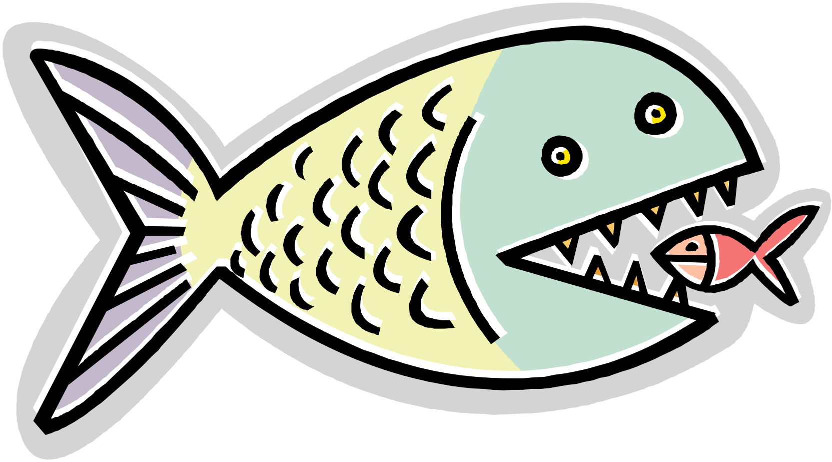
Ecological Energetics in a Freshwater Community.

(AQA A2)



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Teacher's Notes

This unit builds on students' knowledge of food chains, food webs and trophic levels gained through the GCSE syllabuses. It investigates the feeding relationships found within a freshwater stream community, and demonstrates the quantitative investigation of number, biomass and energy contained within each trophic level. The unit helps students understand why food webs will only sustain a limited number of trophic levels, and considers the efficiency of energy transfer between trophic levels.

Key Syllabus Areas

Unit 4 Populations and environment

3.4.5 Energy transfer, energy and food production.

Bibliography

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Introduction

When considering energy transfer in a community, it is necessary initially to divide the community into its component trophic (feeding) levels:

			D
			E
(3o consumers)	Large carnivores	→	C
↑	↑		O
(2o consumers)	Small carnivores	→	M
↑	↑		P
(1o consumers)	Herbivores	→	O
↑	↑		S
(Producers)	Photo-autotrophs	→	E
↑	↑		R
Energy from sunlight			S

(↑ = movement of energy)

Communities are supported by this flow of nutrients and energy.

In terms of nutrient molecules passing through each trophic level, transfer is essentially cyclical – ie. carbon, nitrogen, phosphorus, sulphur, minerals – each molecule remains essentially unchanged when passing from one organism to the next. These molecules are in finite supply and are recycled back into the ecosystem by decomposers when organisms die. Without this mechanism, essential molecules would remain ‘locked up’ in organic material, eventually becoming in limited supply.

In terms of energy passing through each trophic level, transfer is both cyclic and linear – energy enters the global system as incoming solar radiation, and is trapped by producers by the process of **photosynthesis:**

$6CO_2 + 6H_2O$ + energy from sunlight → $C_6H_{12}O_6 + 6O_2$

In the majority of ecosystems, green plants are the producers. The earth’s surface receives between 0 and 5 joules of solar energy per square meter per minute – only 1 to 3% of this energy is trapped by the chlorophyll and converted into chemical energy as carbohydrate. Half of the incoming solar radiation is outside the normal wavelength used in photosynthesis and much is reflected or passes through the leaf. The primary productivity of an ecosystem is the rate at which biomass is produced per unit area by green plants. It can be expressed either as a unit of energy (kJ/m2/yr) or as a unit of biomass (kg/m2/Yr). The total fixation of solar energy by photosynthesis is the gross primary productivity. However, as plants themselves will utilise much of this fixed energy through respiration, the actual rate of production of biomass available for the next trophic level is called the net primary productivity.

Gross primary productivity = Net primary productivity + Plant respiration.

As only the net primary productivity of an ecosystem is available to its consumers, it is used to compare the productivity of ecosystems:

Ecosystem	Mean Net primary productivity (kJ/m2/yr)
Desert	260
Open Ocean	4700
Temperate grassland	15 000
Temperate deciduous forest	26 000
Intensive agriculture	30 000
Tropical rain forest	40 000

In a habitat well supplied with heat, light and water, plants respond by producing many leaves, which photosynthesise and produce energy; In an unfavourable (very dry or very cold) environment, plants do not produce many leaves as they risk wilting or frost damage; In a shady environment, few leaves are produced as the plant wouldn’t reach the compensation point, ie. respiration would exceed photosynthesis, resulting in net loss of biomass.

Carbohydrates are used by green plants as building blocks for growth, and as an energy source – carbohydrate is respired in the cells to provide ATP for endergonic reactions such as protein synthesis. Energy used by the organism is unavailable to the next trophic level:

INPUT	SYSTEM	OUTPUT
Chemical energy →	Water vole →	Increase biomass (Ep: energy of production)
(Ei)		Lost in faeces (Ef)
		Lost in urine (Eu)
$Ei = Ep + Ef + Eu + Er$		Used in respiration

Energy ‘invested’ in biomass, through the growth of the organism, is available to subsequent trophic levels. Energy lost in urine and faeces, and used in respiration and lost as heat is unavailable to the next trophic level. Approximately **90%** of an organism’s energy intake is expended on such activities – only **10%** is typically transferred to the next trophic level.

The percentage of energy successfully transferred from one trophic level to the next is known as the trophic efficiency. Different trophic levels tend to be more or less efficient than one another. For example, the primary consumer level (herbivores) tends to be rather inefficient – cellulose is difficult to digest, and to convert it into protein biomass is energy demanding. Secondary and tertiary consumers (carnivores) are rather more efficient as animal protein is already readily available in a useful form. Small mammals and birds tend to be generally less efficient than larger mammals as they need to work harder to maintain a constant body temperature, due to a large SA:volume ratio.

Applications of modern farming techniques to improve energy transfer between trophic levels:

Trophic efficiency can be improved – the basis of some ‘modern’ intensive farming techniques such as battery farming, veal production and the feeding of animal-based feed to herbivores is the improvement of trophic efficiency.

Animals which are kept indoors in heat-controlled environments, in which they have little freedom to move and no need to wander around looking for food as it is provided infront of them, retain more of the energy from the food that they eat and increase their biomass. Selective breeding ensures that that biomass is invested as increased muscle mass rather than fat. Selective breeding allows farmers to select sperm from catalogues of cattle, which have high birth weights and survival rates, low incidences of disease, fast growth rate and maximised conversion of food to muscle. Easily digested and assimilated food is fed to animals to ensure that as much energy from the food as possible is invested as biomass. In some countries, growth hormones are given, to increase the rate of muscle gain (this has long been outlawed in Europe). Intensively farmed animals are more susceptible to disease, which is more easily transmitted between animals kept close together. Animals will be given antibiotics to control disease, but this is always noted in animals’ ‘personal’ records. Traceability of farm animals from farm to plate is now a legal requirement throughout Europe, and animals are individually identified and extensive records of drug, feeding are stored.

Crop productivity is also increased by modern farming practises. For example, farmers improve the structure of soil in their field by ploughing to make a good seed bed in which most seeds will germinate; putting in drainage in water logged soils or irrigating dry soils; adding lime to improve the pH of the soil; adding fertilisers. Soil fertility and crop production can be greatly improved by using artificial or natural fertilisers (manure – which releases nutrients more slowly, but does improve the soil by increasing humus content, and therefore water-retention capacity). Adding fertilisers to the soil replenishes the nutrients which intensive crop production strips from the soil – a deficiency of any mineral, such as phosphorus, potassium, nitrates will limit plant growth. Fertilisers are carefully selected according to the needs of the soil (which can be tested precisely, and many farmers now use GPS-informed mapping of their fields to target application of fertilisers, pesticides, herbicides, etc. to their fields in the areas which need extra input of agrochemicals).

(NB. Some ecosystems such as those found in deep ocean volcanic vents and in some caves are supported by the energy which chemo-autotrophs fix through complex oxidation reactions.)

Specific Information

In examining the energy budget of a freshwater stream, it can be very difficult to isolate the producers. An upland stream typically has a very low level of primary productivity which will in itself fluctuate through the year according to algal growth in the warmer months. This low level of primary productivity is supplemented from outside the system by detritus from trees and other vegetation upstream.

Aims

To establish the feeding relations between organisms in a freshwater stream community, and construct a food web which represents the community sampled;

To quantify the stream community at its different trophic levels, using pyramids of numbers, biomass and energy;

To determine the trophic efficiency of the stream community.

Objectives

To sample the stream community of the River Souteyran using an appropriate procedure;

To sort the community into trophic levels using observation of behaviour and reference texts;

To establish, using laboratory procedure and data tables, the biomass and energy content of organisms at each trophic level;

To calculate the energy transferred between each trophic level.

Hypotheses

There will be a reduction in the number of organisms at each trophic level, from producers to top consumers;

There will be a reduction in the total biomass of organisms at each trophic level, from producers to top consumers;

There will be a reduction in the energy contained in each trophic level, from producers to top consumers;

The efficiency of energy transfer (the trophic efficiency) between subsequent trophic levels will be approximately 10%.

Data Collection Site

The River Souteyran, opposite the driveway to the Eagle's Nest.

Equipment

50x50cm open frame quadrat
Pond net
2 buckets
White sorting tray
Spoons
Identification key
Small pots for balance
0.0g balance
Plastic cups
Tea strainers
Waterproof pen / pencil

Method and Organisation of Study

In the field, the objective is to collect a representative, sample of the stream community from a known area, so that numbers, biomass and energy per unit area can be calculated. The collection technique used between groups needs to be standardised, as data will be pooled later, so sampling over a specified area, for a specified length of time should be carried out. Producers and consumers are collected using a standard kick sampling technique:

Place the quadrat in the stream in a 'representative' site – some groups could sample pools, others riffles, some near the bank others in the middle of the stream – collectively, the group should try to sample all the available microhabitats in the stream. Groups should not be too close to one another, and be aware that they may inadvertently catch material knocked downstream by other groups.

Position the pond net, which is 25cm across, in front of the quadrat. Treating the quadrat as two halves, first remove any obvious green plants (freshwater macrophytes, filamentous algae and moss), swishing each hand full in front of the net to dislodge any clinging invertebrates. Place these together with any leaves or twigs from the quadrat – decomposing material carried into the area from upstream forms an important part of this food web - in one bucket. Carefully remove any rocks with a film of algae on them – they may appear green or feel slimy to the touch. Wash them carefully in front of the net to dislodge any invertebrates, and place the rocks in the buckets with the producer material.

There will already be a few invertebrates in the net, washed from the rocks and vegetation. To remove the rest from the sample area, carefully disturb the sediment in the quadrat with your foot, dislodging the invertebrates into the net. Kick for one minute. Finally, face upstream and wash the net through a few times to remove any fine sediment, and place the sample in the second bucket, which is half full of water.

Pour the bucket containing the invertebrates into a flat white sorting tray. Identifying them using the key, remove each to a labelled plastic cup containing a little stream water – one for each species / family – using a white plastic spoon. Tally-count each animal. Record on lab sheet 1.

Weigh each type of producer material separately – detritus, emergent green plants, moss, etc. using the pan balance. Record the biomass figure for each species. Record on lab sheet 1.

Field Recording Sheet 1: Analysis of consumers.

Species / Family	Tally	Group Total	Class total
Beetles			
Beetle larvae			
Blackfly larvae and pupae			
Small cased caddis fly larvae			
Large cased caddis fly larvae			
Caseless caddis fly larvae			
Cranefly larvae			
Flatworms			
Leeches			
Mayfly nymphs – flattened, olive and striped			
Midge larvae and pupae			
Mites			
Molluscs			
Small stonefly			
Large stonefly			
Worms			
Moss		x	Biomass:
Detritus		x	Biomass:
Emergent green plants		x	Biomass:

Data Presentation and Analysis

- ✓ Complete the class results spreadsheet on the classroom computer, transferring the number and biomass for each species from lab sheet 1;

- ✓ Individual groups draw up scaled pyramids of numbers, biomass and energy on graph paper;

- ✓ Calculate the energy transferred between each trophic level as a percentage.

- ✓ Using the information on data table 2 (appendix 2), produce a stream food web including the invertebrates found on the day. This will form an important part of the discussion.

Data Interpretation and Discussion

Do the pyramids of number, biomass and energy conform to the expected model of trophic pyramids? It is unlikely that the trophic efficiency between trophic levels will be 10% - between 5 and 25% is more likely. If the trophic efficiency is too high or too low, could this be as a result of experimental error, or are there other explanations? The following points are vital to the discussion:

- What sources of experimental error where in the data collection techniques used? (eg. Invertebrates clinging onto vegetation; invertebrates being swept away or swept into sample area from upstream; some groups are more thorough than others; difficult to sample more mobile species; under estimate of low order consumers compared to high order consumers – small animals are very numerous and difficult to catch compared to the generally larger and more conspicuous higher order consumers; free-floating algae, algae growing on macrophytes, mosses and detritus, microscopic invertebrates and bacteria have not been sampled at all);

- Effect of season? Supplemented ecosystems – ie. input of detritus from outside the habitat during autumn – this river is essentially oligotrophic and relies on the input of detritus as a major source of energy, which is difficult to quantify. Detritivores will flourish during late summer and autumn. Spring and summer flushes of algae on rocks will see an increase in the organisms that feed on them. Not all species are present throughout the year – some may be present as pupae or eggs and buried in the stream bank or attached to vegetation. Many organisms, eg. Mayflies, midges, will become adult as the food supply becomes short in late summer. This creates ‘oscillating pyramids of energy’, in which at any point in the year, the numbers of producers and consumers will vary according to seasonal food supply;

- Standing crop and productivity. The students have measured the standing crop – the amount of biomass or energy in a unit area at one point in time. Because of the seasonal variation of organisms in this (and most) ecosystems, it is more appropriate to measure productivity – the amount of biomass or energy in a unit area in a year.

- Why should dry mass be used to estimate energy content of organisms?

- Why do different organisms contain more energy than others – even as dry mass? (Inert material contained in cased caddis larvae cases, mollusc shells). Different tissues will be more/less energy rich – muscle more so than chitin for example. What effect would this have on the pyramids of biomass;

- Effect of longevity. Some species are more long lived than others – midge larvae pass through all the stages in their life cycle in a few months, whilst leeches and fish may live for several years. When investigating a pyramid of biomass, the primary consumers can appear less numerous as a standing crop than the secondary or tertiary consumers. But because they reproduce more rapidly, their overall productivity (kJ/m2/yr) will be sufficient to support subsequent trophic levels (inverted pyramids of biomass).

- Effect of home range. To acquire the energy they require, higher order consumers will have to cover a much larger area, and so are less likely to be sampled effectively;

- Effect of size. The pyramids of numbers should become smaller from producers to higher order consumers. Is there a difficulty because the organisms are different sizes (inverted pyramids of numbers). What is the best way of quantifying trophic levels?

- When examining the food web, notice that: freshwater invertebrates do not consume macrophytes as they are too tough – lignified cellulose is difficult to shred and digest and may contain toxic anti-feedant chemicals. Animals do not rely on a single food source – a food web is a representation of the complex feeding relationships between organisms, which will shift according to food supply and therefore time of year, and a combination of many food chains.

- What are some of the arguments for and against intensive farm production of animals and crops? Give two environmental/ethical arguments and two economic arguments for and against.

Class Results Sheet. (Complete on classroom computer)

Species / family	Number in quadrat	Biomass in quadrat (g)	Biomass in 1m2	Energy (kJ/g) (from data table)	Energy in 1m2 (kJ/m2)	Feeds on	Trophic level
Eg. Shrimp	52	6.4g	6.4 x 4 = 25.6g	3.40 kJ/g	25.6 x 3.40 = 87.04	Detritus	2 / decomposer

Class Results Compilation.

Trophic level totals	Numbers	Biomass (g/m2)	Energy (kJ/m2)
Total producers (trophic level 1)			
Total 1o consumers (trophic level 2)			
Total 2o consumers (trophic level 3)			
Total 3o consumers (trophic level 4)			

Appendix 1 Energy equivalents of some freshwater invertebrates.

Species / Family	kJ/g fresh mass	kJ/g dry mass
Plants:		
Macrophytes	2.33	15.52
Moss	3.62	18.07
Algae	3.56	16.17
Detritus	5.56	18.54
Animals:		
Alderfly larvae	4.72	
Beetles and their larvae	4.72	
Blackfly larvae and pupae	2.76	
Cased caddis fly larvae (stones) Cased caddis fly (vegetation and detritus)	1.94 2.16	
Caseless caddis fly larvae	4.08	
Cranefly larvae (dicranota and tipula)	2.56	
Fish	3.54	
Flatworms	5.58	
Leeches	3.77	
Mayfly nymphs – flattened	4.72	
Mayfly nymphs – olive	4.72	
Mayfly nymphs - striped	4.72	
Midge larvae and pupae	2.76	
Mites	3.33	
Molluscs	2.02	
Shrimps	3.40	
Stonefly nymphs	4.72	
Water boatman	3.55	
Water hog louse	3.40	
Worm	1.91	

Appendix 2 Diets of freshwater invertebrates

Species / family	Food	Feeding method	Trophic level
Alderfly larvae	All smaller animals	Ripping apart	3
Beetles	Algae and detritus	Shredding	2 / Decomposer
Beetle larvae	All smaller animals	Piercing and sucking	3
Blackfly larvae and pupae	Fine detritus	Filtering	2
Cased caddis fly larvae (less than 10mm long)	Algae and detritus	Shredding	2
Cased caddis fly larvae (greater than 10mm long)	All smaller animals	Ripping apart	3
Caseless caddis fly larvae	All smaller animals	Ripping apart	3
Cranefly larvae (dicranota and tipula)	Midge larvae, blackfly larvae	Piercing and sucking	3
Fish	All smaller animals	Swallowing whole	4
Flatworms	Smaller, less mobile animals, fish eggs	Engulfing	3
Leeches	Smaller, less mobile animals	Swallowing whole	3
Mayfly nymphs – flattened	Algae and detritus	Scraping and shredding	2
Mayfly nymphs – olive	Algae and detritus	Scraping and shredding	2
Mayfly nymphs – striped	Algae and detritus	Scraping and shredding	2
Midge larvae and pupae	Algae and fine detritus	Collecting	2
Mites	Midge larvae, blackfly larvae	Piercing and sucking	3
Molluscs	Algae and detritus	Scraping and shredding	2
Shrimps	Algae and detritus	Scraping and shredding	2
Stonefly (less than 10mm long)	Algae and detritus	Scraping and shredding	2
Stonefly (greater than 10mm long)	All smaller animals	Ripping apart	3
Water boatmen	All smaller animals	Piercing and sucking	3
Water hoglouse	Algae and detritus	Scraping and shredding	2
Worms	Algae and detritus	Swallowing whole	2

Appendix 3 Typical biomasses of freshwater invertebrates (mass for one average-sized individual)

Species / family	Typical biomass for one individual (g)
Alderfly larvae	0.04
Beetles (Elmid)	0.02
Beetles (diving)	0.05
Beetle larvae	0.02 to 0.05
Blackfly larvae and pupae	0.05
Cased caddis fly larvae (greater than 10mm long)	0.05
Cased caddis fly larvae (less than 10mm long)	0.03
Caseless caddis fly larvae	0.02
Cranefly larvae (dicranota and tipula)	0.02
Fish	0.1 to 5!
Flatworms	0.01
Leeches	0.05
Mayfly nymphs – flattened	0.04
Mayfly nymphs – olive, striped	0.02
Midge larvae and pupae	0.005
Mites	0.001
Molluscs	0.03
Shrimps	0.03
Stonefly (greater than 10mm long)	0.04
Stonefly (less than 10mm long)	0.02
Water boatmen	0.06
Water hoglouse	0.03
Worms	0.01