Ecosystem processes

I. Functional attributes of communities and ecosystems – some general points
A. Ecosystem functions
   1. Net primary productivity - energy and carbon capture
   2. Nutrient cycling-- conservation of nutrient capital
   3. Evapotranspiration-- water use and balance
B. Ecosystem services
   1. What do we actually get from a functioning ecosystem? Water, fiber, etc.

II. Productivity of plant communities.
A. Pools that are important in the carbon budget of ecosystems (units of g m\(^{-2}\) of Kg Ha\(^{-1}\))
   1. Biomass -
   2. Litter
   3. Soil organic matter
B. Fluxes that are important in the carbon budget of ecosystems
   1. Solar radiation. (units: Watts m\(^{-2}\))
   2. Gross primary production (GPP: units of g m\(^{-2}\) year\(^{-1}\))—gross photosynthesis by an ecosystem/community
   3. Net primary production (NPP: units of g m\(^{-2}\) year\(^{-1}\)) - rate at which plant biomass is produced per unit ground surface
   4. Net ecosystem production (NEP: g m\(^{-2}\) year\(^{-1}\)) annual increase in biomass of the ecosystem

III. Measurement of primary productivity
A. Plot harvest techniques
   1. easy for annual crops, grasslands
   2. for perennials must sample biomass at beginning and end of season
   3. must account for any litter produced
   4. roots often not included, but should be
B. Sample harvest techniques
   1. harvest individual plants and determine annual increment of growth
      a. annual wood increment
      b. annual leaf production (litter traps)
   2. use allometric equations (dimensional analysis) to scale up to whole community
   3. root production more difficult to estimate
C. Photosynthesis-based techniques
   1. measurement of whole community photosynthesis
      a. large chambers
      b. eddy covariance techniques
D. Simulation models of community photosynthesis
   1. “big-leaf” models
   2. canopy models

IV. Factors limiting primary productivity
A. Solar radiation
   1. Maximum 5-10% of the energy in sunlight ends up in biomass
      a. only 44% of solar radiation of right wavelength
      b. energy conversion efficiency 22% maximum
      c. sunlight can be above saturation for part of the day, reducing the conversion efficiency
      d. only some crops (especially C\(_4\)) > 5%
      e. forests have conversion efficiencies of 1-5%
      f. deserts <1%
   2. Capture of solar radiation depends on leaf area index (LAI) and, especially leaf area duration (LAD)
B. Other resources limit the utilization of solar radiation
   1. water availability
      a. limits photosynthesis of leaves
      b. limits LAI and hence light interception
   2. nutrients-- especially N and P --- limit canopy development and (for N) photosynthetic capacity
   3. carbon dioxide
   4. temperature can be too low -- and growing season too short

C. Herbivores may typically have only a small impact on primary productivity

V. Nutrient cycling within ecosystems
   A. A generalized cycle
      1. How do we study
         a. pool sizes
         b. flux rates
         c. watershed studies
   B. Characterize a nutrient cycle by
      1. turnover rates
      2. location and sizes of pools
      3. "leakiness"
   C. Examples of nutrient cycles
      1. generalized cycle holds for nutrients where few biological transformations occur
      2. nitrogen, because of its many biological transformations, is an exception

D. Differences in nutrient cycles between ecosystems (see attached table)
   1. rates of cycling depend on:
      a. NPP
      b. Litter decomposition rate (low in dry and cold environments, low for "acid" (i.e. coniferous) litter, litter with high lignin content)

   2. Location of nutrient pools depends on:
      a. properties of soils such as cation exchange capacity, pH, capacity for mineralization
      b. biomass and litter pool sizes
      c. precipitation and potential for leaching

VI. Evapotranspiration
   A. Sum of evaporation and transpiration (transpiration is by far the largest component)
   B. The water balance of a community
      1. precipitation captured by a community is stored in the soil.
         a. excess above water holding capacity drains off
         b. if rate of precipitation is excessive, surface runoff can occur
      2. plants extract and transpire water via the soil-plant-atmosphere continuum
         a. rate of evapotranspiration is a function of
            1. energy input (absorbed solar radiation, temperature)
            2. humidity
            3. canopy conductances (stomata, boundary layer +conductance of canopy)
         b. LAI influences energy absorbed and canopy conductance.
         c. if evapotranspiration exceeds precipitation, soil moisture will be drawn down and a water deficit will develop
            1. stomatal closure
            2. leaf shedding

VI. Comparison of selected ecosystems -see tables
VII. Summary point: Geographic variation in ecosystem properties depends primarily on temperature and precipitation.
A. Communities generally can be arranged within a triangle described by different combinations of temperature and precipitation
B. Ecosystem functional properties also vary in a predictable manner with this variation in communities

Readings:

(TEXT) Chapter 15 covers the basic information on ecosystem processes and especially a good overview of nutrient, carbon and water cycles with some examples drawn from selected ecosystems. Chapter 19 summarizes the major features of the of the different biomes.

(Whittaker) pages 111-170. The early part of this reading focuses on niches and community structure and is related more to material in previous lectures (lecture 14 and 15 in particular). Pages 135-170 give a good description of the major biome types of the terrestrial biosphere and the environmental gradients responsible for the geographic distribution. Also, Whittaker covers nutrient circulation in chapter 6 (pages 237-302)

Study Questions:

1. A number of studies, especially in agricultural plant communities, have revealed a high correlation between the solar radiation absorbed by the community and net primary productivity. Why does this correlation exist? What factors determine the amount of radiation absorbed?

2. In California, two types of chaparral communities can be found. One, called coastal sage is common in southern California and is drought deciduous (leafless period generally in the summer). The other is an evergreen chaparral community similar to what we observed near Lake Berryessa. Contrast the productive structures of these two communities. What factors (both plant characteristics and environmental factors) are important in determining the net primary productivity of each? Think about how the summer drought period might influence the productivity of each. Also, what limitations might be present in the winter in a normal year with some rain (not like this one so far!). Finally would you expect to find the same good correlation discussed in question 2 for these two communities? Why?

3. Your first job after graduation is as a researcher studying the impact of carbon dioxide on the primary productivity of an oak woodland herein California (the pay is not so great but it sure is fun!). What approaches might you consider using to assess the primary productivity of this community? Which method might be most useful if you wanted to make an estimate of the possible impact of an increasing atmospheric CO₂ concentration on productivity? (We will talk more about this problem in the last lecture.)

4. What is the difference between net ecosystem productivity and net primary productivity?

5. As part of a project assessing the impact of global climate change, you are asked to evaluate the controls primary productivity of the oak woodland community of northern California. What factors would you want to take into account in order to assess the NPP of this community and also to understand what limits it?

6. Why is LAI such an important parameter in our understanding of the functional attributes of an ecosystem?

7. What are the main factors responsible for the differences in the location of the major pools of nutrients and the rates of cycling of nutrients between a boreal and a tropical forest.

8. Why is it often useful in terrestrial ecosystem studies to use the boundaries of a watershed as the boundaries of an ecosystem for studies of ecosystem functioning?
<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>BOREAL FOREST</th>
<th>TEMPERATE DECIDUOUS FOREST</th>
<th>TROPICAL RAINFOREST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment</td>
<td>Short (4-5 mo) growing season, but warm temperatures during it. Long photoperiod in growing season. Irregular permafrost prevents drainage, leaching. Precipitation is low (30-80 cm year but exceeds PE by a factor of two.</td>
<td>5-7 mo. growing season with moderately long photoperiod and summer precipitation. Precipitation &gt;= PE so there are only short periods of water limitation during the growing season.</td>
<td>12 mo. growing season warm temperatures all year. Precip. &gt; PE except for short drought periods when water can be limiting.</td>
</tr>
<tr>
<td>Productive structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>biomass</td>
<td>20 - 60 kg m(^{-2})</td>
<td>40 - 60 kg m(^{-2})</td>
<td>40 - 60 kg m(^{-2})</td>
</tr>
<tr>
<td>NPP</td>
<td>0.2 - 0.4 kg m(^{-2}) y(^{-1})</td>
<td>1 - 8 kg m(^{-2}) y(^{-1})</td>
<td>2.5 - 3 kg m(^{-2}) y(^{-1})</td>
</tr>
<tr>
<td>LAI</td>
<td>5-12</td>
<td>4 - 6</td>
<td>6 - 8</td>
</tr>
<tr>
<td>The short growing season, low N availability, low photosynthetic capacity limit NPP.</td>
<td>longer growing season, minimal water limitation, greater N availability, higher photosynthetic capacities favor</td>
<td>continuous growing season, warm temperatures, high LAI and long leaf area duration favor high NPP</td>
<td></td>
</tr>
<tr>
<td>nutrient cycle properties</td>
<td>Rates of litter decomposition are very slow because of cold temperatures, high lignin &amp; acidity, limiting return of nutrients to soil. Most nutrients are in plants or litter. Acid soil results in low cation exchange capacity, rapid leaching. Slow rates of nutrient turnover.</td>
<td>Rates of litter decomposition faster because of warmer temperatures, less acid litter, lower lignin. Nutrient turnover rates more rapid because of high litterfall. High cation exchange capacity yields higher nutrient content in soil. Nutrients in soil and plants</td>
<td>Rapid litter decomposition due to warm temperatures, humid conditions, generally low lignin and acidity. Rapid nutrient turnover. Soils have low cation exchange capacity. Most nutrients in plants, little in soils.</td>
</tr>
<tr>
<td>disturbance factors</td>
<td>Fire cycle 80-100 years. Fire important in removing litter returning nutrients to soil, also leading to higher soil temps. All these act to increase NPP.</td>
<td>Fires are rare. Primary disturbance is windthrow, hurricanes are important. Heavy human use.</td>
<td>Fires are rare. Primary disturbance is wind and human activities such as shifting agriculture where small areas are cleared, the trees burned and crops grown for 2-5 y before abandonment.</td>
</tr>
<tr>
<td>Property</td>
<td>TEMPERATE GRASSLAND</td>
<td>DESERT</td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Environment</td>
<td>6-8 mo. growing season, increasing in southerly direction. Start determined by temperature. Generally warm temperatures and moderate photoperiods during growing season. Ann precip. 20-60 cm y⁻¹, which is &lt; potential evapotranspiration. Water deficits are significant and high year to year variation is important.</td>
<td>Warm deserts-the growing season is set by water availability (and spring temperature in cold desert.) the fall. Lack of water is the dominant env. factor. Ann. variation in NPP function of ann. variation in precip. Very high temperatures and evaporation rates in summers. 2-25 cm year⁻¹ precipitation&lt;&lt; potential evapotranspiration.</td>
<td></td>
</tr>
<tr>
<td>Productive structure</td>
<td>1-3 kg m⁻²</td>
<td>0.1-4 kg m⁻²</td>
<td></td>
</tr>
<tr>
<td>biomass</td>
<td>0.2-1.3 kg m⁻² y⁻¹</td>
<td>0.01-25 kg m⁻² y⁻¹</td>
<td></td>
</tr>
<tr>
<td>NPP</td>
<td>0.5 –3</td>
<td>0.2-1</td>
<td></td>
</tr>
<tr>
<td>LAI</td>
<td>low LAI and drought limit NPP. Photosynthetic capacities are high because the required N is readily available and low LAI gives high light saturated photosynthesis.</td>
<td>Drought limits LAI that can be supported and efficiency of photosynthesis. Photosynthetic capacities relatively high when water is available. Most NPP in late winter and spring</td>
<td></td>
</tr>
<tr>
<td>nutrient cycle properties</td>
<td>Moderate to high litter decomposition rates because of favorable conditions for decomposers. Low precip. means little leaching so nutrients accumulate in soils and are the location of the largest pools Rates of nutrient turnover are moderately high.</td>
<td>Very low litter decomposition rates. slow rates of nutrient turnover. Nutrients are in the soil because they are not leached out. Although concentrations are low, there is often little competition for them.</td>
<td></td>
</tr>
<tr>
<td>disturbance factors</td>
<td>Fire frequencies 2- 10 years set by lightning and indigenous people. Grazing is a major factor; 25-40% of the biomass may be consumed.</td>
<td>Water driven erosion and deposition. Little evidence of a successional sequence. Fire is insignificant except in wettest regions.</td>
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