Chapter 9

Biological Productivity and Energy Flow

CASE STUDY: THE IMPORTANCE OF FIREWOOD

- In many parts of the world, firewood is the primary energy source for heating and cooking. I many countries, gathering firewood is a full-time occupation for younger females in a family. Firewood fuel accounts for about 5% of the world's total energy use. This chapter deals with the relationship of energy to the existence of life on this planet.

It is clear from historical documents that humans have been capable of managing biological resources in a sustained manner for centuries. Take for example documents pertaining to the management of Heylewode in 1346. It is remarkable that medieval landowners understood the concept of sustainable yield. Other examples of sustainable use exist from early human cultures, such as the practice of slash and burn agriculture. In contrast, modern human history has witnessed the over-exploitation of forests, fisheries, grazing lands, wild animal populations, and soil.

9.1 HOW MUCH CAN WE GROW… or how fast can we grow it?

● The sustained use of biological resources is inexorably linked to biological production, the subject of this chapter.

9.2 BIOLGICAL PRODUCTION

● Ecosystems are powered by solar energy (with some exceptions, e.g. chemosynthesis), and the conversion of solar energy to chemical energy is accomplished by photosynthesis, as previously discussed. The rate growth of a plant is equal to the difference between its rate of photosynthesis and its rate of respiration. Similarly, the rate of growth of an animal is the difference between its assimilation of food and its respiration rate.

● **Net production** is analogous to growth rate. Net production is the growth rate of biomass. Net production can be expressed in a number of ways, as the net rate of CO_2 uptake, as the net rate of O_2 production, as the growth rate of biomass ($C_6H_{12}O_6$). Net primary production is (see working it out 9.2):

$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6$ (glucose) $+ 6O_2 + 6H_2O$ photosynthesis or gross production
minus $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ respiration
= net production (NP) or net photosynthesis

Or, GP = NP + R and NP = GP – R

When the rate of photosynthesis is greater than the rate of respiration, then there will be a net production of glucose, which accounts for the gain in weight of the plant, or growth. About 17.6 kJ of energy are stored per gram of glucose produced (see Working it Out 9.1 and 9.2).

● Not all autotrophs derive their energy from sunlight. Those that do are termed **photoautotrophs**. There are bacteria that fix CO_2, but use the energy available in inorganic molecules to do so. This group is referred to as **chemoautotrophs**.

● **Biomass** is the amount or weight of organic matter, analogous to body weight, in a particular place, in an ecosystem, biosphere, or organism. In an ecological context, the biomass and net production of terrestrial ecosystems are commonly based on surface area, and in aquatic ecosystems they are expressed volumetrically or aerially. Positive changes in biomass, summed over a finite period of time, are commonly used to compute net production (see working it out 9.1).

● Units – For example the biomass of a forest of trees could be expressed in units of g/m^2, its net production as $g\ m^{-2}\ yr^{-1}$, while the biomass of plankton in a lake could be expressed as g/liter and its net production as $g\ liter^{-1}\ yr^{-1}$.

9.3 ENERGY FLOW

● Definition – Energy is the ability to do work, and work can be defined as the movement. Energy is a difficult, abstract concept. Energy can exist in one of two forms (kinetic and potential), and there are different kinds of energy (heat, light, chemical).

● Energy that enters an ecosystem as photosynthesis or chemosynthesis (deep sea thermal vent communities) flows along food chains until it is either temporarily stored in net production or dissipated as heat. While the material building blocks of life are recycled (conservation of mass), energy does not recycle. It flows in as light energy and out as heat. The flow of energy powers the biogeochemical cycles and sustains life.

9.4 THE ULTIMATE LIMIT ON THE ABUNDANCE OF LIFE

● The Laws of Thermodynamics

First law- energy neither be created nor destroyed, it can be transformed from one type into another type. Think about this, the energy content of the universe is constant!

Second law- for any conversion of energy from one form to another, some of the initial energy input is always degraded into another form, usually heat. No energy conversion is 100% efficient. See A Closer Look 9.1

A CLOSER LOOK 9.1: The Second Law of Thermodynamics

● Order requires energy, and the second law of thermodynamics predicts that the level of disorder (**entropy**) in the universe is constantly increasing. A simple demonstration of this is the disorder that overtakes a dorm room when the occupants fail to invest the energy necessary to maintain order. How then can we explain the existence of life, which is the pinnacle of order? Life exists only by increasing the disorder or entropy of the entire system. Then can life exist forever? This is heady stuff.

● These are extremely powerful generalities that have practical applications as well as theoretical star power. For example, the second law explains the pyramid of biomass and suggests how to maximize the number of people that can be supported on a piece of land.

● Energy Efficiency and Transfer Efficiency
The 2nd law informs us that organisms cannot be 100% efficient in assimilating the energy that they consume. There is an unavoidable loss of energy as heat and other losses. For examples energy is also lost in waste products. Thus, as the energy passes from one organism to another, from prey to predator, the amount of useful energy decreases. The rule of thumb is that about 10% of the energy on any trophic level is assimilated by the next trophic level (See A Closer Look 9.2). Consequently, the biomass that can be supported by primary producers declines at each level up the food chain. This phenomenon explains the **pyramid of biomass** that is a common feature of ecosystem structure. To put this another way, it takes far more land to support a top predator than it does to support an herbivore.

9.5 EXAMPLES

- Old field.
    - 15% of energy lost as plant respiration
    - 68% of energy input to mice lost as respiration
- Stream
- Ocean

A CLOSER LOOK 9.2: Ecological Efficiencies

● Table 9.1 gives values for growth efficiency, or gross production efficiency (P/C), which is the ratio of the material produced by an organism or population to the material consumed.

CRITICAL THINKING ISSUES

● Should people eat lower on the food chain? The average North American requires five times as much land as a person in India. One could make the case that our cardiac health would improve if we lowered our average trophic position, and we would have a smaller ecological foot print.

● Is there a connection between the economic system (capitalism, socialism) and the management of resources? Who wins when short term profits are maximized at the expense of long term, sustainable profits? Who looses?

Web Resources

http://nationalatlas.gov/dynamic/dyn_green.html An animation of the seasonality of greening (a surrogate for productivity) of the U.S. from space.