Constructing pyramids of energy

MEASURING ENERGY FLOWS IN ECOSYSTEMS

Collecting the data needed to construct a pyramid of energy is very time-consuming and has only been done fully for a few ecosystems. Energy flow through each species in the ecosystem must be measured and then the species are classified into trophic levels.

The lowest bar of a pyramid of energy is the total amount of energy that flows through the producers in the ecosystem. This is also called the gross production.

Gross production is the total amount of organic matter produced by plants in an ecosystem. Gross production and all the other energy flows in a pyramid are measured in kilojoules of energy per square metre per year (kJ m^{-2} $year^{-1}$). Gross production does not have to be measured directly, as it can be calculated from net production and plant respiration.

Net production is the amount of gross production of an ecosystem remaining after subtracting the amount used by plants in respiration.

gross production = plant respiration + net production

Example – an old field community in Michigan, USA

net production = 20.79×10^3 kJ m^{-2} $year^{-1}$

plant respiration = 3.68×10^3 kJ m^{-2} $year^{-1}$

gross production = $(20.79 + 3.68) \times 10^3$ kJ m^{-2} $year^{-1}$

$= 24.47 \times 10^3$ kJ m^{-2} $year^{-1}$

The upper bars of a pyramid of energy are the total amounts of energy that flow through the various groups of consumers. This is the amount of energy in the food that the consumers ingest.

CLASSIFYING ORGANISMS INTO TROPHIC LEVELS

When real food webs are constructed, many species are seen to exist partly in one trophic level and partly in another.

The following examples illustrate this.

- *Euglena*, a unicellular organism found in ponds, has chloroplasts and photosynthesizes, but it also feeds heterotrophically by endocytosis.
- Chimpanzees mainly feed on fruit and other plant matter, but they also sometimes eat termites and even larger animals such as monkeys, so they are both first and second consumers.
- Herring are second consumers when they feed on *Calanus* and other first consumers (right), but they are third consumers when they feed on sand eels and other second consumers.
- Oysters (*Ostrea* species) and many other filter feeders consume both ultraplanktonic producers and microplanktonic consumers, so they are first and second consumers. They also consume dead organic matter, so they are also detritivores.

It is difficult to decide into which trophic level these types of organism should be classified. The only practical solution is to classify each species according to its main food source.

USING DATA TO CONSTRUCT A PYRAMID OF ENERGY

The data below was obtained from an Arctic tundra ecosystem on Devon Island in northern Canada.

Trophic level	Energy flow (kJ m^{-2} $year^{-1}$)
Producers	4925
Primary consumers	24
Secondary consumers	4

This data can be used to construct a pyramid of energy. Each bar of the pyramid should be drawn to the same scale and labelled with the trophic level. Other examples are shown on page 39.

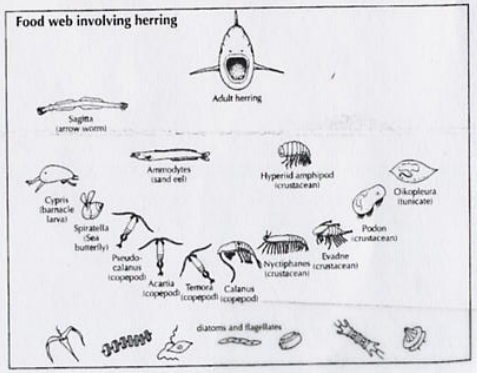
REASONS FOR SMALL NUMBERS AND LOW BIOMASS OF ORGANISMS IN HIGHER TROPHIC LEVELS

Pyramids of energy show that there are large losses of energy at each trophic level. The reasons for these losses of energy are explained on page 38. Losses of energy in ecosystems are accompanied by losses of biomass.

Biomass is the total dry mass of organic matter in organisms or ecosystems.

Respiration is an example of a process in which both energy and biomass are lost. When glucose or another respiratory substrate is oxidized in respiration, energy from the glucose is released for use in the cell and is then lost as heat. The mass of the glucose does not disappear – it passes into the carbon dioxide and water that are produced in respiration. When these waste products are excreted, biomass is lost. As a result of respiration and other processes, both energy and biomass are lost at each stage in a food chain. The energy content per gram of food does not decrease along a food chain. If anything, the food eaten by the higher trophic levels is richer in energy per gram than that eaten by lower trophic levels. However, the total biomass of food available to higher trophic levels is very small. It cannot support large numbers of organisms, especially as these organisms need to be large to overpower their prey. Higher trophic levels therefore usually contain very small numbers of large organisms, with a low total biomass per unit area of ecosystem.

Food web involving herring



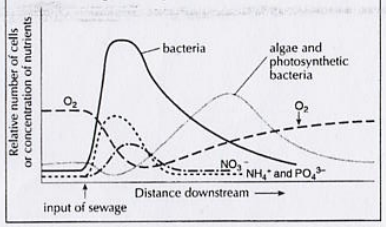
Eutrophication and biological fuels

EFFECTS OF RAW SEWAGE ON RIVERS

Raw sewage and other forms of pollution that are rich in organic matter have profound effects on river ecosystems. The effects can be studied by measuring biotic and abiotic variables at different distances below the sewage input (right).

1. Bacteria consume the organic matter and proliferate.
2. The bacteria use oxygen in aerobic cell respiration. As the numbers of bacteria rise, they consume more and more oxygen, so the **biochemical oxygen demand** of the river water increases. The aeration of the water does not increase, so the water becomes **deoxygenated**. Fish and other animals that depend on dissolved oxygen are sometimes killed.
3. Digestion of organic matter by bacteria causes release of ammonia and phosphate. The ammonia is converted to nitrate by nitrifying bacteria. The increase in levels of nitrate, phosphate and other mineral nutrients is called **eutrophication**.
4. Eutrophication causes proliferation of algae and photosynthetic bacteria (formerly known as blue-green algae). If the numbers of algae are high enough they cause a discolouration of the water, called an **algal bloom**. The algae absorb nutrients from the water, reducing concentrations in the water.
5. The algae release oxygen by photosynthesis, so the water becomes reoxygenated.
6. Primary consumers feed on the algae, reducing their numbers. Conditions in the river are then similar to those before the sewage input – the river has recovered.

Effects of sewage discharge into a river



EFFECTS OF NITRATE FERTILIZER ON RIVERS

Nitrates can also have profound effects on rivers.

1. Nitrate ions are very soluble and are leached from soils very easily if excessive amounts are applied to crops. If phosphate and other minerals also reach a high concentration, a river becomes eutrophic.
2. As with eutrophication caused by sewage pollution, algae proliferate and **algal blooms** develop. Nitrate from fertilisers sometimes cause such excessive growth of algae that some of the algae are deprived of light and die.
3. Bacteria decompose the dead algae. The bacteria create an increased **biochemical oxygen demand** and **deoxygenation** of the water.
4. Low oxygen levels kill fish and other aquatic animals.

BIOLOGICAL FUELS

Biomass already provides large amounts of fuel, in the form of wood, crop residues and dried manure. Methods now exist for converting biomass into fuels that are more convenient to use, such as ethanol and methane.

METHANE GENERATION

Methane is sometimes called marsh gas, because it is naturally produced in anaerobic conditions by methanogenic bacteria. These conditions are recreated in bioreactors used for methane generation (below). Any organic waste can be the raw material, but sewage and manure or slurry from farms are most commonly used. The raw material is loaded into the bioreactor where anaerobic conditions encourage the growth of three groups of naturally occurring bacteria.

The first groups convert organic matter into organic acids and alcohol.

The second group convert organic acids and alcohol into carbon dioxide, hydrogen and acetate.

The third group of bacteria are the methanogens –they produce methane from carbon dioxide, hydrogen and acetate.

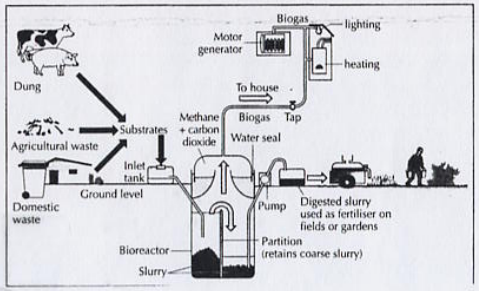
Carbon dioxide + hydrogen → methane + water

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

Acetate → methane + carbon dioxide

$CH_3COOH \rightarrow CH_4 + CO_2$

Methanobacterium and Methanococcus are examples of methanogens.

The gas that is produced in bioreactors is sometimes called biogas and is 40–70% methane. It can be used as a fuel for cooking or lighting. If it is compressed in cylinders it can be used as a fuel in vehicles. It is renewable and non-polluting. Production of it helps to dispose of potentially polluting wastes. The organic matter left over at the end of methane generation can be used as an organic fertilizer, rich in mineral nutrients.

A bioreactor