Ecosystems & Ecophysiology – Lecture 2

Rivers

Objectives

1. Understand the calculation of stream order and the physical characteristics of low, middle and high order streams.

2. Know morphological and behavioural adaptations of organisms to life in running water.

3. Describe the food web in a typical low order temperate stream, especially the importance of CPOM, conditioning by microorganisms, and shredders.

4. Explain why primary production becomes more important in a middle order stream, the difference between heterotrophic and autotrophic streams, and the increase of scraper-grazers.

5. Describe the sources and importance of FPOM in a high order stream, and the dominance of collectors.

6. Understand the River Continuum Concept of longitudinal variation along a stream system.

Rivers

Rivers have small volume but important for biodiversity, including evolution of several invertebrate groups - chironomids, dragonflies, mayflies, stoneflies

Average river replaces its water 20 times per year. Flow determined by gravity, downhill to the sea or to an inland sink. Biology of a river depends on rate of flow and quality of water, determined by the catchment

■ Rivers are classed by stream order, usually by the Strahler method. A first order stream has no tributaries, fed by runoff and groundwater. Two first order streams merge to form a 2^{nd} order stream

Two 2^{nd} order streams merge to a 3^{rd} order stream etc. Merging with a tributary of lower order does not change stream order. Britain has four 6^{th} order rivers. Nile is 10^{th} order, Amazon 12^{th} order

The basic feature of river ecosystems is a predictable change of physical characteristics, habitats and organisms with stream order

■ Rainwater has few impurities, except near coast (values * below). Water picks up solutes and suspended matter from the land

		ppm sea	ppm rain	ppm river
Chloride	Cl^-	19350	0.2-10*	6
Sodium	Na^+	10760	0.2-5*	5
Sulphate	SO_4^{2-}	2710	1-3	8
Magnesium	Mg^{2+}	1290	0.05-1.5*	3
Calcium	Ca^{2+}	410	0.2-4	13
Potassium	K^+	390	0.1-0.6	1
Bicarbonate	HCO_3^-	140	0	52

Concentrated by further inputs and by evaporation, so an increase of solutes and suspended matter downstream along the river. Low $\rightarrow$ high nutrients (typical values shown)

Water movement
River current is the major feature, pelagic communities poorly developed (only fish), the benthos is dominant in most rivers

Epibenthos have hooks, claws or suckers, or behaviour to find sheltered sites. *Simulium* (blackfly) larvae secrete silk pad on rock, attach with 8000 hooks on abdominal prolegs

Spores of aquatic hyphomycete fungi are 10-40 $\times$ larger than terrestrial species, with tetraradiate shape to avoid being washed away

However, many benthic animals do drift in the water column by accident, to avoid predators or pollution, or to find food

■ Catastrophic drift after pollution, to avoid conditions or passively immobilised. Shows greatly increased drift following experimental acidification, above baseline value of about 1 m^{-3}

Drift is dangerous as weak swimmers, no control over current, and exposed to predation by fish. Normal drift is higher at night, when less visual predation, suggests active process. Most animals drift for 1-10 m, settle again quickly

Rivers without visual predators (Madeira, Andes) have aperiodic drift, → nocturnal peak where fish introduced. Drift aperiodic at high altitude in Nepal, nocturnal at low altitude where fish present

Why are upstream areas not depleted? Colonisation cycle hypothesis - adults move upstream, but little evidence for this. Not yet explained, alternatives are upstream movement of larvae, and source populations in sheltered refuges

■ Streams have riffle - pool structure, alternating regions of high flow (rapids, large particle substrate) & low flow (shallow slope, finer sediments), each with characteristic biota

Zonation of benthic fauna along the stream with flow and nutrient characteristics, e.g. net-spinning caddis flies Hydropsychidae in Rhone

■ *Hydropsyche siltalai* frequents rapidly flowing, turbulent conditions, replaced by *H. pellucidula* as flow reduced, coexist in riffles & pools

H. contubernalis is more tolerant of low oxygen & moderately high OM, in mid reaches. Only *H. modesta* tolerates the lower Rhone

In general, species diversity decreases as solutes increase, especially if water becomes dirty from OM - may be abrupt change from a point source

Benthic macroinvertebrates show large differences in tolerance of OM, can predict water quality from species assemblage

■ Few, most resistant species where high OM, especially oligochaete worms (e.g. *Tubifex*) and chironomid larvae, but often in very high numbers

Then molluscs, leeches, mayflies & *Asellus* crustacean. Only cleanest water supports stoneflies, need high O_2 as no gills

■ Biotic index of water quality, allocates each taxon (usually family) a score, proportional to its sensitivity to pollution (most sensitive = highest score). Note low scores for chironomidae & oligochaeta

Sum of scores is the index, higher for cleaner water. We will use the Biological Monitoring Working Party (BWMP) index in Practical 1

Energy inputs

Primary production

Phytoplankton usually low as continually lost downstream, also little light in turbid large rivers. Light may penetrate only to 1 m but water mixed to 10 m, so plankton spend most time in dark

Phytoplankton is not limited by nutrients. Often a bloom where a river enters a lake, shows that its water had sufficient nutrients, exploited in still clear water

Attached primary producers limited by low light in higher order streams, from turbidity and sediments. Flowering plants may also be damaged by high flow, macroalgae more resistant

Moss may be important, especially at low light levels in shaded streams, also tolerates low nutrients & low temperature

Chalk streams have most macrophytes - shallow clear water, high nutrient levels & stable flow. Stream water crowfoot dominates, 0.2 kg m^{-2} yr^{-1} biomass production

■ Attached algae. Algae are the most important primary producers in most streams & rivers, including filamentous green algae, & unicellular green algae & diatoms

Single cells are unaffected by current in boundary layer next to substrate, but size limits total biomass. Forms slimy biofilm on upper surface of river stones (makes stream bed slippery)

■ Biofilm (also periphyton) is a complex environment, mucilage (carbohydrate polymers) secreted by diatoms & bacteria, with cyanobacteria, fungi, and POM & attached green algae on surface

Supports scraper-grazer invertebrates, mouthparts scrape off the biofilm. Mayfly larvae use the upper layer of loosely attached algae, caddis larvae scrape close to the substrate (with stone cases, ballast against high flow)

■ Secondary production

Detritus is often the most important energy source, especially in shaded streams, imported as dead leaves from surroundings. Detritivores are most important consumers in rivers - even in chalk streams

Macrophytes usually consumed as detritus after death, not as live tissues. "Herbivores" may be eating biofilm & detritus particles on macrophytes

CPOM input often seasonal with leaf fall. River Garonne receives 3.3 kg m^{-1} yr^{-1} along bank, mostly from overhanging trees. 2/3 of this is leaf litter, > half of which occurs in 2 months

0.7 kg m $^{-1}$ yr $^{-1}$ branches and twigs, year-round input. Main effect of woody detritus is to trap leaves so they can be used by detritivores

Detritus is low quality food, low N (protein) & high cellulose and lignin which animals cannot digest. C:N ratio of 200-1300:1 in woody CPOM, compared to 6-10:1 in algae, high quality food

But CPOM is colonised by microorganisms, bacteria & especially hyphomycete fungi. Filamentous mycelia can make up >10% of detritus mass. Rate of breakdown $\propto$ fungal activity and $\propto$ 1/ initial lignin content

Decomposition of alder & ash fast, oak & beech slow. Weakens detritus structure, increases fragmentation & leaching. Also improves nutritional quality & palatability for detritivores, known as conditioning

Detritivores select conditioned detritus, & most nutritious type. Alder (C:N = 15:1) leaves 95% consumed by following spring, compared to beech (50:1) leaves only 39% consumed

■ **Time course** of conditioning a deciduous leaf in temperate area:

1. Leaching soluble components to DOM, 5-25% mass lost in few days
2. Microbial colonisation & softening, 5% mass lost in 10-20 days
3. Detritivore consumption, 20-35% mass lost in 20-100 days
4. Further attrition, consumption & decay to FPOM, 15-25% mass loss in 100-250 days
5. Final ingestion or decay, 30% mass lost after >250 days

Detritus food web. CPOM input to stream, converted to FPOM and DOM by shredders, microbial decomposers and physical attrition & leaching

■ Shredders important where CPOM abundant. Larvae of stoneflies, Tipulid flies & caddis larvae with organic cases (CPOM where flow low)

Mouthparts tear & shred leaves, $\rightarrow$ FPOM as debris & faeces. Crayfish lose 1/3 of ingestion as FPOM. Shredders need well-oxygenated water (also necessary for fungal conditioning)

Danish stream had 0.72 kg m $^{-2}$ yr $^{-1}$ CPOM input, 71% leaves, seasonal input. (Compare 0.2 kg m $^{-2}$ yr $^{-1}$ for macrophytes in chalk stream). Output 0.53 kg m $^{-2}$ yr $^{-1}$, of which 92% was FPOM downstream, less seasonal

Much processing of CPOM was by shredders - insecticide treatment reduced litter processing by half, and export of FPOM by 2/3

■ FPOM is main food source of collectors, of two types:

Filterers. Use nets or body parts. Nets of Hydropsychid caddis larvae, with fixed cases

■ Blackfly (Simuliid) larvae use mouthparts with fine hairs, & mucus

■ Gatherers. Collect FPOM from the sediment, under rocks & in other deposition zones, e.g. *Baetis* mayflies, generalised mouthparts

Also predators, including stoneflies, & caddis larvae without cases (agile)

The largest carbon pool in rivers is DOM. Used directly by bacteria, up to 25 million cells ml^{-1} in river water

Also many bacteria in biofilm. Productivity 0.07 kg m^{-2} yr^{-1} in chalk streams (1/3 of macrophytes), proportionally more important in less productive streams

Nutrient cycling
Rivers are a longitudinal system, materials & organisms exported downstream. Nutrient use differs from other systems, which have a cycle between OM & inorganic nutrients available to plants

Rivers have a nutrient spiral, where nutrients taken up by plants, & restored as inorganic nutrients further downstream. So nutrients lost downstream, replaced from upstream

Calculate spiralling distance, the transport in water or in organisms between successive releases as inorganic nutrient. 190 m for phosphorus in a Tennessee stream

■ **River continuum concept (RCC)**
based on longitudinal links along the river. How the balance of factors changes along a river

Headwaters in shaded forest (orders 1-3), narrow rocky or sandy bottom. Too little light for algae, too few nutrients for macrophytes, so mosses dominate

■ Most energy input as allochthonous CPOM. Respiration > photosynthesis, so streams are heterotrophic (analogous to use for organisms). Shredders 35% of fauna, collectors 45%, scraper-grazers 5%, predators 15%

Collectors get FPOM from shredders & physical attrition. Predators make up similar proportion all down the river, but the taxa change. Headwaters export much FPOM to mid reaches

■ **Middle reaches** (orders 4-7) are wider, bottom well-lit as banks further apart, temperatures higher, nutrient levels increased, all leading to many algae (filamentous & diatoms) and macrophytes (rooted in sediments)

■ CPOM decreases, less canopy & greater area of water. CPOM input only in 6^{th} order streams in Canada was only 4% of that in 1^{st} order streams

Photosynthesis > respiration, so autotrophic stream. Scraper-grazers increased to 30% as many plants

Collectors 50% as high FPOM from upstream, but shredders decreased to only 5% as little CPOM. Predators still 15%. FPOM & detritus from primary production are exported downstream

Lower reaches (orders 8+) are deep. Usually faster flow than streams, as less friction from sides. Increased turbidity prevents algal & macrophyte growth, except at shallow edges. Phytoplankton also limited by low light

Not lake-like, as flow mixes water, no anoxic zone, low primary productivity, unstable sediment, low benthic populations. Most energy input as FPOM from upstream

Respiration > photosynthesis again, heterotrophic. Collectors 85%, dominate as much FPOM. Molluscs, oligochaetes or dipteran larvae with burrows or tubes in sediment, filter or gather FPOM

Shredders & scraper-grazers absent as little CPOM or plants, except for snails feeding on biofilm on marginal plants. Predators still 15%

The RCC works in many areas, some variation. Low order streams in deserts don't have CPOM input or shading, main energy input is primary production, so similar to middle reach streams elsewhere

Does not work for large rivers that flood regularly. Lateral exchange of materials with the flood plain, more important than longitudinal transfer. Flood-pulse concept (Lecture 5)