Macroinvertebrates and water quality: a teaching guide

CBER Contract Report Number 18

Prepared for the Biotin teachers' evening

by

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30 August 2002

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1. Introduction to stream ecology

Streams support a diverse community of plants and animals on or in the stream bed. These organisms comprise the benthos. Among the benthos are worms, molluscs, crustaceans, and larval insects. Insect larvae are usually the most numerous animals of the benthos. Collectively the animals of the benthos are known as benthic macroinvertebrates because of where they live, and their large size (often 10-35 mm).

The dominant animals in the macroinvertebrate community of a stream depends on several physical factors of the stream. Chief among these are:

1. Stream gradient
2. Stream width
3. Streamside (or riparian) vegetation.

Stream gradient is important because it controls

1. Substrate size
2. Water velocity.

Stream width is important because it controls the influence of shading (narrow streams are more easily shaded than wide streams)

Riparian vegetation is important because it controls

1. The degree of channel shading (trees provide more shade than shrubs, and pasture grass provides no shading).
2. Energy inputs (leaf litter from overhanging trees in forest streams, light energy in unshaded streams)
3. Water temperature

Considering these factors together, shaded, high-gradient streams provide cool, well oxygenated water with stable, cobble substrates. These streams normally occur in the headwaters of streams, and support the most diverse macroinvertebrate communities, and the ones by which all other parts of a stream are judged (sometimes unfairly!). As a stream flows from upstream to downstream, other tributaries join as the catchment area increases, stream width and stream order increase, and stream gradient decreases. This has been summarised as the river continuum concept (Fig. 1).

Finally, macroinvertebrates can be grouped by their foods, otherwise known as their functional feeding category (e.g., scrapers, shredders, collectors, and predators). Most of the aquatic insect larvae become winged adults, which allows dispersal to other streams and recolonisation after floods.

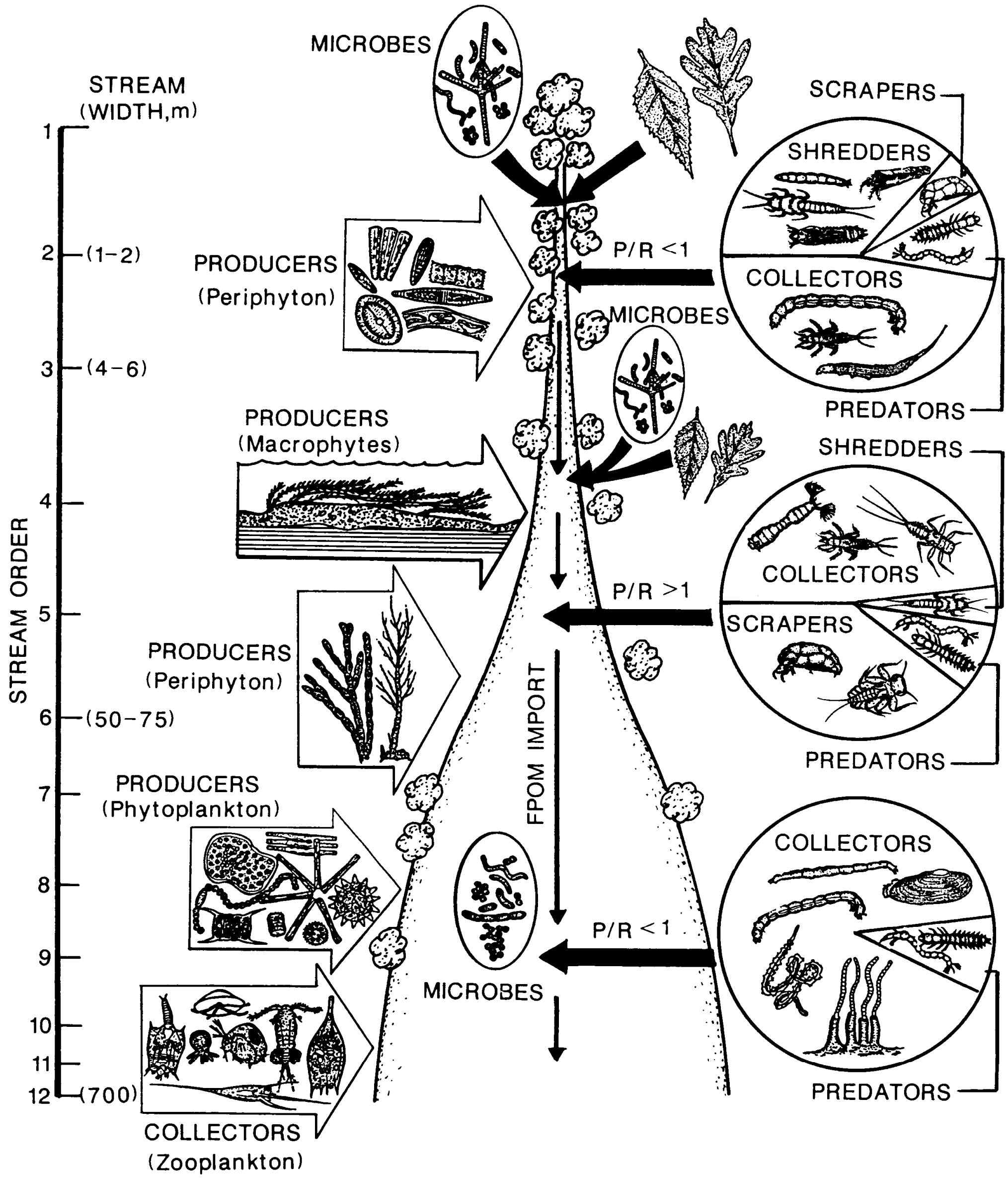

Fig. 1. Changes in the importance of energy sources with increasing stream width and stream order (from Murphy & Meehan 1991, after Vannote et al. 1980). P = photosynthesis, R = respiration, and FPOM = fine particulate organic matter.

2. Macroinvertebrate community health

Monitoring stream health can be done by measuring water quality (e.g., water temperature, dissolved oxygen concentration, pH, and conductivity). However, many measurements and complex equipment would be needed (or continuous monitoring in the extreme). This is time consuming, expensive, and generally not possible.

The composition of the macroinvertebrate community integrates the water quality over a year, as most macroinvertebrates have annual life cycles, and must survive all year in a stream. Therefore an index that combines the occurrence of all the macroinvertebrates into a single number would be very useful.

The macroinvertebrate community index, or MCI, is routinely used to assess the health of streams in New Zealand. It is used to compare sites

1. on different streams
2. before and after disturbance, e.g., a flood
3. upstream and downstream of a discharge
4. in different seasons.

There are other measures of community health, e.g., density of macroinvertebrates (number of individuals m^{-2}), taxonomic richness (number of species or taxa), and various indices of diversity. These measures or indices are mostly closely related to the number of species.

The MCI was developed in New Zealand for macroinvertebrates in stony riffles by Stark (1993). This is especially useful because unlike many indices developed overseas it ranks New Zealand taxa according to their pollution intolerance. I use the word taxa here because not all invertebrates are classified to the same level. About 135 taxa (usually genera, sometimes Phylum (Mollusca) or Class (Oligochaeta) are used. A more recent listing of the MCI scores is given in Collier and Winterbourn (2000).

The MCI score is used widely by biological consultants in New Zealand, as evidence in resource consent hearings, and in the Environment Court where water quality is an issue. Individual taxa are given a score between 1 (pollution tolerant) and 10 (pollution intolerant), based on their occurrence in stony riffles at sites classified as unpolluted, moderately polluted, or grossly polluted.

3. Calculation of MCI

Procedure:

1. Collect a kick or Surber sample of benthic macroinvertebrates from a stony riffle.
2. Either preserve the invertebrates in 70% ethanol or isopropyl alcohol, or store the sample overnight with the top off the container in a fridge at 4^{o}C.
3. Place the contents of a kick or Surber sample in a white tray, and sort the macroinvertebrates from the leaves, gravel, and sticks (be careful not to discard the animals that may cling to the detritus).
4. Identify all taxa.
5. Record only the presence of a taxon (number of individuals is not important - it doesn't matter to the index whether there are hundreds or only one).
6. Calculate the MCI according to the formula

$$\text{MCI} = \frac{\text{Sum of scores for taxa}}{\text{N of scoring taxa}} \times 20$$

The resulting index ranges from 10 (all taxa have a score of 1) to 200 (all taxa have a score of 10). The MCI is a very useful indicator of nutrient enrichment. A depressed MCI will show if stream is subject to high nutrient levels even when the nutrients themselves are not present.

Examples:
The MCI of a forest stream site with *Coloburiscus* (9), *Helicopsyche* (10), *Ichthybotus* (8), and *Stenoperla* (10) would be

$$MCI = \frac{9+10+8+10}{4} \text{x} 20 = 185 .$$

The MCI of a pasture stream site with *Potamopyrgus* (4), *Oxyethira* (2), Amphipoda (5), *Austrosimulium* (3), and Oligochaeta (1) would be

$$MCI = \frac{4+2+5+3+1}{5} \text{x} 20 = 60 .$$

In samples taken from stony riffles, the MCI can be compared to previously determined ranges (Boothroyd and Stark 2000):

> 120	indicates clean water
100-119	indicates moderate enrichment
80-99	indicates probable moderate pollution
<80	indicates probable severe pollution.

4. SHMAK level-1 invertebrate score
A simplified form of the MCI uses the stream health and monitoring kit (SHMAK) system (Biggs et al. 1998). The kit is available from NIWA at a cost of $395 plus GST (see http://www.niwa.co.nz/pubs/no8/shmak/). Less detail is required in identification of the stream invertebrates than for the MCI, but the score is calculated in the similar manner, but without the x20 multiplier. The following table from Boothroyd and Stark (2000) gives the individual taxon scores that are used in the SHAMK level 1 invertebrate score. SHMAK scores for a site can range from 1 to 10.

$$\text{SHMAK score} = \frac{\text{Sum of scores for taxa}}{\text{N of scoring taxa}}$$

A much cheaper stream monitoring kit is available through the Royal Society of New Zealand as part of its National Waterways Project (http://nwp.rsnz.org/). This well-organised programme markets a kit for under $40 from Connovation Research Ltd, PO Box 58 613, Greenmount, Auckland.

5. Identification of macroinvertebrates
Because species of macroinvertebrates are so diverse, identification can be problematic. There are, however, some simple approaches. There are four broad groups of insects:
1. stoneflies (two tail filaments)
2. mayflies (three tail filaments)
3. caddisflies (either in an open-ended case or resembling a small caterpillar
4. dipterans (maggot-like larvae).

In addition, there are oligochaetes, molluscs, flatworms, and insect groups with only a few representatives (dobsonflies, damselflies and dragonflies, and beetles). Page 8 gives a simple key to some common forms, and pages 9-10 give an illustrated guide that also gives the individual MCI and

SHMAK scores for each taxon. Appendix 1 gives a guide to the equipment requirements to teach this exercise.

Table 14.5 from Boothroyd and Stark (2000). Individual taxon scores for use in calculation of the stream health monitoring (SHMAK) invertebrate score.

Types of invertebrates	Scientific name	Taxon score
Worms	Mainly *Tubifex*	1
Ostracods	Ostracoda	1
Midge larvae	Chironomidae	2
Flatworms, leeches	Platyhelminthes, Hirudinea	3
Snails, rounded	*Physa* and others	3
Small bivalves	*Pisidium* etc.	3
Axehead caddis larvae	*Oxyethira albiceps*	3
Snails, pointed end	*Potamopyrgus*	4
Amphipods and water fleas	Amphipoda and Cladocera	5
Cranefly larvae	e.g., *Aphrophila*	5
Beetle larvae and adults	e.g., Elmidae	6
Caddisfly larvae (several types)	e.g., *Pycnocentrodes, Aoteapsyche, Hydrobiosis*	6
Limpet-like molluscs	*Latia* sp.	7
Smooth-cased caddisflies	*Olinga feredayi*	9
Mayflies	Ephemeroptera (e.g., *Deleatidium*)	9
Spiral-cased caddisfly	*Helicopsyche* sp.	10
Stoneflies	Plecoptera (e.g., *Stenoperla, Megaleptoperla*)	10

Acknowledgements
The keys and macroinvertebrate diagrams came from Dr Russell Death's notes, The Ecology Group, Institute of Natural Resources, Massey University.

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Questions for discussion in class

1. Would you expect the MCI or SHMAK score of a stream to vary from upstream to downstream, and if so, would the scores vary in a predictable way?

2. What are the macroinvertebrates that are characteristic of the cool, shaded, headwaters?

3. What are the macroinvertebrates that are characteristic of the warmer, open reaches downstream?

4. If you had two sites with equal catchment area, but one was in native forest and the other was in pasture, which do you think would have the highest MCI of SHMAK score and why?

5. If you compared a winter sample with a summer sample from the same site, which would you expect to have the highest MCI or SHMAK score?

Related class exercises

1. Relation of dissolved oxygen concentration to water temperature is a key determinant of macroinvertebrate distribution in streams. The saturation concentration of dissolved oxygen (DO, measured in g m^{-3}) is described by the equation DO = $14.4-0.338T+0.00354T^2$, where, and T = temperature in degrees Celcius. This relationship is valid between 1 and 39^{o}C (Hoare and Rowe 1992, p209). Measure some water temperatures and calculate the saturation DO for the temperature. If you have an oxygen meter, measure the absolute DO in g $m^{-3}$and calculate the percent DO.

2. Frequency distributions of substrate size are related to stream gradient. Measure and plot 100 randomly selected substrate particles from different sites, and compare the frequency distributions.

Key to common macroinvertebrates

1	With a portable case or shell	2
	Without a case or shell	7
2	Case or shell spiral (tightly coiled)	3
	Case straight or slightly curved	4
3	Case of very small sand grains	*Helicopsyche*
	Shell without sand grains (water snails)	*Potamopyrgus*
4	Case flattened, transparent	*Oxyethira*
	Case not flattened	5
5	Case a hollow twig or made of leaf fragments stuck together	*Triplectides*
	Case tubular, without plant material	6
6	Case with sand grains	*Pycnocentrodes*
	Case without sand grains	*Olinga*
7	With jointed legs	8
	Without jointed legs	18
8	More than 3 pairs of legs	Crustacea (Amphipoda)
	3 pairs of legs (watch for lateral gills on some insects)	9
9	With 3, multi-segmented caudal filaments ('tails')	10
	With 2, multi-segmented caudal filaments	14
	Without multi-segmented caudal filaments	16
10	Tails less than half as long as body and fringed with hairs	11
	Tails about as long as body, without fringes	12
11	Gills feathery, large projecting jaws	*Ichthybotus*
	Gills leaf-like, fast swimmers	*Nesameletus*
12	Gills forked, spiny and held up over abdomen, middle tail shorter than outer tails	*Coloburiscus*
	Gills leaf-like or simple filaments	13
13	Gills single (one on each side of each abdominal segment)	*Deleatidium*
	Gills double	*Zephlebia*
14	Lateral filamentous gills on abdomen, body green	*Stenoperla*
	Rosette of gills between tails	15
	3 filamentous gills between tails	*Austroperla*
15	Legs with long hair fringes, antennae and tails very long	*Zelandoperla*
	Legs without fringes, antennae and tails short	*Zelandobius*
16	Paired finger-like gills on abdomen (looks like a centipede)	*Archichauliodes*
	Tufts of gills on abdomen	*Aoteapsyche*
	No gills, or only on last segment	17
17	All body segments with heavy cuticle, rosette of gills in a small chamber at posterior end	Hydora
	Head and at least 1st thoracic segment with heavier cuticle than abdomen	Hydrobiosis
18	Body flattened, moves with smooth gliding	Planaria
	Body rounded in cross section	19
19	Multi-segmented, all segments similar	Oligochaeta
	Less than 15 body segments, some differentiation of segments	20
20	Posterior abdomen swollen, fans of setae on head	*Austrosimulium*
	Not as above	21
21	Transverse raised bars on abdomen, no prolegs	*Aphrophila*
	Single or paired prolegs on first and/or last body segments	Chironomidae

Questions for discussion in class with model answers

1. Would you expect the MCI or SHMAK score of a stream to vary from upstream to downstream, and if so, would the scores vary in a predictable way?

(Yes - MCI should be less in the lower gradient reaches downstream than in the cool, shaded headwaters. The stream in the lower reaches will be warmer, wider, and less shaded, and the substrate is more likely to be fine gravels and silt compared to cobble substrates of upstream reaches)

2. What are the macroinvertebrates that are characteristic of the cool, shaded, headwaters?

(Stoneflies and mayflies)

3. What are the macroinvertebrates that are characteristic of the warmer, open reaches downstream?

(Molluscs, chironomids, and oligochaetes)

4. If you had two sites with equal catchment area, but one was in native forest and the other was in pasture, which do you think would have the highest MCI of SHMAK score and why?

(The native forest site would have the highest score, because the stoneflies and mayflies that have the highest individual scores will be found at the forested site, but are less likely to occur at the pasture site).

5. If you compared a winter sample with a summer sample from the same site, which would you expect to have the highest MCI or SHMAK score?

(The winter sample, because if the site was marginal for stoneflies, they might well occur in winter when water temperatures were low, but not in summer as the temperatures increased beyond their tolerance).

Related class exercises

1. Relation of dissolved oxygen concentration to water temperature is a key determinant of macroinvertebrate distribution in streams. The saturation concentration of dissolved oxygen (DO, measured in g m^{-3}) is described by the equation $DO = 14.4 - 0.338T + 0.00354T^2$, where, and T = temperature in degrees Celcius. This relationship is valid between 1 and 39^{o}C (Hoare and Rowe 1992, p209). Measure some water temperatures and calculate the saturation DO for the temperature. If you have an oxygen meter, measure the absolute DO in g $m^{-3}$and calculate the percent DO.

2. Frequency distributions of substrate size are related to stream gradient. Measure and plot 100 randomly selected substrate particles from different sites, and compare the frequency distributions.

Appendix 1. Equipment for sample collection and the laboratory for a class of 24

Surber sampler
Kick net
Sieve on stick
12 White trays
Winterbourn and Gregson books
Winterbourn, Gregson, and Dolphin books
Mollusc key
Fresh water Algae of NZ keys
Video feed from dissecting scope
Cold light source
4 fine meshed sieves for washing invertebrates
20 waterproof labels about 5cm by 10 cm
4 wash bottle filled with tap water
10 pencils
Calculator
20 petri dishes or similar for sorting invertebrates
Paper towels
Fine metal forceps
Lab alcohol for preservation of sorted samples
Large sieve in sink for disposal of samples
Container for dirty glassware
Dissecting microscope with video camera hook up
500 ml screw cap containers for preserving sorted samples