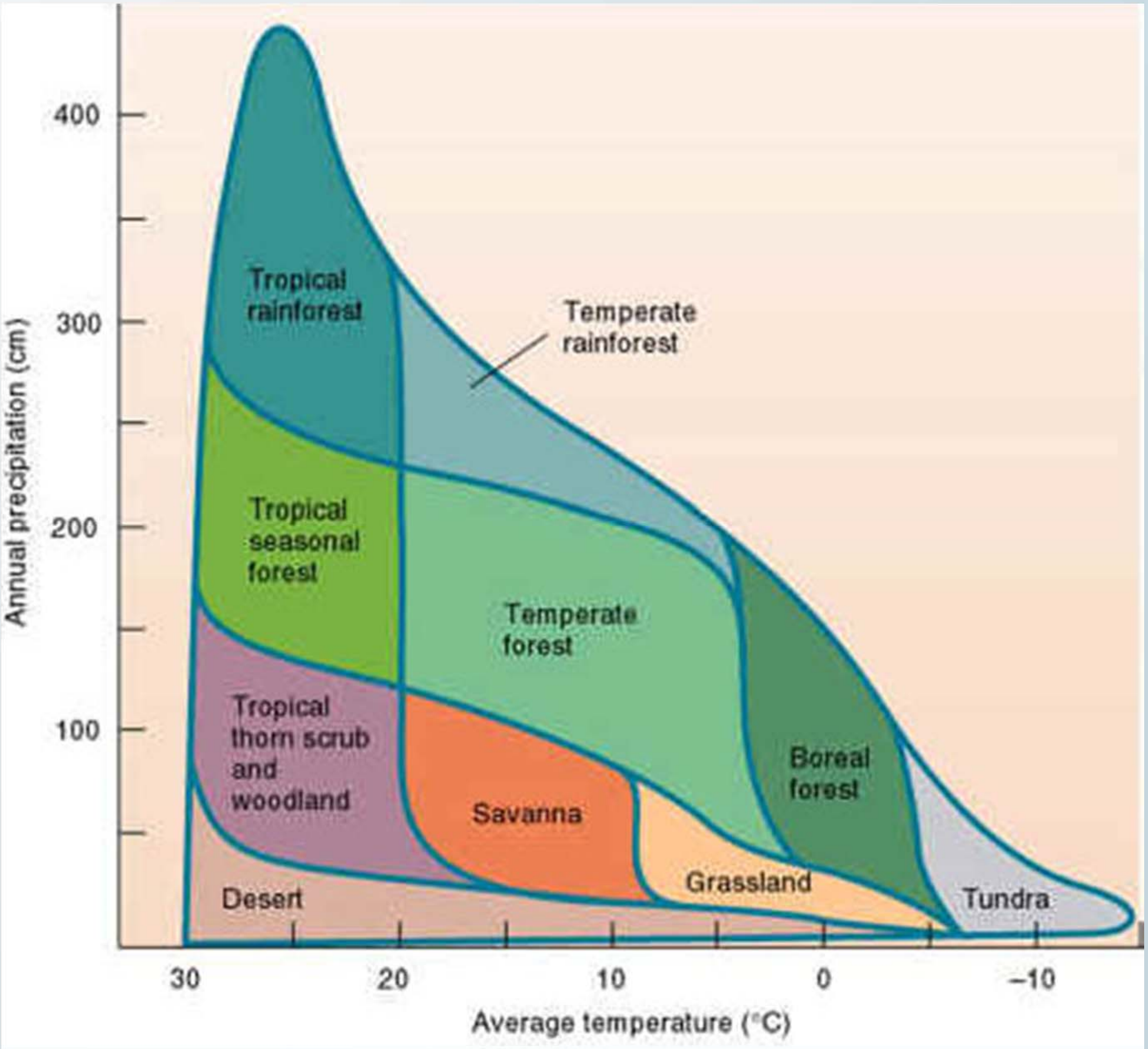

Savanna


Tundra

Earth’s Biomes



Biome distribution is governed by temperature and precipitation.



after Whittaker, 1975

Carbon Stocks and NPP of Terrestrial Biomes

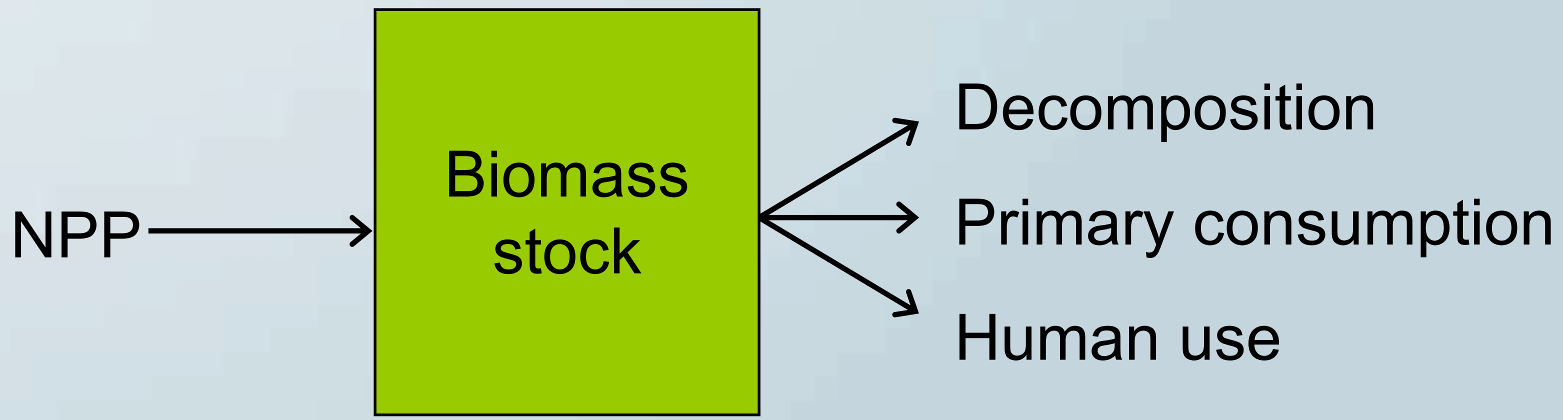
Ecosystem	Area (10^{12} m^2)	NPP (Pg_C/y)	Plant C (Pg)	Soil C (Pg)	NPP/area (kgC/m^2·y)	NPP/ Plant C
Forest, tropical	14.8	13.7	244	123	0.93	6%
Forest, temperate	7.5	5	92	90	0.67	5%
Forest, Boreal	9	3.2	22	135	0.36	15%
Woodland, temperate	2	1.4	16	24	0.70	9%
Chaparral	2.5	0.9	8	30	0.36	11%
Savanna, tropical	22.5	17.7	6	264	0.79	295%
Grassland, temperate	12.5	4.4	9	295	0.35	49%
Tundra, arctic/alpine	9.5	1	6	121	0.01	2%
Desert and scrub	21	1.4	7	168	0.07	20%
Desert, extreme	9	0.1	0	23	0.01	n/a
Perpetual ice	15.5	-	-	-	n/a	n/a
Lake and stream	2	0.4	0	-	0.20	n/a
Wetland	2.8	3.3	12	202	1.18	28%
Peatland	3.4	-	-	455	n/a	n/a
Cultivated	14.8	6.3	3	117	0.43	210%
Human area	2	0.2	1	10	0.10	20%
TOTAL	150.8	59	486	2057		

Stocks vs. Flows of Biomass

- The amount of standing biomass (C stock) is *not* necessarily correlated the flow of new biomass (NPP) (contrast e.g. tropical savannah and arctic tundra).
- Financial analogy:

  Biomass stock = **total amount** in your bank account

  NPP = flow = how much you **deposit** each month



How do humans use NPP?

- Food
- Fodder
- Fuel
- Fiber
- Building materials
- Other *(medicine, dye, household goods...)*

Some economies depend on NPP more directly than others. For example, in Malawi:

- 90% of the population are subsistence farmers
- 90% depend on wood as primary energy source
- 86% of export earnings are from tobacco and other cash crops

Human Impacts on Oceans

- We don’t consume ocean water as we do freshwater, but still have significant effects:
  - **Fishing**
  - **Pollution**
  - Global climate change:
    - Increased sea surface **temperature**
    - Increased **storm** intensity
    - **Acidification** (due to increased CO_2)
    - **Sea level rise**
- Fisheries are an urgent concern. 52% of all stocks are fully exploited and 28% are overexploited. Extrapolating current trends, all ocean fish will be gone by 2048!

Source: Worm, B. et al. (2006). “Impacts of biodiversity loss on ocean ecosystem services.” *Science* 314(5800): 787-790.

Human Impact on Marine Ecosystems

- The authors of the paper, *A Global Map of Human Impact on Marine Ecosystems* by B. S. Halpern, et al in Science 2008;319:948-952 conclude that, “Our analysis indicates that no area [of the world’s oceans] is unaffected by human influence and that a large fraction (41%) is strongly affected by multiple drivers.”
- Land-based activities affect the runoff of pollutants and nutrients into coastal waters and remove, alter, or destroy natural habitat.
- Ocean-based activities extract resources, add pollution, and change species composition.

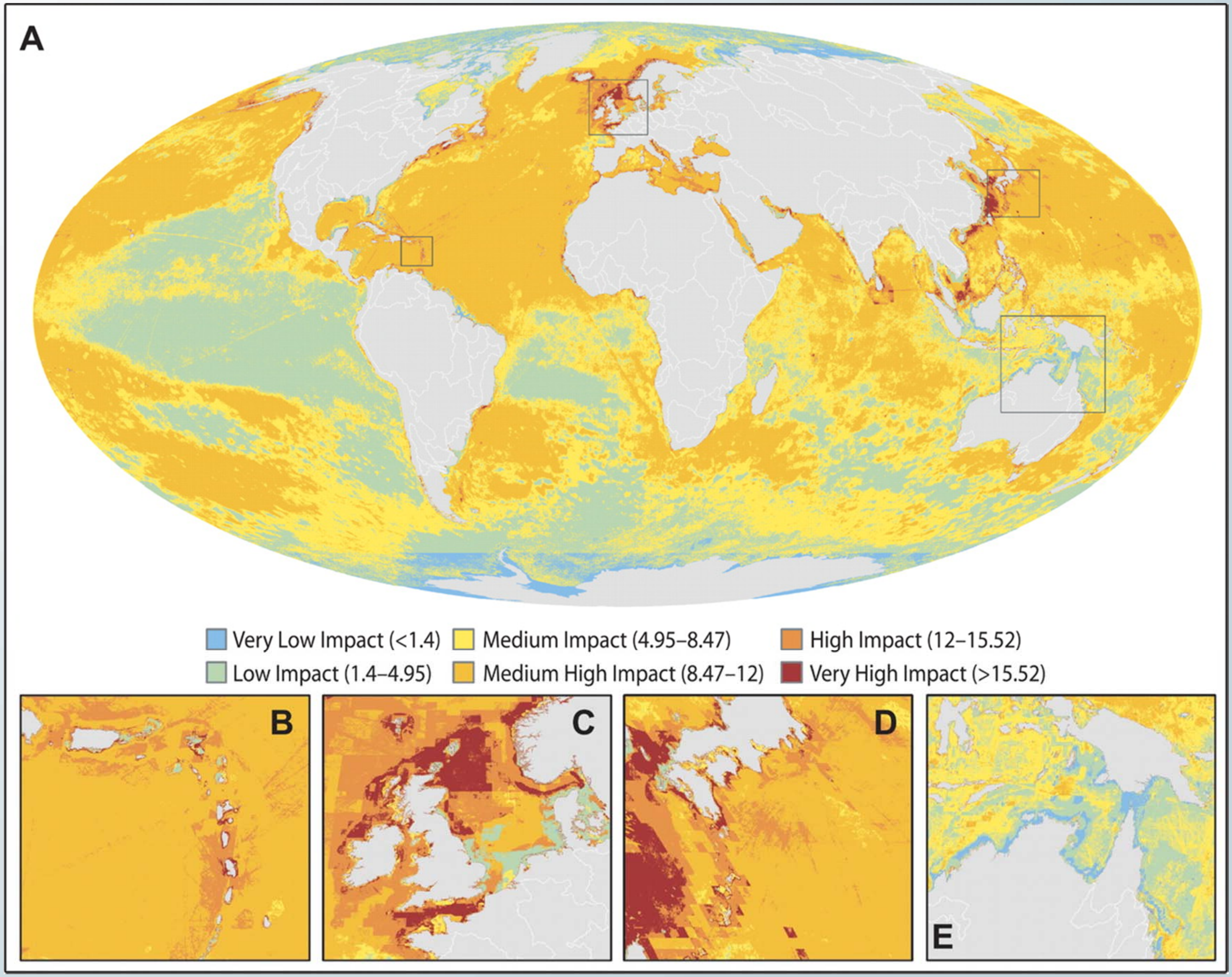
B S Halpern et al. Science 2008;319:948-952

Human Impact on Marine Ecosystems

- *Over a third (41%) of the world's oceans have medium high to very high [impact], with a small fraction (0.5%) but relatively large area (~2.2 million km^2) experiencing very high impact.*
- *Most of the highest predicted cumulative impact is in areas of continental shelf and slope, which are subject to both land- and ocean-based anthropogenic drivers.*
- *Large areas of high predicted impact occur in the North and Norwegian seas, South and East China seas, Eastern Caribbean, North American eastern seaboard, Mediterranean, Persian Gulf, Bering Sea, and the waters around Sri Lanka.*

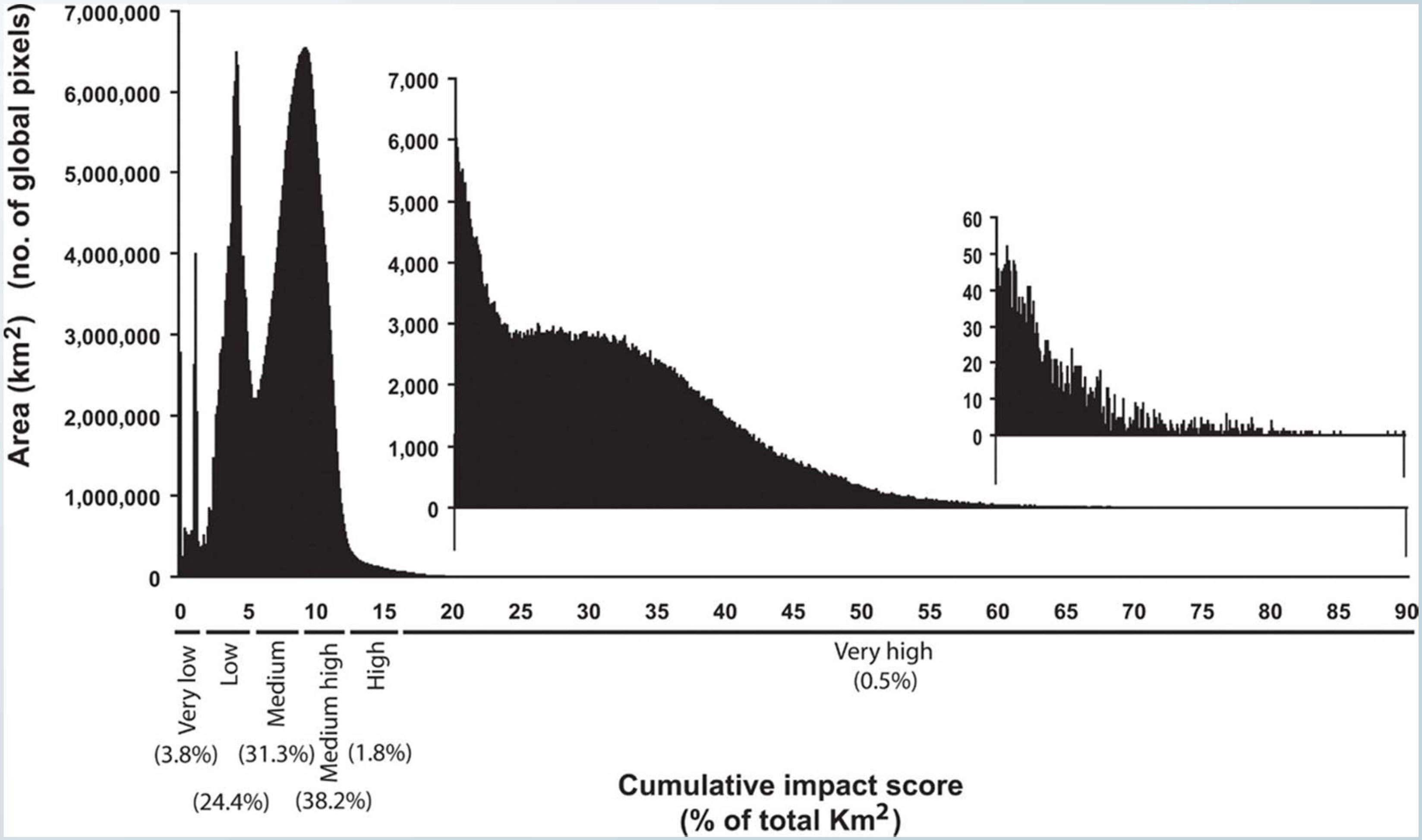
B S Halpern et al. Science 2008;319:948-952

Cumulative Human Impact Ocean Ecosystems



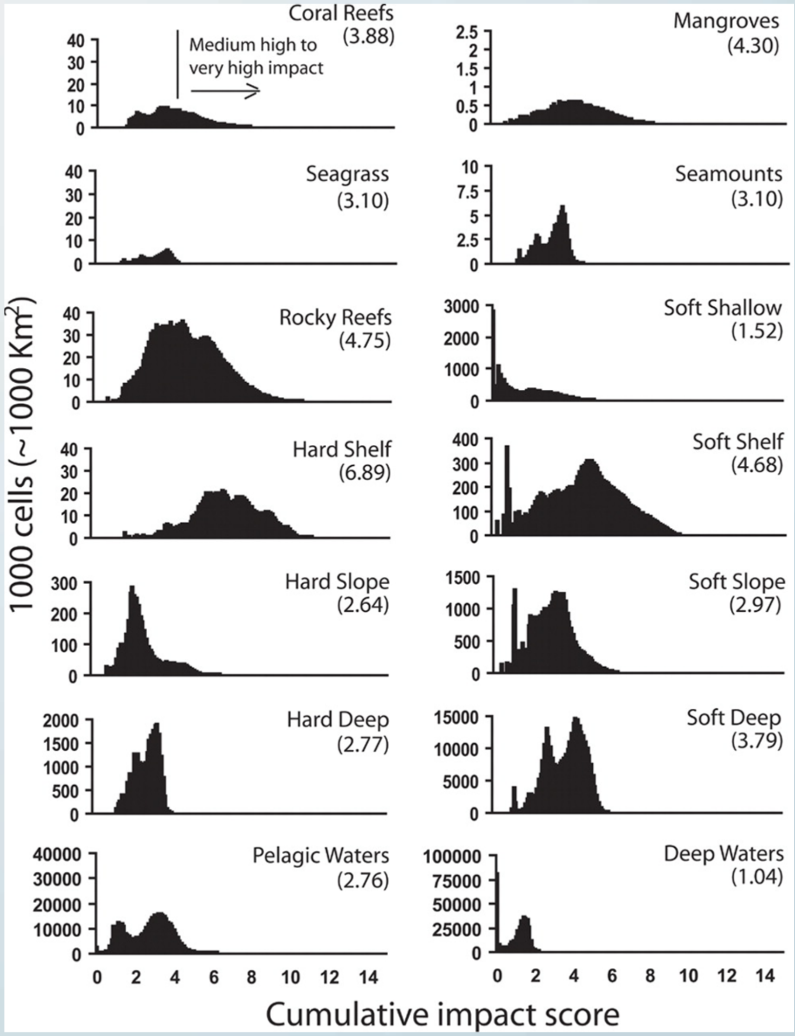
B S Halpern et al. Science 2008;319:948-952

Histogram of cumulative impact scores depicting the fraction of global area that falls within each impact category.



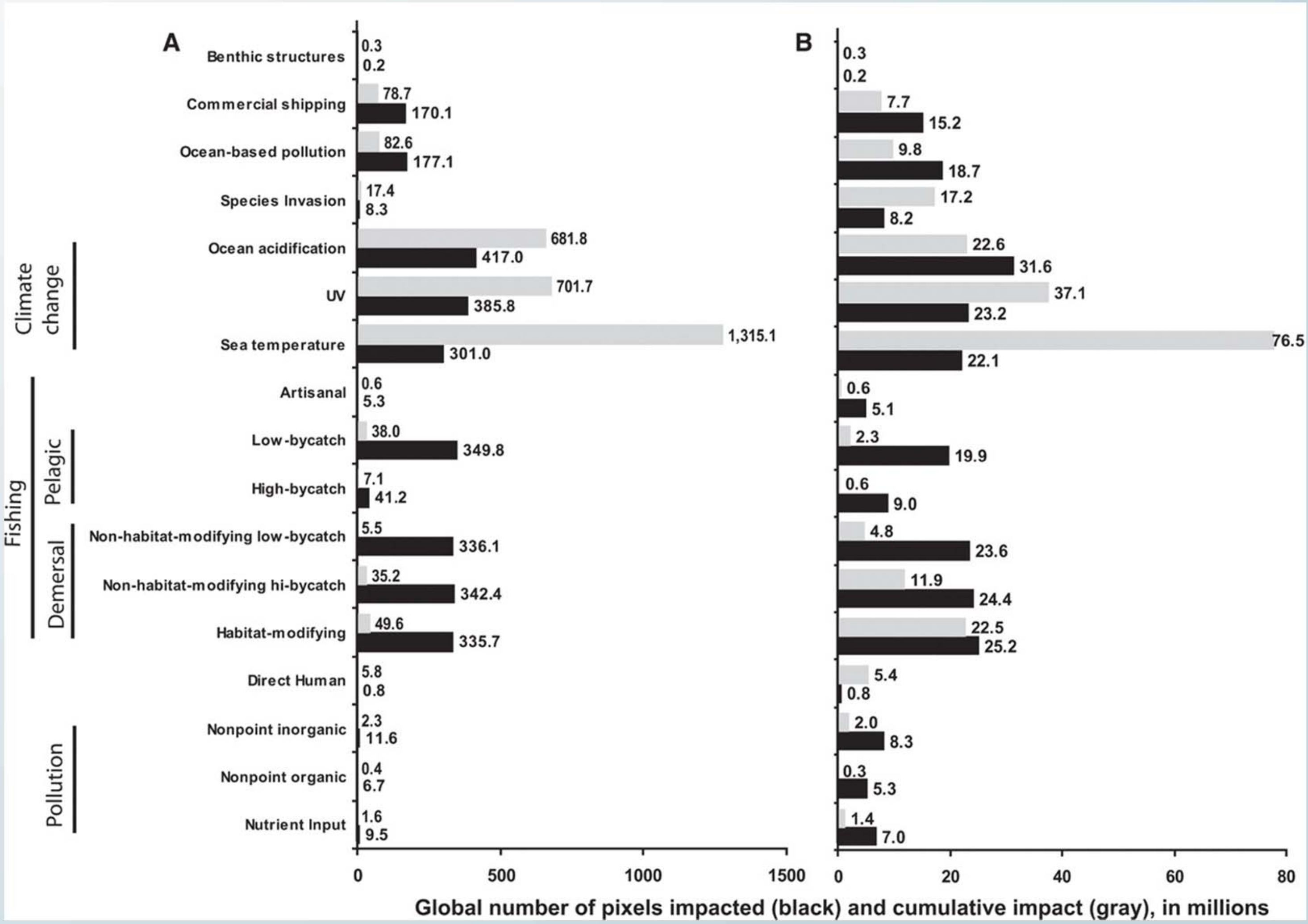
B S Halpern et al. Science 2008;319:948-952

The distribution of cumulative impact scores for each ecosystem in our analyses (means in parentheses)



B S Halpern et al. Science 2008;319:948-952

Total area affected (square kilometers, grey bars) and summed threat scores (rescaled units, black bars) for each anthropogenic driver (A) globally and (B) for all coastal regions <200 m in depth.



B S Halpern et al. Science 2008;319:948-952

Ocean Impacts of Anthropogenic Climate Change

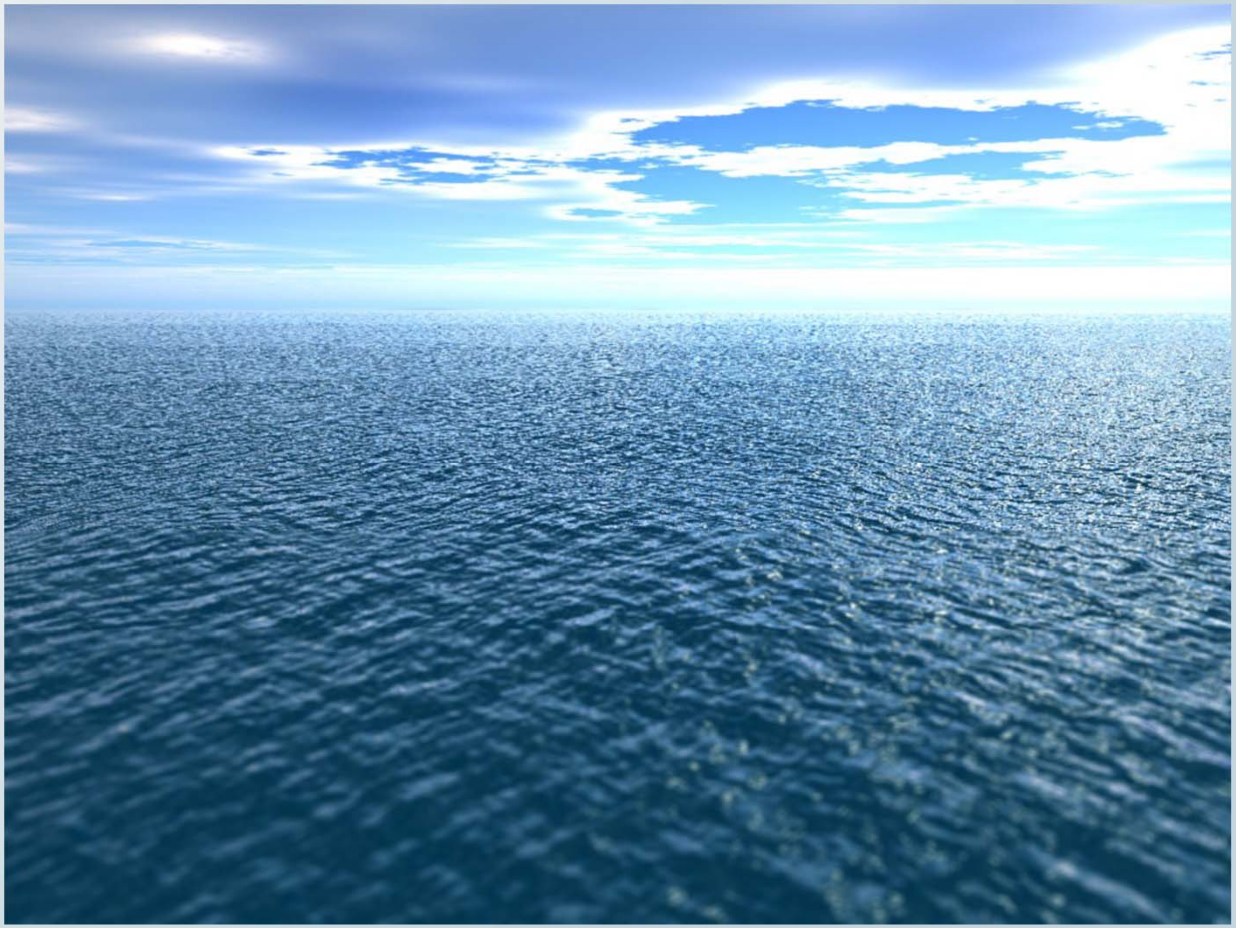
- Decreased ocean productivity,
- Altered food web dynamics,
- Reduced abundance of habitat-forming species,
- Shifting species distributions,
- A greater incidence of disease.

O Hoegh-Guldberg, J F Bruno
Science 2010;328:1523-1528

Less Understanding of Effect of Climate Change on Ocean Ecosystems

- Due to to the size and complexity of the ocean,
- And relative difficulty of taking measurements in marine environments.

O Hoegh-Guldberg, J F Bruno
Science 2010;328:1523-1528



Ocean as Global Heat Sink

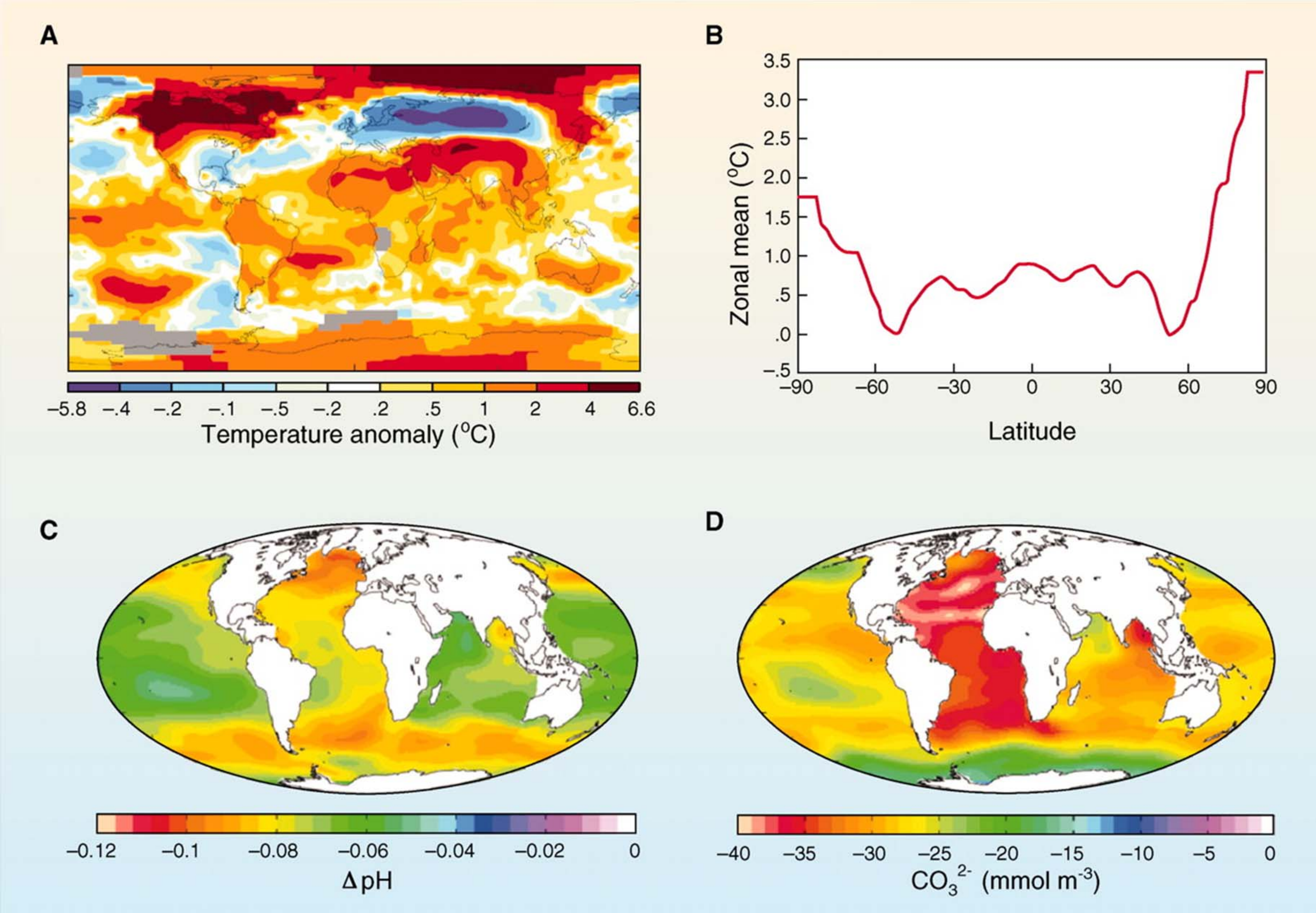
- According to the authors of *The Impact of Climate Change on the World's Marine Ecosystems* (O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528), "*the heat content of the upper 700 m of the global ocean has increased by 14 × 10^{22} J since 1975, with the average temperature of the upper layers of the ocean having increased by 0.6°C over the past 100 years.*
- *Global ocean surface temperatures in January 2010 were the second warmest on record for the month of January, and the period June to August 2009 reached 0.58°C above the average global temperature recorded for the 20th century, 16.4°C."*

Effect of CO_2 Absorption in Ocean

- *Oceans have absorbed approximately one-third of the carbon dioxide produced by human activities.*
- *The absorption of anthropogenic CO_2 has acidified the surface layers of the ocean, with a steady decrease of 0.02 pH units per decade over the past 30 years and an overall decrease since the pre-industrial period of 0.1 pH units.*
- *Although these increases appear small in terms of pH, they are associated with a substantial decline in the concentration of carbonate ions.*

O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

Recent changes in ocean temperature, acidity, and carbonate ion concentration.



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Other Effects of Climate Change on Oceans

- *Increased ocean volume and sea level from*
  - *Thermal expansion of the oceans*
  - *Increased meltwater and discharged ice from terrestrial glaciers and ice sheets*
- *Warmer oceans also drive more intense storm systems and other changes to the hydrological cycle.*
- *The warming of the upper layers of the ocean also drives greater stratification of the water column, reducing mixing in some parts of the ocean and consequently affecting nutrient availability and primary production. These changes have increased the size of the nutrient-poor "ocean deserts" of the Pacific and Atlantic by 6.6 million km^2, or 15%, over the period 1998 to 2006.*
- *General circulation models also predict that oxygen concentrations in the upper layers of the ocean are likely to decrease as a consequence of increasing stratification.*

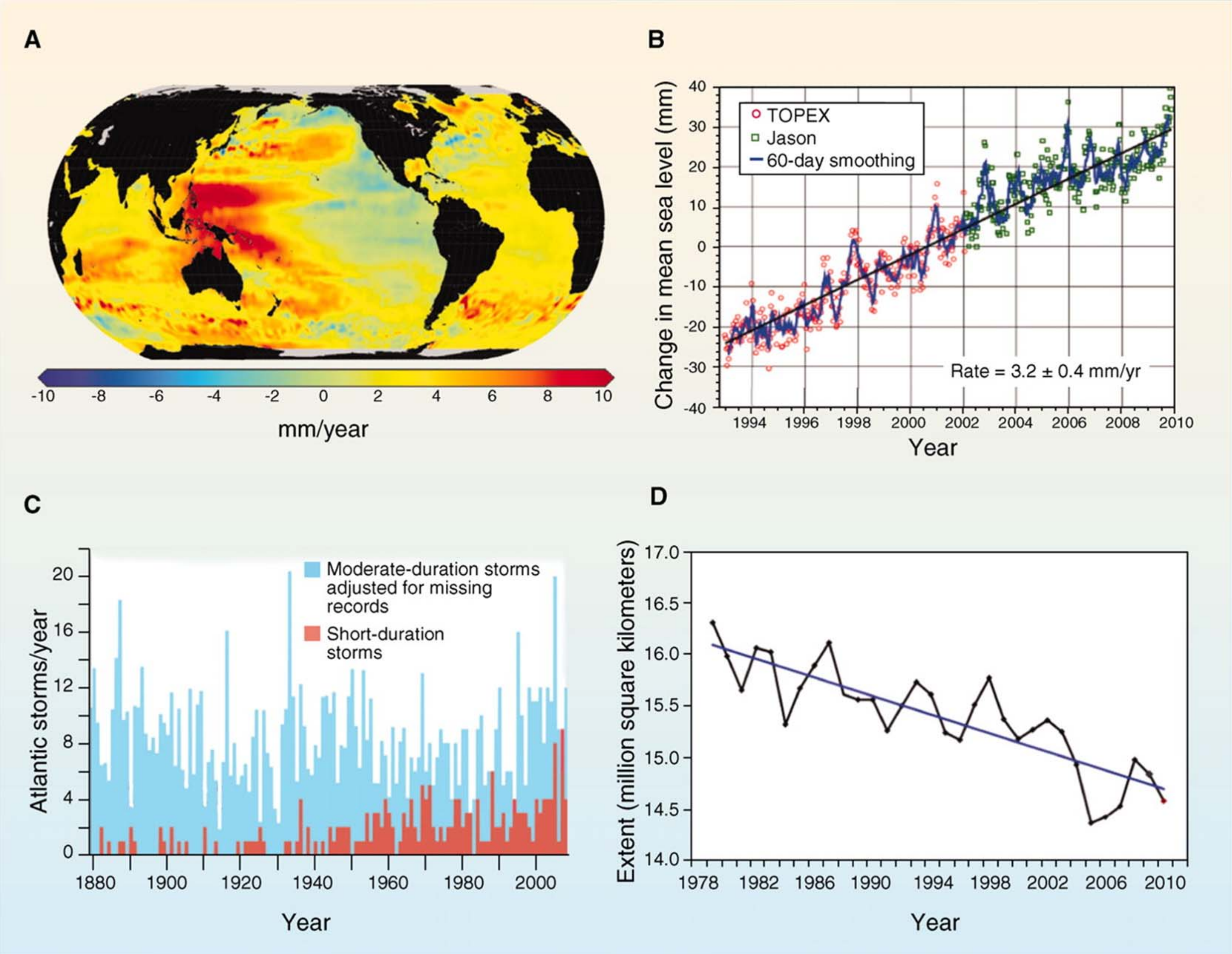
O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

Other Effects of Climate Change on Oceans

- *Changes in the behavior of ocean currents have the potential to strongly influence the distribution and abundance of marine ecosystems.*
- *Some of the most striking impacts of global climate change have appeared in polar oceans, where Temperatures and acidities of the polar oceans are changing at more than twice the global average.*
- *Arctic sea ice is steadily decreasing, its area being 16.5 million km^2 in March 1979 but reduced to 15.25 million km^2 by March 2009.*
- *Summer sea ice (measured in September each year) is projected to disappear completely by 2037.*
- *Satellite altimeter data reveal that the average global sea level is changing at a rate of 3.3 ± 0.4 mm/year (over the period 1993–2006).*

O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

(A and B) Average rate of global sea level rise (1993–2010) from TOPEX/Poseidon and Jason satellite altimetry data, shown as a map (A) and as a global mean sea level (B).



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Temperature Effect on Organisms

- *Increases in temperature increase metabolic rates, which ultimately determine life history traits, population growth, and ecosystem processes.*
- *Organisms tend to adapt to local environmental temperatures, with optimal physiological responses matching temperatures that are close to the environmental average.*
- *Organisms are able to acclimatize to a range of temperatures around these optimal values. Beyond this range, however, acclimatization fails, mortality risk increases, fitness is reduced, and populations decline or are driven to local extinction.*

O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

NPP of Oceans

- *The annual primary production of the world's oceans has decreased by at least 6% since the early 1980s, with nearly 70% of this decline occurring at higher latitudes and with large relative decreases occurring within Pacific and Indian ocean gyres.*
- *These findings have implications for the ability of [ocean organisms] to capture and store carbon dioxide, with the potential for these critical ocean processes to decline as temperature increases. Warming has also been found to decrease the size of individual phytoplankton, further altering the functioning and biogeochemistry of shallow pelagic ecosystems and, in particular, reducing their potential for carbon sequestration.*

O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

Reduced Habitat Complexity

- *Although mangrove deforestation (1 to 2% per year) represents a greater near-term threat, risks from sea level are increasing, with expected losses of 10 to 20% of mangroves by 2100.*
- *Sea ice, like coral reefs and kelp forests, plays a critical role in structuring the biodiversity of polar oceans. The spring melt has a major role in determining the timing of phytoplankton blooms and consequently influences polar marine food web dynamics.*

O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

Other Effects

- *A rising number of species are expanding their ranges, often with large-scale impacts on ecosystems at the destination.*
  - *For example, the southeastern Australian sea urchin Centrostephanus rodgersii (Diadematidae) has recently expanded its range into Tasmanian waters, where it has transformed macroalgal communities into taxonomically impoverished "urchin barrens".*
- *Climate change has been implicated in recent variation in the prevalence and severity of disease outbreaks within marine ecosystems.*

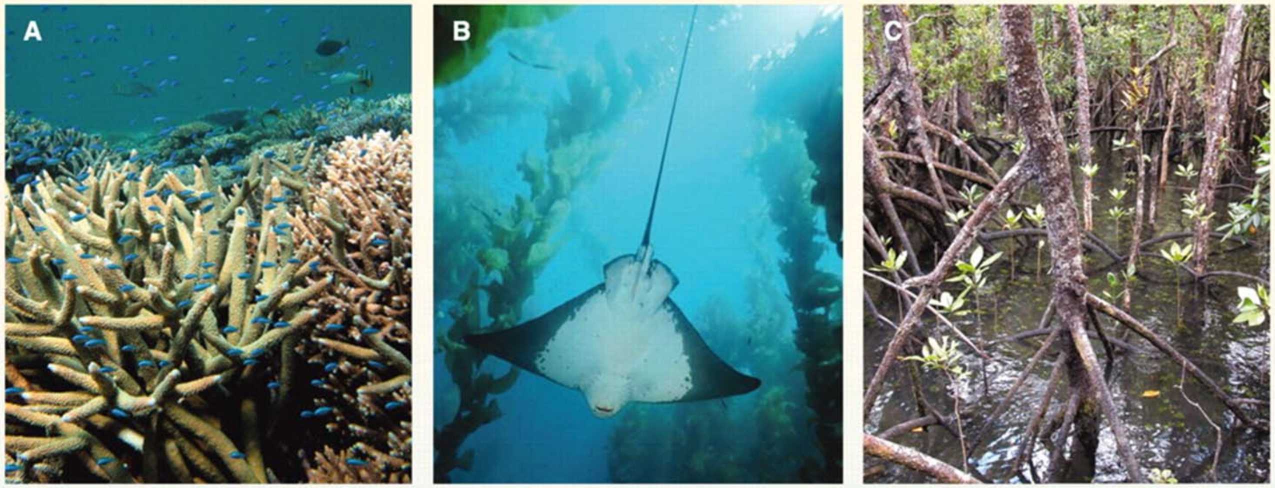
O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

Coral Reefs and Carbonate Balance

- *Increasing ocean temperatures and acidities associated with atmospheric CO_2 concentrations of 450 parts per million (ppm) represent a serious threat to ecosystems, such as coral reefs.*
- *Temperatures that exceed 2°C above pre-industrial temperatures are very likely to drive an unsustainable frequency of mass coral bleaching and mortality.*
- *Ocean acidification associated with atmospheric CO_2 above 450 ppm will push coral reefs into a negative carbonate balance.*

O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

Marine ecosystems are already responding to the rapid pace of change in the physical and chemical conditions that surround them.



Box 1. Marine ecosystems are already responding to the rapid pace of change in the physical and chemical conditions that surround them (see table S2 for summary of recent literature). One of the most important impacts has been on the organisms and physical processes that create habitat for millions of other species. (**A**) Heron Island, southern Great Barrier Reef. Coral Reef ecosystems are declining because of anomalously warm sea temperatures, which are driving an increased frequency of coral bleaching and mortality. These impacts are combining with local impacts, as well as the slowing of reef accretion due to the impact of ocean acidification. Complex coral-dominated reef ecosystems like this one are likely to be rare by 2050. (**B**) Kelp forest (*Macrocystis pyrifera*, with California bat ray, *Myliobatis californica*) near San Clemente Island, California, USA. Warming ocean temperatures are driving a major contraction in the distribution of kelp forests worldwide. (**C**) Daintree River, northeastern Australia. Mangroves are critically important coastal habitat for numerous coastal species. The loss of 10 to 20% of mangroves is projected if sea levels rise by 1 m above today. (**D**) The loss of summer sea ice by 2040 in the Arctic will have a strong impact on a range of dependent organisms, both above and below the ice. [Credits: (A) and (C) O. Hoegh-Guldberg; (B) Philip Colla, www.Oceanlight.com; (D) Daniel J. Cox, www.NaturalExposures.com]

O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

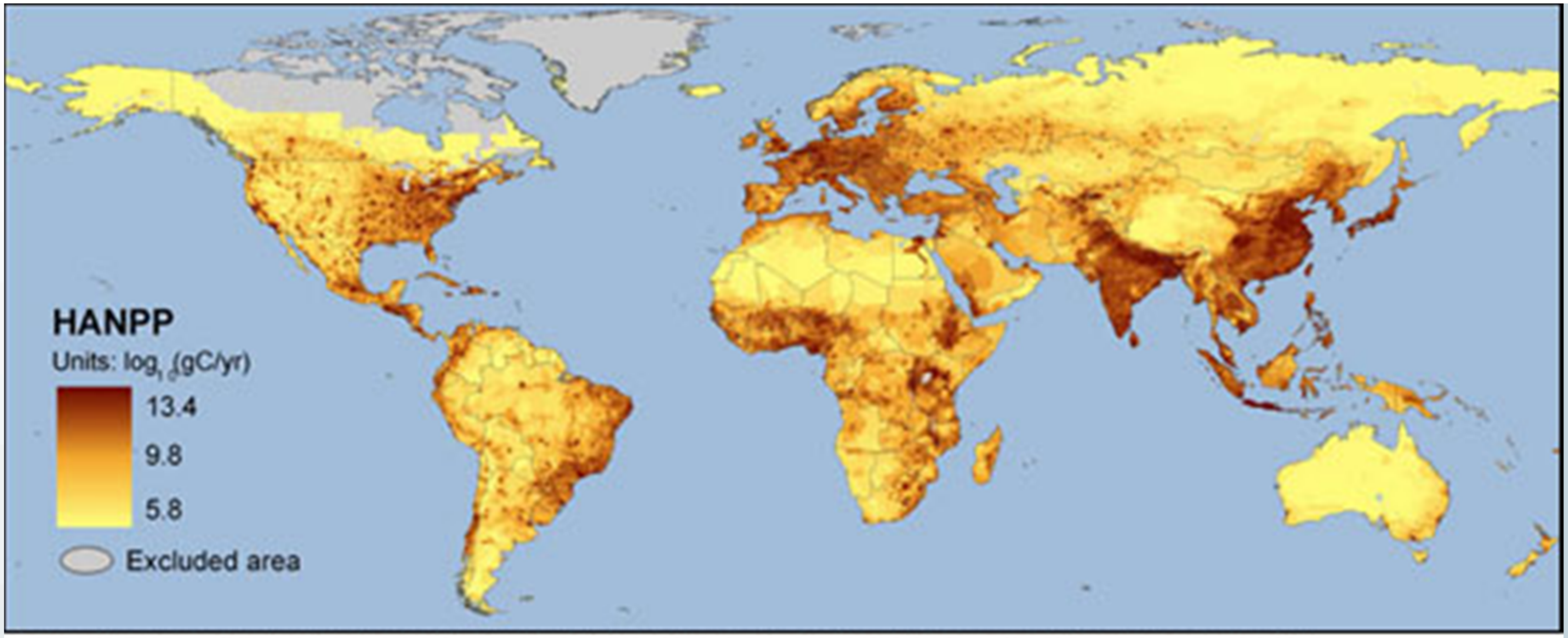
Total human appropriation of NPP

Total appropriation of NPP by humans = 20-25 Gt C
= 30-40% of terrestrial NPP

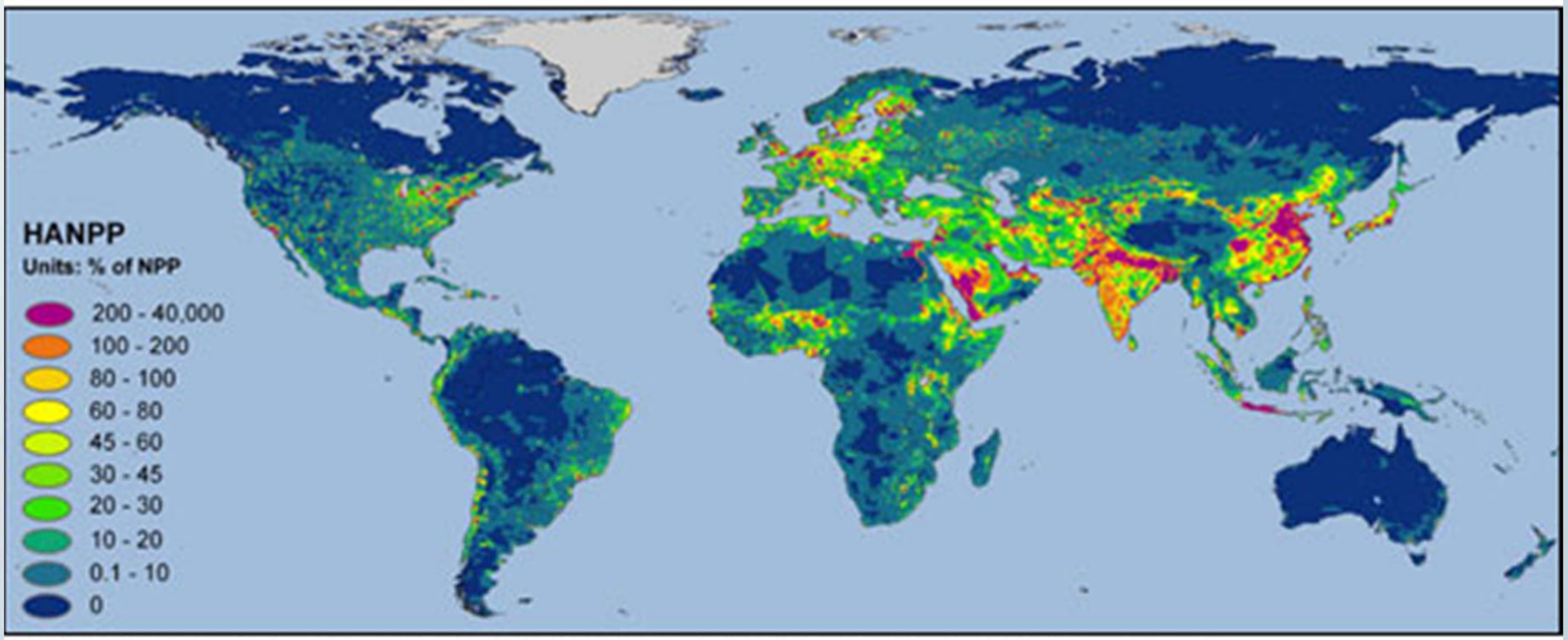
- Direct consumption = 2.4 Gt C/y out of 60 Gt C/y
  = 4% of NPP
- Cooptation + consumption = 18.5 Gt C out of 60 Gt C/y
  = 30% of NPP
- Lost opportunities + cooptation + consumption
  = 27.5 Gt C out of 68 Gt C = 40% of NPP
- Use of ocean NPP ≈ 8%

Cooptation = indirect use (e.g. livestock grazing)
Lost opportunities = reduced NPP due to land degradation

Source: Vitousek, P.M., et al. (1986). "Human appropriation of the products of photosynthesis." *BioScience* 36(6): 368.



Human Appropriation of Net Primary Production (grams of carbon per year)



Human Appropriation of Net Primary Production (percent of local NPP)

Land, Soils, and Ecosystems

Human influence is ubiquitous.

- There is virtually no part of the land surface that remains unaffected by human activities:
  - Polar regions receive atmospheric pollutants.
  - Hawaiian rainforests are infested with invasive plants.
  - Remote islands are affected by sea level rise.
- However, in this section we will focus on *direct* land use effects.

Human Land Uses

- Potentially land suitable for crops
  $= 30 \times 10^6$ km^2 = 20% of Earth's land surface. Virtually all is used.
- Cropland = 15×10^6 km^2 = 10% of land surface
  - Irrigated cropland = 3×10^6 km^2 = 2%
- Grazing =10×10^6 km^2 = 7%
- Managed forests = 5×10^6 km^2 = 3%
- Urbanization = 2×10^6 km^2 = 1%
- Reservoirs, dams, canals
  $= 0.3 \times 10^6$ km^2 = 0.2%
- Mining = $.03 \times 10^6$ km^2 = 0.02%

Land Conversion and Degradation

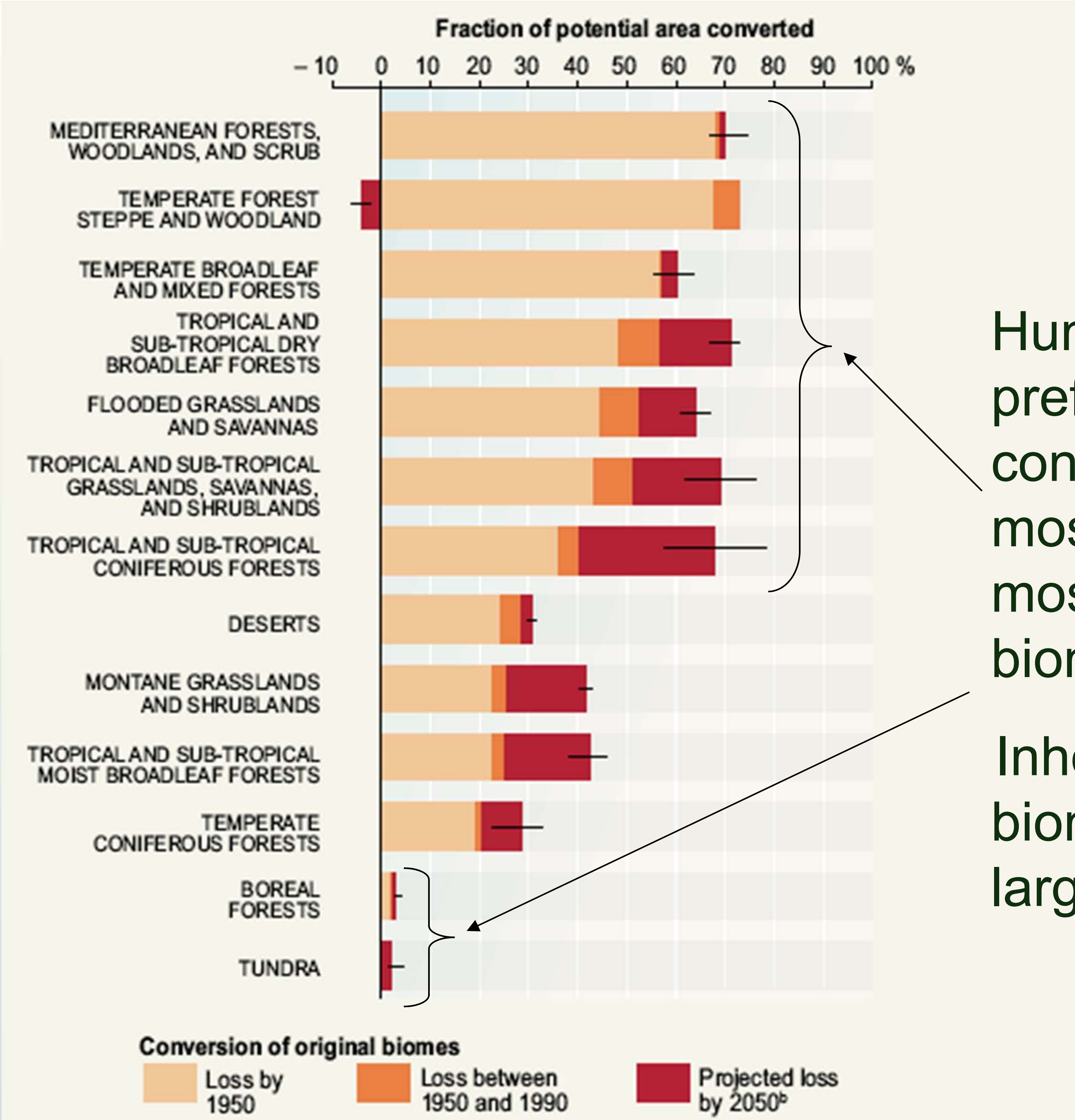
- Total land converted by humans since prehistoric times
  $\approx 30 \times 10^6$ km^2 = 20% of land surface.
  3/4 of this occurred since 1700 AD.

  Example: Forests & grasslands to croplands:
  15×10^6 km^2 = 10%

- Total land degraded $\approx$ 40-50 $\times 10^6$ km^2 = 30%.

  Example: Forests & grasslands to desert:
  15×10^6 km^2 = 10%

- Current desertification rate $\approx$ 60,000 km^2/yr



Humans have preferentially converted the most useful, most fertile biomes.

Inhospitable biomes remain largely intact.

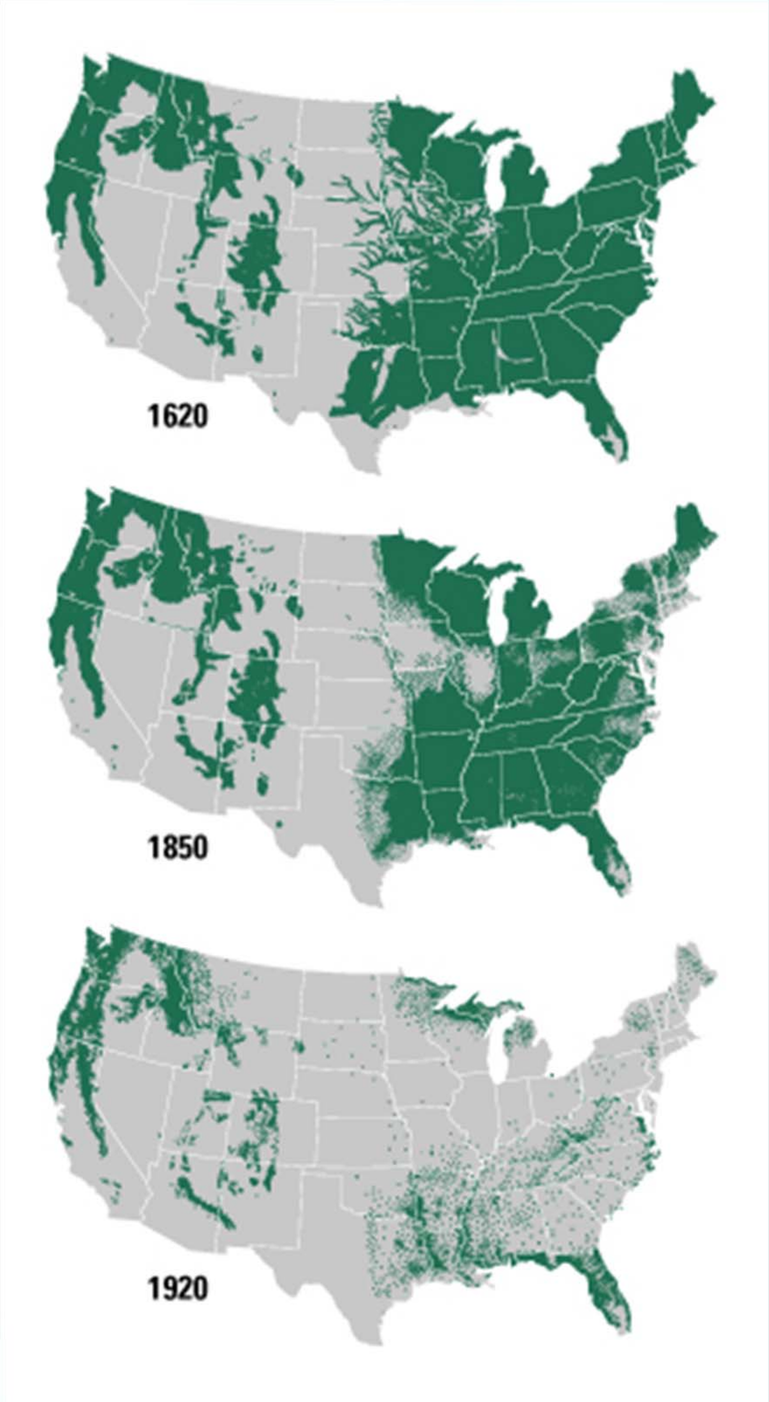
Millennium Ecosystem Assessment

Deforestation

Deforestation

- About half of the world's original forests have disappeared.
- According to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat,
  - Subsistence farming - 48%
  - Commercial agriculture - 32%
  - Logging - 14%
  - Fuel wood removals - 5%
- According to the Intergovernmental Panel on Climate Change, deforestation could account for up to one-third of total anthropogenic carbon dioxide emissions.

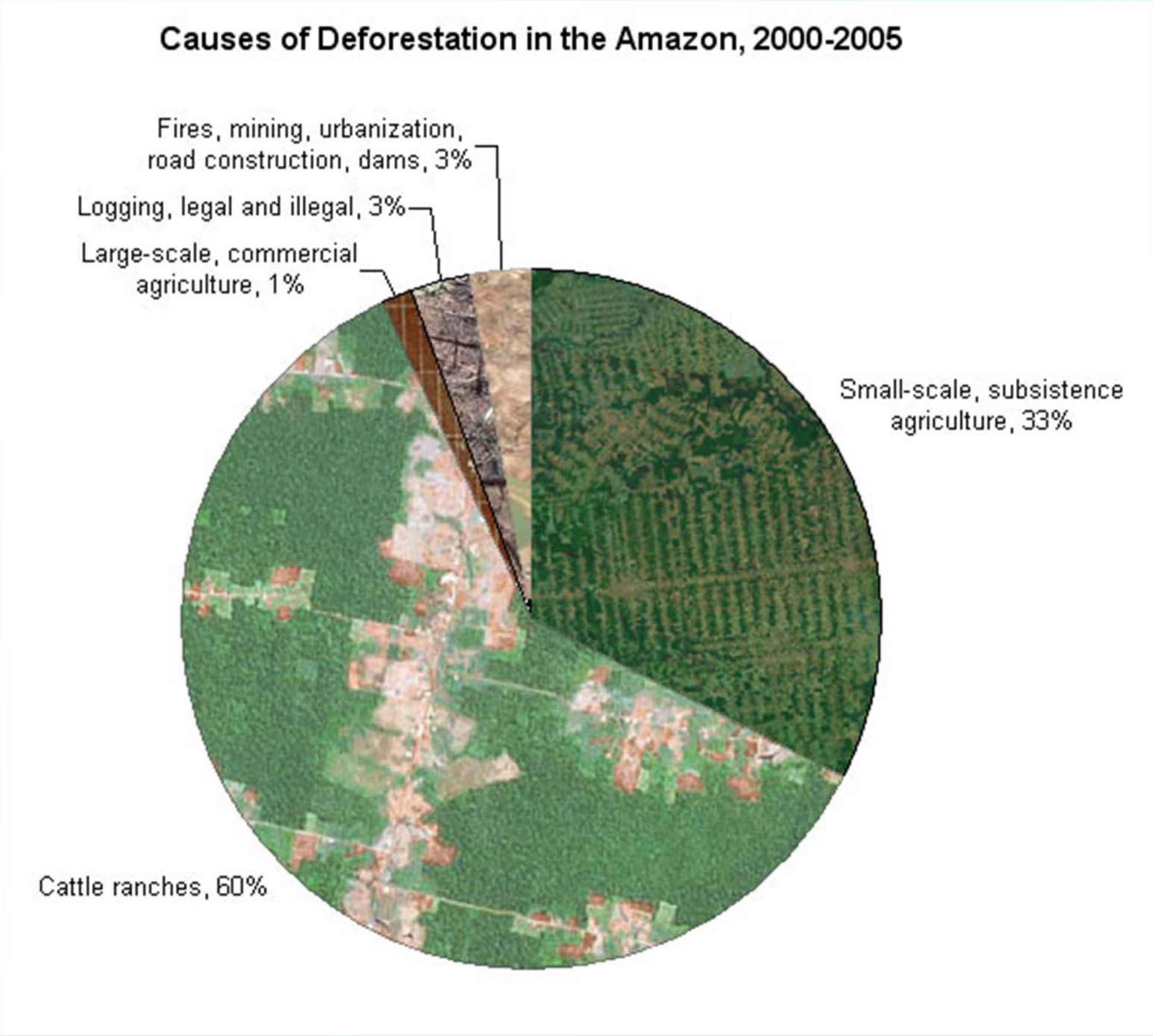
Deforestation in U.S.



Tropical Deforestation

- Current deforestation rate 100,000 - 200,000 km^2/y
  - Amazon basin: total forest area = 6×10^6 km^2; today losing 1.5×10^4 km^2 per year
  - Tropical forest declining 1-2% per year (annual loss the size of Pennsylvania)
- Why special concern for tropical deforestation:
  - (1) Relatively irreversible process, long recovery time
  - (2) Forests are essential to people outside market economy
  - (3) High levels of biological diversity

Tropical Deforestation



Deforestation Effects

- According to the Intergovernmental Panel on Climate Change deforestation, mainly in tropical areas, could account for up to one-third of total anthropogenic carbon dioxide emissions. (http://www.ipcc.ch/)
- Reduces soil cohesion, leading to erosion, flooding and landslides
- Increased runoff
- Decreased evapotranspiration, decreasing atmospheric moisture, changing precipitation levels
- Decline in biodiversity

Top 10 Most Endangered Forests 2011

Endangered forest	Region	Remaining habitat	Predominate vegetation type
Indo-Burma	Asia-Pacific	5%	Tropical and subtropical moist broadleaf forests
New Caledonia	Asia-Pacific	5%	Tropical and subtropical moist broadleaf forests
Sundaland	Asia-Pacific	7%	Tropical and subtropical moist broadleaf forests
Philippines	Asia-Pacific	7%	Tropical and subtropical moist broadleaf forests
Atlantic Forest	South America	8%	Tropical and subtropical moist broadleaf forests
Mountains of Southwest China	Asia-Pacific	8%	Temperate coniferous forest
California Floristic Province	North America	10%	Tropical and subtropical dry broadleaf forests
Coastal Forests of Eastern Africa	Africa	10%	Tropical and subtropical moist broadleaf forests
Madagascar & Indian Ocean Islands	Africa	10%	Tropical and subtropical moist broadleaf forests
Eastern Afromontane	Africa	11%	Tropical and subtropical moist broadleaf forests Montane grasslands and shrublands

REDD

- United Nations Collaborative initiative on Reducing Emissions from Deforestation and forest Degradation (REDD) in developing countries
- Started September 2008 to assist developing countries prepare and implement national REDD+ strategies, and builds on the convening power and expertise of the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP).
- Programme currently supports 44 partner countries spanning Africa, Asia-Pacific and Latin America, of which 16 are receiving support to National Programme activities.

http://www.un-redd.org/

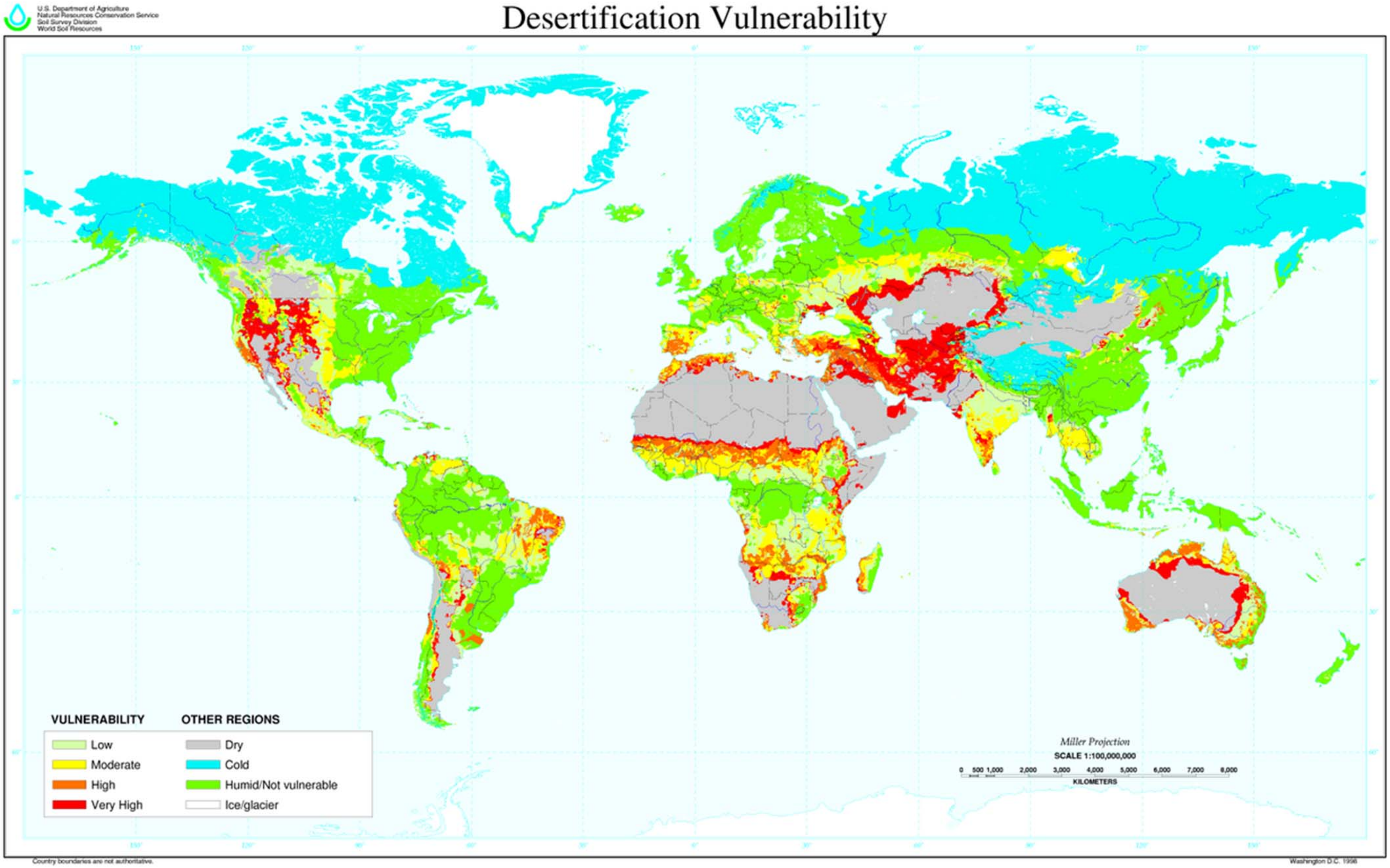
Desertification

- **Desertification** = the process of fertile land transforming into desert typically as a result of deforestation, drought or improper/inappropriate agriculture
- Drylands occupy approximately 40-41% of Earth's land area
- About 10–20% of drylands already degraded
- Desertification between 6 and 12 million km^2
- 1–6% of the inhabitants of drylands live in desertified areas, and a billion people are under threat from further desertification.

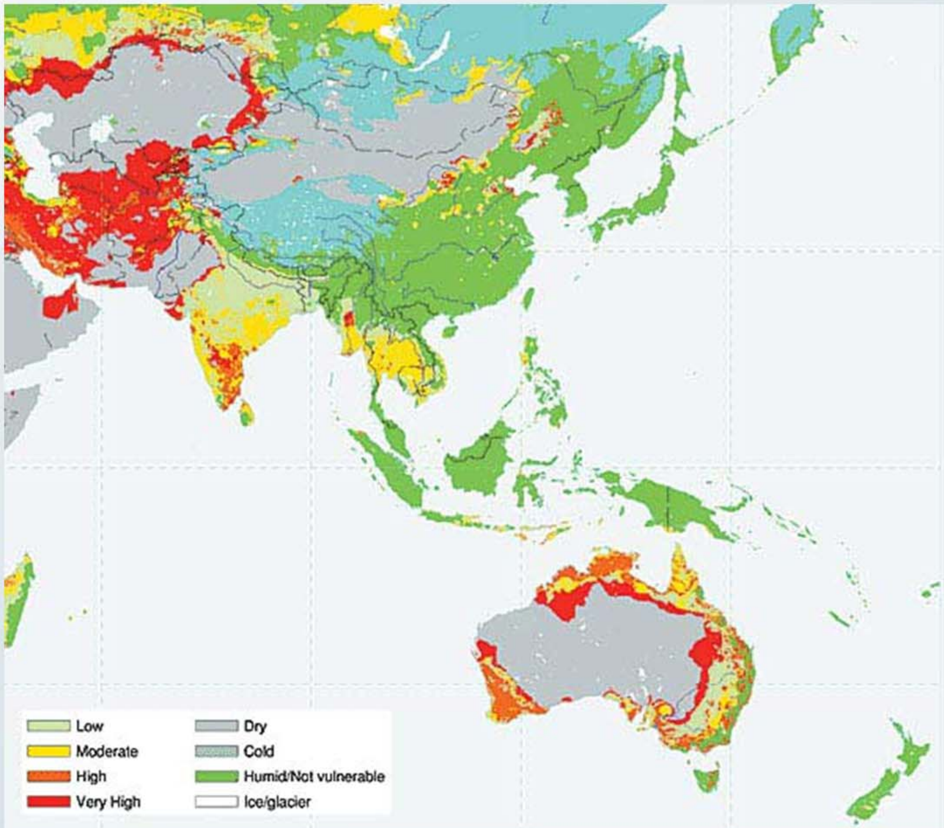
Desertification Causes

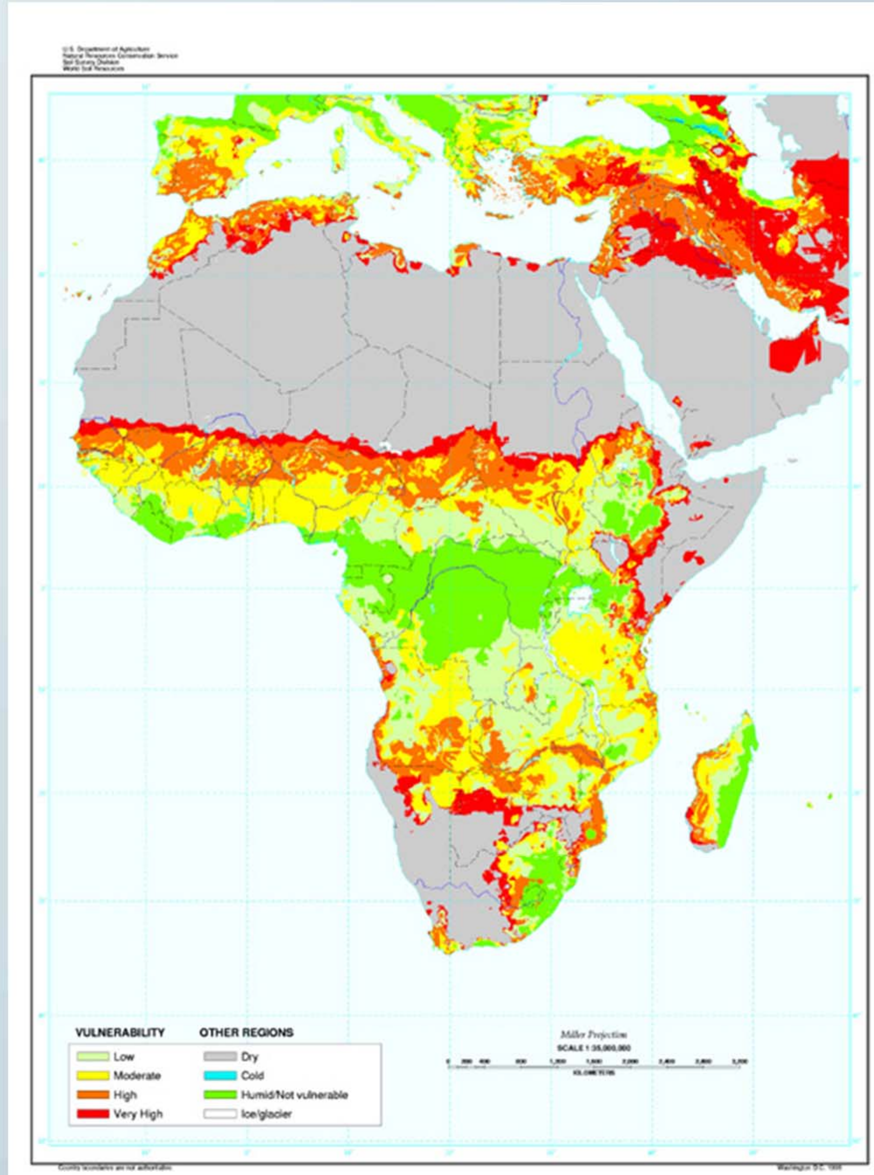
- Over cultivation of desert lands, leading to loss of nutrients in the soil
- Improper irrigation practices result in salt buildup in soils and depletion of aquifers.
- Erosion and runoff decreases vegetation cover.
- Overgrazing removes this vegetation causing erosion and loss of topsoil.

Desertification



Desertification in Asia and Africa





Soil Degradation

- Soils determine fertility and productivity of land. They are...
  - the source of nutrients and water
  - the matrix for reactions that make nutrients available
  - the anchor to support plants
- Soils are typically 1-2 m deep (but can be much less or more)
- It takes 200 - 1000 years to form 1 cm of soil
- Two main types of damage:
  - topsoil loss
  - chemical changes
- Premodern erosion rate 5 Gt soil/yr; modern 30 Gt soil/yr
  - natural forest ~ 10 t/km^2 y
  - natural grasslands ~ 100 t/km^2 y
  - cropland ~ 2000 t/km^{2}y
  - construction sites ~ 20,000 t/km^{2}y

Why U.S. Farms in Midwest are so Vulnerable to Summer 2012 Drought in U.S.

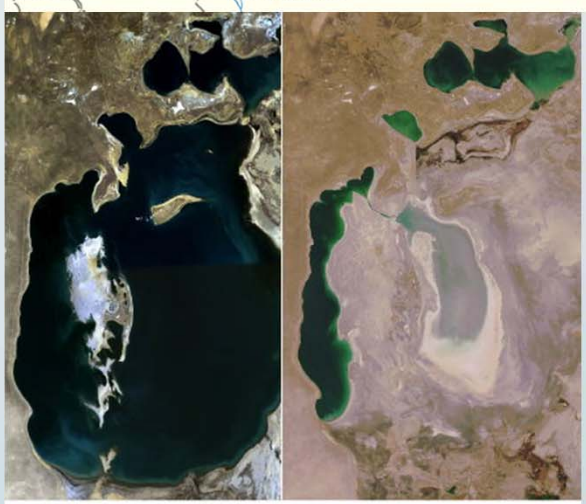
- Monocultures…mostly corn and soybeans.
  - Possible solution - diversification
- Corn and soybeans are annuals with shallow roots, bred for rapid summertime growth. They cannot withstand a bad season.
  - Possible solution - shifting to other farming systems…more perennial crops and deep-rooted grasses and trees
- Industrial farming have depleted organic matter in soil, reducing ability to absorb and store moisture.
  - Possible solution - no-till agriculture and organic farming practices can restore the health of the soil, and greatly improve the resilience of crops to extreme weather.

Why U.S. Farms in Midwest are so Vulnerable to Summer 2012 Drought in U.S.

- Commodity agriculture inefficient – Most of American corn and soybeans are used to feed animals (where cattle require 30 pounds of grain to add one pound of boneless beef) and produce ethanol rather than feed people directly.
  - Possible solutions – replace some of the corn and soybeans with more resilient grains, fruits, and vegetables that go directly into the human diet and with grasslands to feed animals and create cellulosic biofuels would feed more people.

Impacts of Water Use on Aquatic Ecosystems

- Aquatic ecosystems are among the most degraded by human activities.
- 1/3 of aquatic species are threatened/endangered
- Human activities cause changes in water flow, timing, temperature, nutrients, sediments.
- Bad synergies with pollution, grazing, climate change
- Example of synergy: riparian habitat degraded by grazing, loses water retention capacity + dried out by water diversion upstream



July - September, 1989

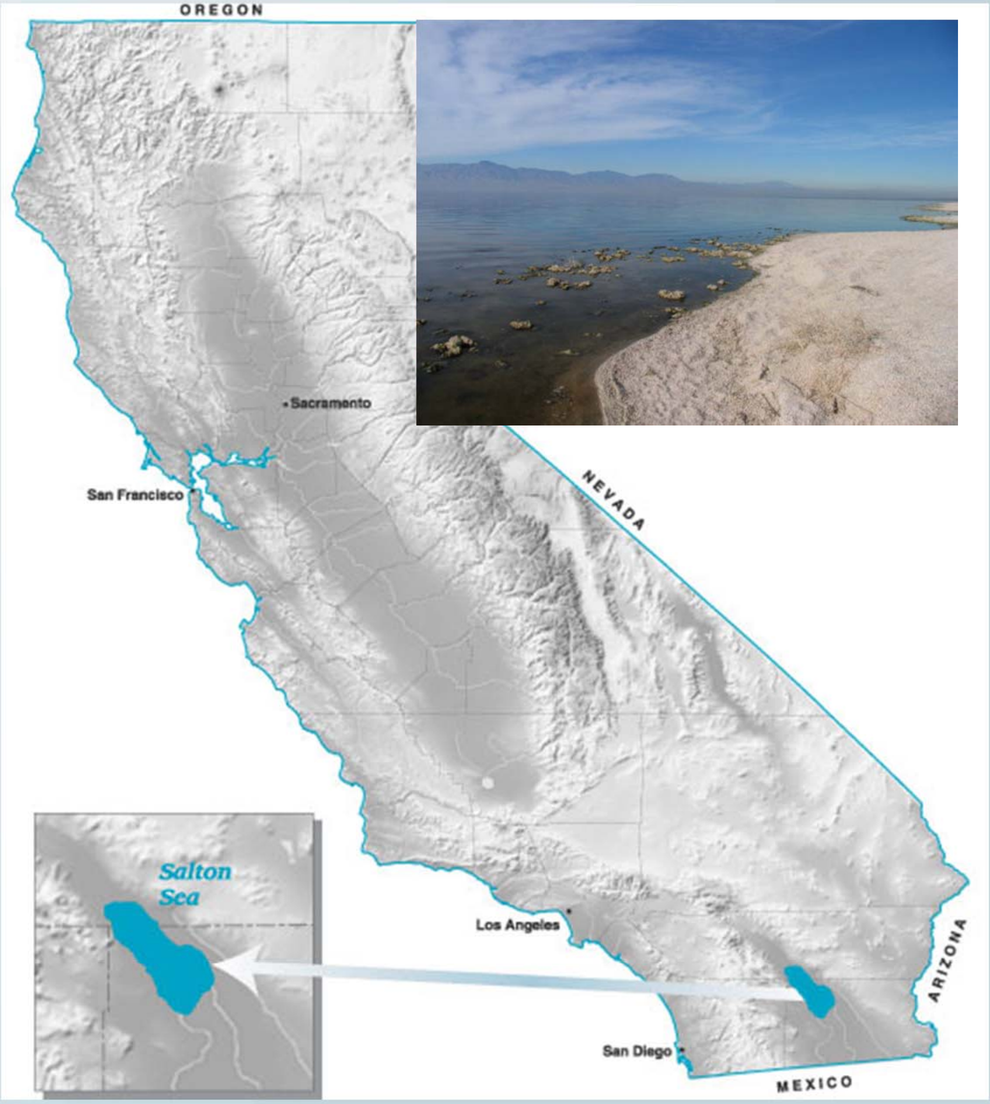
October 5, 2008

Aral Sea

- Formerly world's 4th-largest inland sea (1100 km^3), on Kazakhstan - Uzbekistan border.
- In 1940s, the two main rivers feeding the Aral Sea were diverted for agriculture (cotton and cereals) in the desert.
- By 1960 the sea began to shrink; in 2009 it is 9% of original surface area.
- Remaining fragments are >2x saltier than the ocean. The dry seabed is a wasteland of salt and toxic chemicals.
- Restoration is being discussed but will be extremely difficult.

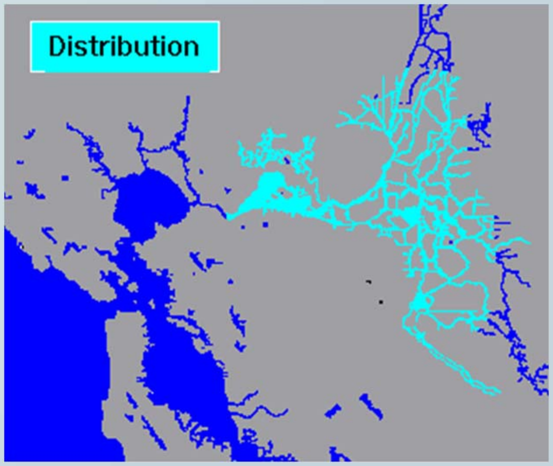
Salton Sea

- Located in desert basin 300 feet below sea level with no outflow.
- Current sea formed in 1905 due to levee breach on Colorado River.
- Salton Sea now sustained by agricultural runoff.
- Important for migratory birds & tourism.
- Sea suffering ongoing degradation:
  - Fertilizer & pesticide runoff
  - Increasing salinity



Delta smelt: example of ecosystem impacts

- Wetland, river, and lake ecosystems are among the most affected by humans.
- The Delta smelt is a small fish endemic to the Sacramento Delta. In the 1980s and 1990s, water withdrawals for agriculture increased the Delta's salinity and devastated fish populations.
- It was listed as an endangered species in 1993. The Sacramento Delta is "critical habitat" for the smelt, and protection of the Delta is therefore required by law.
- However, the agriculture fed by Delta water is economically and socially valuable, giving rise to a legal battle.



Biodiversity

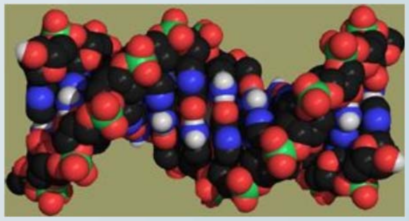
Biodiversity

- **Biodiversity** is = the degree of variation of life forms within a given species, ecosystem, biome, or an entire planet. Biodiversity is a measure of the health of ecosystems.
- Biodiversity is much harder to measure than the other resources we've discussed.
- Estimates of human impact on biodiversity are highly variable.
- However, there is broad agreement that humans are having a profound effect - it has been called the "6th mass extinction."
- The United Nations designated 2011-2020 as the United Nations Decade on Biodiversity. (http://www.cbd.int/2011-2020/)




Ways to Describe Biodiversity

- Biodiversity can be defined at several different scales:



Genetic diversity
Number of gene variants in a population

Species diversity
Number of different species in an ecosystem

Ecosystem diversity
Number of different ecosystem types

- Diversity at one level impacts diversity at the other levels: for example, loss of ecosystems causes loss of species.
- We tend to focus on **species diversity** because it is easier to quantify and understand.

Biodiversity Distribution

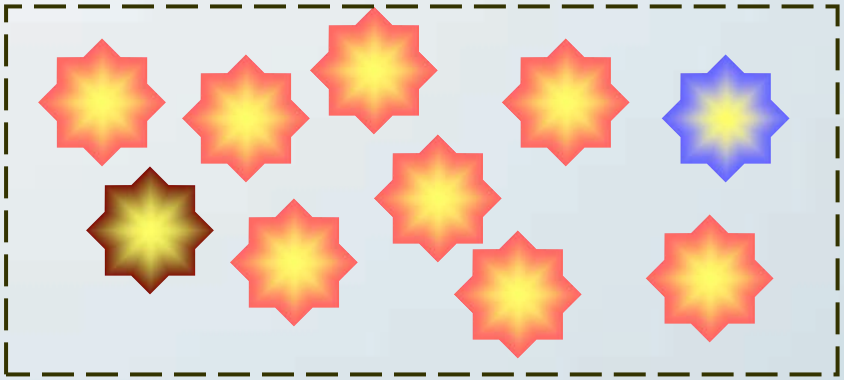
- Biodiversity depends on
  - Temperature
  - Precipitation
  - Altitude
  - Soils
  - Geography
  - presence of other species.
- Diversity greater in the tropics and lower in polar regions

Diversity Calculations

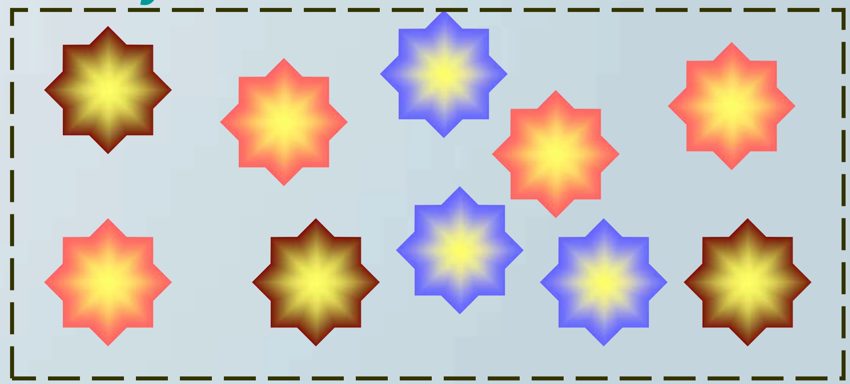
Diversity (of anything) is related to:

- Richness: how many different types are there?
- Evenness: how well distributed are the different types?

Ecosystem 1



Ecosystem 2



Ecosystem 1:

Richness = 3

Evenness ($\tilde{D}$) = 0.34

Ecosystem 2:

Richness = 3

Evenness ($\tilde{D}$) = 0.66

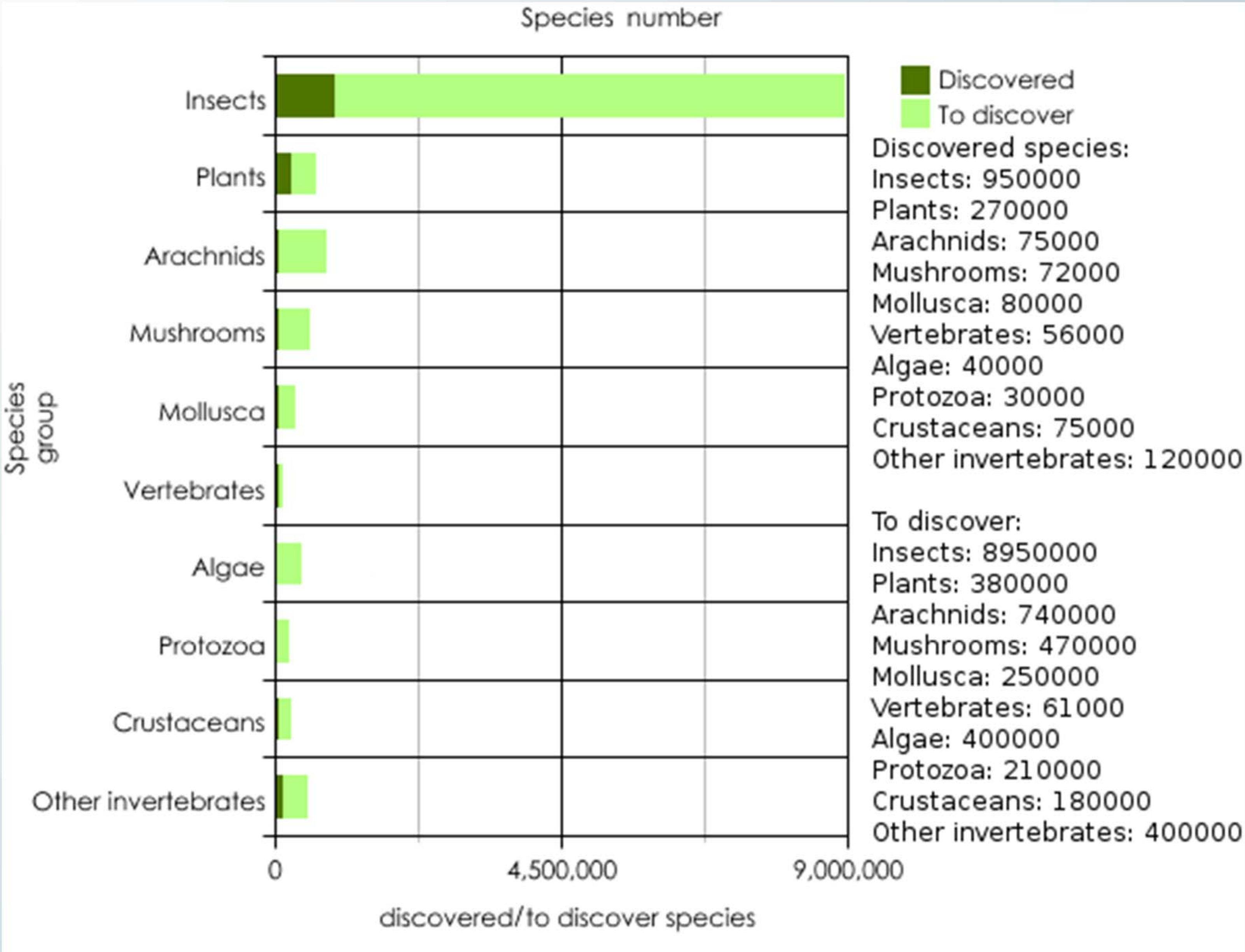
$$\tilde{D} = 1 - \sum_{i=1}^{S} p_i^2$$

where $\tilde{D}$ = index of diversity;
s = number of species;
p_i = fraction of all individuals in the ith species

Number of Species

- According to the Global Taxonomy Initiative and the European Distributed Institute of Taxonomy,
  - 10–30 million insects (including 0.9 million we know today)
  - 5–10 million bacteria
  - 1.5 million fungi (including 0.075 million we know today)
  - 1 million mites
  - The number of microbial species is not reliably known

Undiscovered Species Chart



Threats to Biodiversity

- Habitat loss and habitat fragmentation (e.g. pandas, tigers, lemurs) - most important
- Pollution (e.g. bald eagles and DDT)
- Hunting / overharvesting (e.g. wolves, passenger pigeons)
- Invasive species (e.g. dodo and egg-eating rats)
- Introduced diseases (e.g. chestnut blight)
- Climate change:
  - directly, through changing T or precipitation
  - indirectly, by influencing other factors above

Note that these effects all relate to the other human impacts.

Extinctions and Threatened Species

- There have been nearly **1,000 recorded extinctions** since 1600, and doubtless many more unrecorded ones.
- There are **15,000 threatened species** (1% of the total) on the International Union for Conservation of Nature, IUCN, Red List (http://www.iucnredlist.org/). This is a lower limit for the real total.

	Number threatened	Percent threatened
Vertebrates	5188	9.0%
Mammals	1101	20.0%
Birds	1213	12.0%
Reptiles	304	4.0%
Amphibians	1770	31.0%
Fish	800	3.0%
Invertebrates	1992	0.2%
Insects	559	0.1%
Molluscs	974	1.0%
Crustaceans	429	1.0%
Others	30	0.0%
Plants	8321	2.9%
Mosses	80	0.5%
Ferns	140	1.0%
Gymnosperms	305	31.0%
Dicots	7025	4.0%
Monocots	771	1.0%
Total	**15501**	**1.0%**

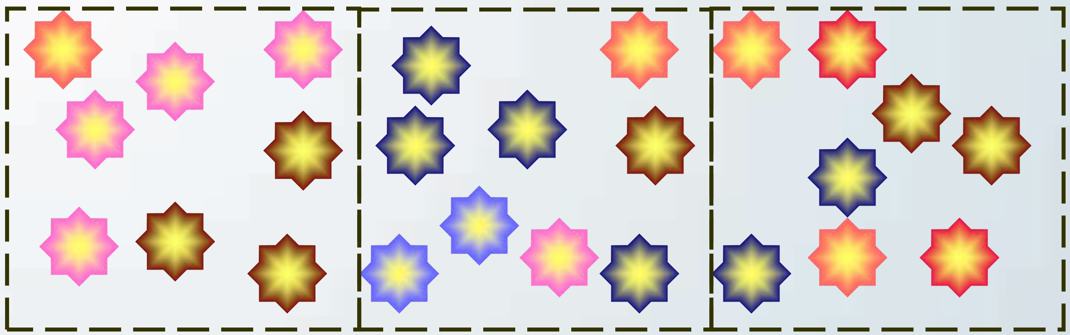
Which taxa are most vulnerable?

- **Amphibians**
- **Mammals**
- **Birds**
- **Gymnosperms** (conifers & kin)

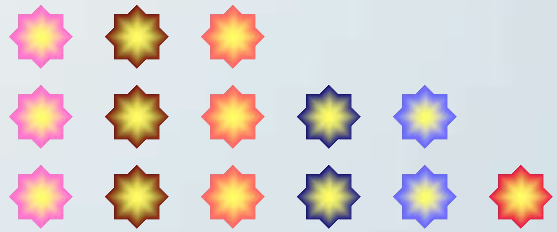
Why? We don't exactly know...

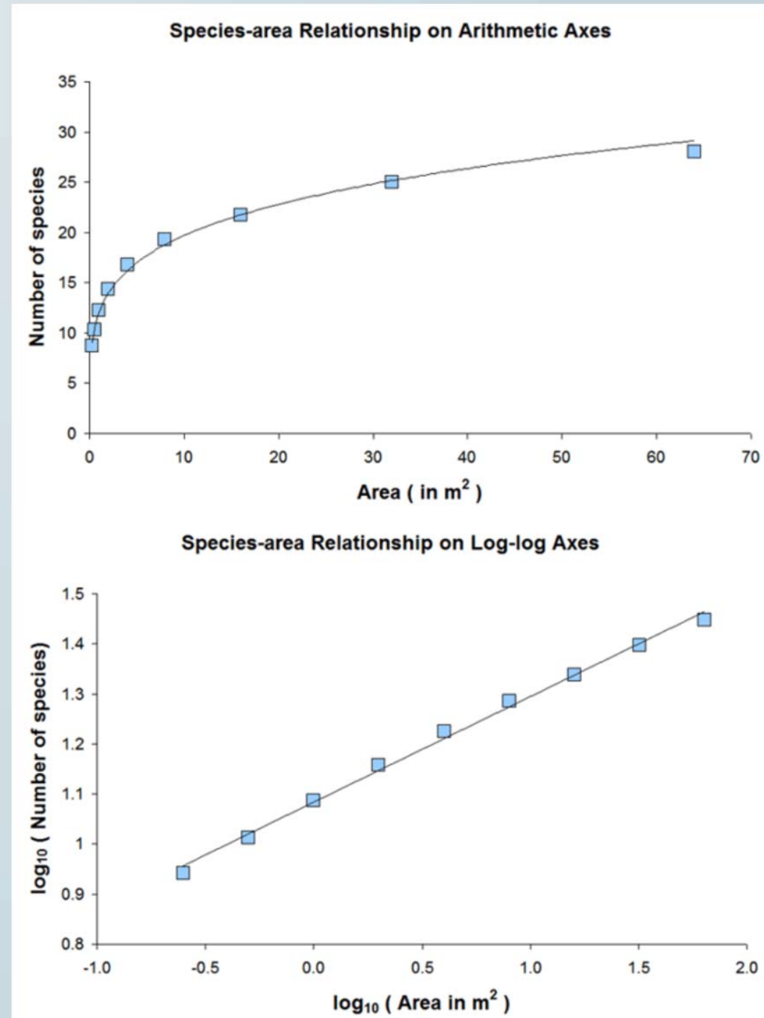
Data from IUCN (1994), cited in Botkin & Keller

Species-area Relationship



A = 1 *s* = 3
A = 2 *s* = 5
A = 3 *s* = 6





A species-area relationship (SAR) describes how the cumulative number of species increases as land area increases. It is usually concave, and often fits the curve $S = cA^z$ (where c and z are constants for that system).

Species-area relationships allow us to predict total species in an area (or species lost to habitat destruction) without counting them.

Current vs. Historical Extinction Rates

Extinction rates are **very hard to measure** (especially from fossils), but we estimate that

Background rate =

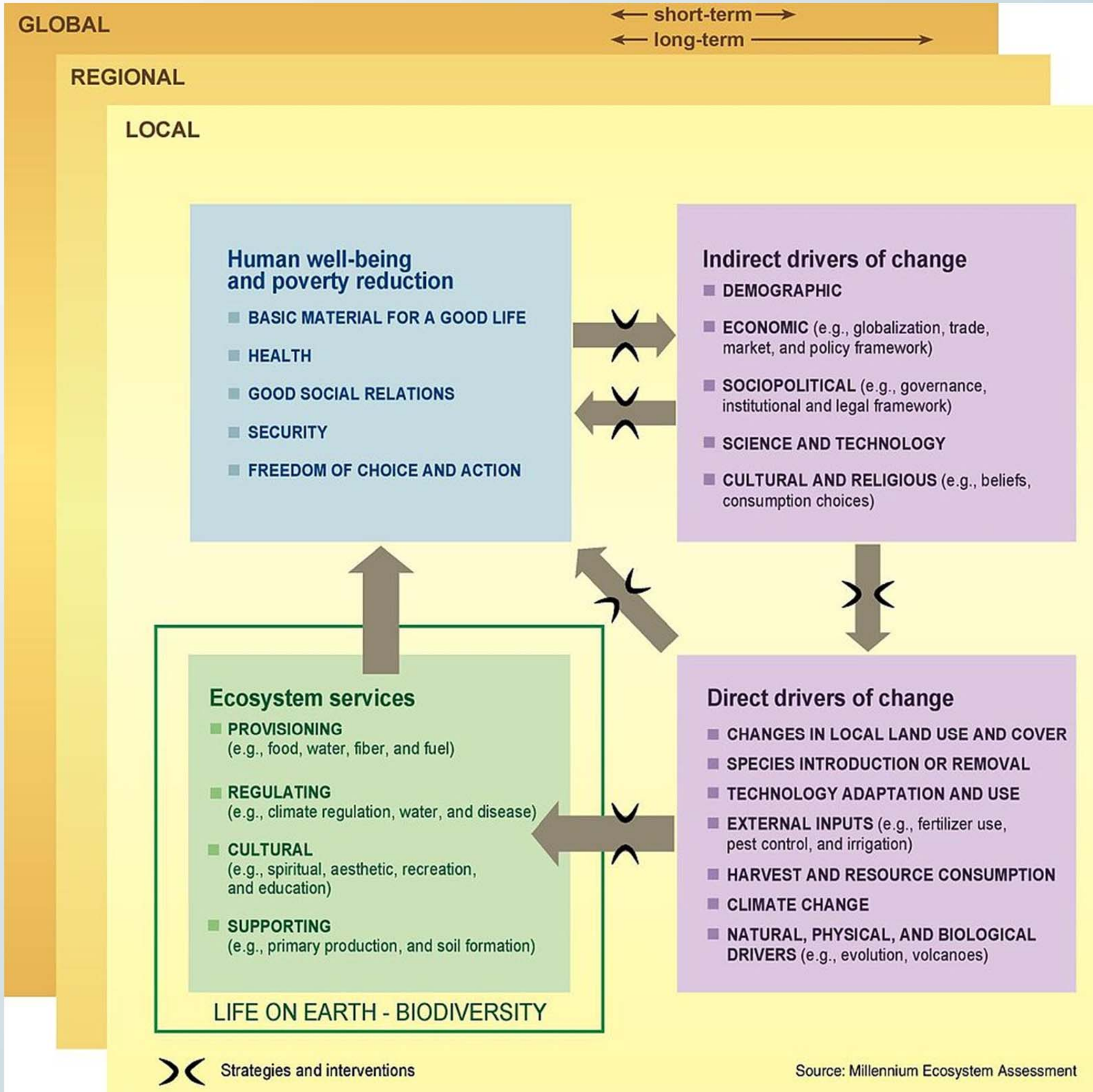
1 extinction / (**10^6** species·year)

Current rate =

1 extinction / (**10^4** to **10^5** species·year)

An increase of 10 to 100 times.

Several prominent biologists (Edward Wilson and Peter Raven) have suggested that **>50% of species will disappear by 2100**.



GLOBAL
REGIONAL
LOCAL
short-term
long-term
Human well-being and poverty reduction
BASIC MATERIAL FOR A GOOD LIFE
HEALTH
GOOD SOCIAL RELATIONS
SECURITY
FREEDOM OF CHOICE AND ACTION
Indirect drivers of change
DEMOGRAPHIC
ECONOMIC (e.g., globalization, trade, market, and policy framework)
SOCIOPOLITICAL (e.g., governance, institutional and legal framework)
SCIENCE AND TECHNOLOGY
CULTURAL AND RELIGIOUS (e.g., beliefs, consumption choices)
Ecosystem services
PROVISIONING (e.g., food, water, fiber, and fuel)
REGULATING (e.g., climate regulation, water, and disease)
CULTURAL (e.g., spiritual, aesthetic, recreation, and education)
SUPPORTING (e.g., primary production, and soil formation)
LIFE ON EARTH - BIODIVERSITY
Direct drivers of change
CHANGES IN LOCAL LAND USE AND COVER
SPECIES INTRODUCTION OR REMOVAL
TECHNOLOGY ADAPTATION AND USE
EXTERNAL INPUTS (e.g., fertilizer use, pest control, and irrigation)
HARVEST AND RESOURCE CONSUMPTION
CLIMATE CHANGE
NATURAL, PHYSICAL, AND BIOLOGICAL DRIVERS (e.g., evolution, volcanoes)
Strategies and interventions
Source: Millennium Ecosystem Assessment

International Agreements

- Convention on Biological Diversity
  http://www.cbd.int/
- Convention on International Trade in Endangered Species
  http://www.cites.org/
- Convention to Combat Desertification
  http://www.unccd.int/en/Pages/default.aspx
- Ramsar Convention on Wetlands
  http://www.ramsar.org/cda/en/ramsar-home/main/ramsar/1_4000_0__
- Convention on Migratory Species
  http://www.cms.int/
- Millennium Ecosystem Assessment
  http://www.maweb.org/en/index.aspx

Summary Notes

What is Earth's current population?

7.0 billion, increasing 1.1% per year

What do we mean by I = PAT?

Impact = Population × Affluence × Technology

Humans have transformed what fraction of Earth's surface?

About 20%; nearly all of the arable land

What is NPP? What fraction of it do humans intercept?

Net primary production; 30-40%

What two variables determine the distribution of biomes?

Precipitation and temperature

Summary Notes (cont.)

How much of available runoff do humans use?

More than 50%

What is the biggest global water use?

Agriculture

Which ecosystem types have been altered the most?

Wetlands, riparian, many types of forest

By what factor has the extinction rate increased?

10 to 100 times

How many species are there?

2-10 million