PRODUCTIVITY: THE “METABOLISM” OF ECOSYSTEMS

Ecologists use the term “productivity” to refer to the process through which an assemblage of organisms (e.g., a trophic level or ecosystem assimilates carbon. **Primary producers** (autotrophs) do this through photosynthesis; **Secondary producers** (heterotrophs) do it through the assimilation of the organic carbon in their food. Remember that all organic carbon in the food web is ultimately derived from primary production.

**DEFINITIONS**

**Primary Productivity**: Rate of conversion of CO$_2$ to organic carbon (photosynthesis) per unit surface area of the earth, expressed either in terms of weight of carbon, or the equivalent calories e.g., $g$ C m$^{-2}$ year$^{-1}$

**Primary Production**: Same as primary productivity, but usually expressed for a whole ecosystem e.g., tons year$^{-1}$ for a lake, cornfield, forest, etc.

**NET vs. GROSS:**

**For plants**: Some of the organic carbon generated in plants through photosynthesis (using solar energy) is oxidized back to CO$_2$ (releasing energy) through the respiration of the plants – $R_A$.

**Gross Primary Production**: (GPP) = Total amount of CO$_2$ reduced to organic carbon by the plants per unit time

**Autotrophic Respiration**: ($R_A$) = Total amount of organic carbon that is respired (oxidized to CO$_2$) by plants per unit time

**Net Primary Production** (NPP) = GPP – $R_A$

The amount of organic carbon produced by plants that is not consumed by their own respiration. It is the increase in the plant biomass in the absence of herbivores.

**For an entire ecosystem**: Some of the NPP of the plants is consumed (and respired) by herbivores and decomposers and oxidized back to CO$_2$ ($R_H$). The amount of carbon that is left is called:

**Net Community Production** (NCP) = Organic carbon produced through photosynthesis that is not lost through $R_A$ or $R_H$.

**Thus**:

NPP = GPP - $R_A$

NCP = GPP - $R_A$ - $R_H$ = NPP - $R_H$

**Properties that can be calculated for ecosystems in steady state:**

(Note that “biomass” refers to the amount of living matter)

Mean Residence Time (MRT) = \[
\frac{\text{mass flux}}{(\text{Biomass/area}) (\text{Gross Primary Productivity})} = \frac{g \text{ m}^{-2} \text{ yr}^{-1}}{g \text{ m}^{-2}} = \text{years}^{-1}
\]

Fractional turnover ($k$) = \[
\frac{1}{\text{MRT}} = \text{years}^{-1} \text{ (x100 = % per year)}
\]
ENERGY FLOW, FOOD WEBS, AND EFFICIENCIES

\[ P_n = \text{Productivity at trophic level } n \text{ (net)} \]
\[ P_{n-1} = \text{Productivity at trophic level } n-1 \text{ (net)} \]
\[ R_n = \text{Respiration at trophic level } n \]
\[ F_n = \text{Fecal matter produced at trophic level } n \]
\[ I_n = \text{Amount Ingested at trophic level } n \]
\[ A_n = \text{Amount assimilated and available for metabolism} \]
\[ D_n = \text{Fraction of } P_{n-1} \text{ not consumed by trophic level } n \]
\[ B_n = \text{Biomass at trophic level } n \]

We can now define the following efficiencies (%):

**Explotation Efficiency (EE)**, sometimes called consumption efficiency

\[
EE = \frac{I_n}{P_{n-1}} \times 100
\]

<table>
<thead>
<tr>
<th>n-1</th>
<th>n</th>
<th>( \frac{I_n}{P_{n-1}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trees</td>
<td>Insects</td>
<td>1-10%</td>
</tr>
<tr>
<td>Grass</td>
<td>Animals</td>
<td>20%</td>
</tr>
<tr>
<td>Phytoplankton</td>
<td>Zooplankton</td>
<td>20-40%</td>
</tr>
</tbody>
</table>

**Assimilation Efficiency (AE)**

\[
AE = \frac{A_n}{I_n} \times 100
\]

Herbivores \( \sim 20 - 50\% \)
Carnivores \( \sim 80\% \)

**Production Efficiency (PE)**

\[
PE = \frac{P_n}{A_n} \times 100 = \frac{P_n}{P_n + R_n} \times 100
\]

Warm-blooded organisms \( \sim 2\% \)
Cold-blooded organisms \( \sim 40\% \)

**Ecological Efficiency**

\[
\frac{I_n}{P_{n-1}} \times \frac{A_n}{I_n} \times \frac{P_n}{A_n} \times 100 = \frac{P_n}{P_{n-1}} \times 100
\]

- Tells us how much energy is lost in one trophic transfer in the grazing food chain
- Some of this goes to the detritus food web, some goes to respiration