Introduction to macroinvertebrate monitoring in freshwater ecosystems

Version 1.0

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Inventory and monitoring toolbox: freshwater ecology

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Department of Conservation
Te Papa Atawhai

Introduction

Sampling macroinvertebrates in wadeable streams

Why monitor?

The realisation of the vulnerability of stream systems to greater demands upon their resources and need for effective techniques to monitor the quality of running water have increased rapidly over recent years. Monitoring may be performed to gauge long-term trends in general water quality or assess the effects of specific localised impacts or restoration attempts. Historically, water quality has been assessed using chemical analyses of the water, but this approach has been criticised because results only describe conditions in a stream at the moment of sampling. However, biological monitoring is now widely recognised as providing a time-integrated appraisal of water quality (Boothroyd & Stark 2000). Although any biological community within a stream may be used to assess water quality, the most commonly used group are the macroinvertebrates.

Macroinvertebrate monitoring

Macroinvertebrates are operationally defined as those invertebrate animals which will not pass through a 0.5 mm sieve (Winterbourn 2000). The New Zealand macroinvertebrate fauna is characterised by a high proportion of endemic taxa (those only found in New Zealand). The most well-known and diverse of the stream taxa are the insects which include the mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera), collectively known as the EPT taxa, but also the Dipterans or true flies. Taxa which pass through a 0.5 mm sieve, but are retained by a 0.04 mm sieve, are collectively known as meiofauna. Whilst being an important part of stream communities, meiofauna require sampling techniques and processing methodologies beyond the scope of these protocols. A comprehensive description of the New Zealand stream fauna and publications describing each group can be found in Winterbourn (2000).

Advantages of using macroinvertebrates for stream monitoring:

- Macroinvertebrate assemblages are good indicators of localised conditions. Because many benthic macroinvertebrates have limited migration patterns or a sessile mode of life, they are particularly well-suited for assessing site-specific environmental conditions (upstream–downstream studies).
- Macroinvertebrates integrate the effects of short-term environmental variations. Most species have a complex life cycle of approximately 1 year or more. Sensitive life stages will respond quickly to changing environmental stressors (both degrading and rehabilitating); the overall community will respond more slowly.
- Degraded conditions can often be detected by an experienced biologist with only a cursory examination of the benthic macroinvertebrate assemblage. Macroinvertebrates are relatively easy to identify to family; many ‘intolerant’ taxa can be identified to lower taxonomic levels with ease.

- Benthic macroinvertebrate assemblages are made up of species that constitute a broad range of trophic levels and pollution tolerances, thus providing strong information for interpreting cumulative effects.
- Sampling is relatively easy, requires few people and inexpensive gear, and has minimal detrimental effect on the resident biota.
- Benthic macroinvertebrates serve as a primary food source for higher trophic levels such as fish and river birds, including many which are at risk of extinction (wrybill, black-fronted terns, non-diadromous galaxiids).
- Benthic macroinvertebrates are abundant in most streams. Many small streams (1st and 2nd order), which naturally support a diverse macroinvertebrate fauna, only support a limited fish fauna.

The history of biological monitoring using macroinvertebrates in New Zealand began in the 1950s. The practice is now enshrined within State of the Environment (SOE) monitoring, Assessment of Environmental Affects (AEE) and compliance monitoring. Commensurately, there are also numerous statistical methods and mathematical measures of community response developed for analysing macroinvertebrate data (Boothroyd & Stark 2000).

Stream zones

The majority of sampling for macroinvertebrates will be done in the benthic zone of wadeable streams. The benthic zone of a stream constitutes the immediate stream bed and top, approximately 10 cm of substrate. It is in this zone, particularly in streams without substantial aquatic weed growths or woody debris, that the majority of stream macroinvertebrates live. There are other zones in streams and rivers such as the pelagic, or open water zone, and hyporheic, or saturated interstice zone which require specialised sampling techniques beyond the scope of these protocols. It is also unusual to sample the benthos of large rivers, although methods are available. Techniques range from sampling accessible river margins to the sampling of deep water using boat-based grab samplers or artificial substrates.

Stream types

Wadeable streams may be separated into those with a hard or soft bottom (Stark et al. 2001). Hard-bottomed streams are defined as those whose substrate is dominated by particles of gravel size or over (i.e. < 50% sand/silt). Riffle habitats are usually common in these streams reflecting a steeper stream gradient. Soft-bottomed streams tend to have a lower gradient and may be dominated by run and pool habitats with either macrophyte growths in unshaded reaches or woody debris in forested sections providing macroinvertebrate habitat. Soft-bottomed streams require a different set of protocols which reflect the very different physical characteristics and biotic communities within them.

Stream characterisation

Stream ecologists tend to characterise streams and rivers by the relative amount of run, riffle or pool that occur at the sampling sites. This is an important consideration when comparing biotic communities between two or more sites. In hard-bottomed streams riffle habitats are often common, easily recognisable and biologically productive habitats that can be sampled safely even in larger rivers. However, in soft-bottomed streams riffle habitats may be rare or absent. A riffle is defined as an area of fast 'whitewater', usually associated with a constriction in the channel and where stony or wood substrate may occur above the surface. Conversely, a pool is an area of slow flowing or standing water, not including the 'whitewater', usually at the base of a riffle. This is the deepest habitat in a river. Intermediate between pools and riffles are runs. These areas are characterised by laminar flow with a mostly unbroken surface.

Sampling design and methodology

Holistic planning

Before setting out to sample any stream communities it is important to have a good idea of the question you wish to answer and the specific information you need to answer it. This may seem like an obvious statement, but if sampling techniques and designs are not appropriate your results and conclusions will not be valid and a lot of time and money is wasted. Consideration should also be given during the design stage to methods of analysis. There are specific criteria for the numbers of replicate samples within a particular analysis/design which render the results meaningful or otherwise. Statistically the greater the number of replicate samples taken the better; however, logistical and resource constraints often dictate a lesser number of samples. It is a good idea to consult an experienced biometrician or freshwater ecologist with regards to your study design prior to the start of any field work.

What do you want to know?

Sampling of macroinvertebrates can be performed to provide a gradient of different information about stream communities. At one end of this scale is an assessment of biodiversity, or inventory, which seeks to identify all the taxa present at a location. At the opposite end of this spectrum is an assessment of community composition which focuses on the number of individuals of each species/group. However, the specific purposes of any sampling often fall somewhere between inventory and community composition and the methods and design used are often a meld of those available.

The specific objectives of the study design must be clearly stated and understood from the outset. Subsequently, the design of the sampling strategy must consider the number and location of sampling sites, sampling frequency, sampling methods, sample replication, sample processing and the need for either qualitative, semi-quantitative or fully quantitative abundance data.

Sampling location

Sample site location is strongly dictated by the opposing forces of data requirements and available budget. To assess the ecological integrity of or any change in a stream ecosystem, basic requirements are for an impacted/monitoring site and at the very least a single reference or control site with which to compare. Sample replication should occur within the site when quantitative data is required, so in either an upstream versus downstream (or control versus impact) design, or separate treatment and control streams, with at least one (preferably more) sites per treatment category selected, multiple samples are taken from each. This permits an estimation of the variance between samples within a site. In the upstream–downstream example, a second (or third) upstream site may be added to estimate variation between the control sites, whilst further downstream sites may be added to measure the extent of the impact. In order to assess differences in water quality it is essential that all sites are as physically similar as possible, i.e. substrate types, riparian vegetation, flow and stream dimensions, so that confounding effects on macroinvertebrate communities are minimised or eliminated. A final reference site is often selected on an adjacent, or nearby un-impacted stream, and used to assess the condition of the entire study stream relative to regional stream conditions and communities.

Sampling frequency may also be a consideration depending upon the study objectives. New Zealand stream faunas show less seasonal variation than comparable systems in the northern hemisphere (Winterbourn et al. 1981; Towns 1985) and the temporal absence of taxa is more likely to be a result of environmental disturbance than life-history patterns. Towns (1985) suggests that one summer and one winter sampling is adequate to assess species richness.

When to sample

One of the primary determinants of invertebrate richness and biomass is antecedent flow. Floods, in particular those which mobilise bed material, cause large mortality and displacement of invertebrates and several weeks of stable flows may be required for communities to regain characteristics observed prior to the flood. In a survey of 11 regional councils, the National Institute of Water and Atmospheric Research (NIWA), and a private consultancy, a range of antecedent flow sampling thresholds were described (Stark et al. 2001).

Rivers all vary in their hydrological regime and a basic knowledge of the ‘flashiness’ of a particular system provides a lot of information about a pragmatic ‘stand-down’ period following a flood event. In flashy rivers such as the Waiau in Canterbury or Pātea River in Taranaki (flow events three times greater than the median flow (FRE3) 15.6 and 31.3 respectively), floods are commonplace and communities are adapted to that flow regime There would be little point in waiting 4 weeks since the last fresh as the next fresh is likely to come along before the stand-down period has elapsed. Option 3 (above) would be most appropriate in this situation. Conversely, in a very stable river, such as the lake-fed Clutha River (FRE3 0.6), flood disturbance is less common and any unusual flows will have a significant effect. Consequently, option 4 might be more appropriate as it focuses on the most influential events. Many regions may also have specific recommendations on a stand-down

period written into regional plans or consent conditions. At the very least it is essential to note the preceding flow conditions if possible and state any stand-down period observed.

Sampling method

There exists a great variety of methods for sampling freshwater invertebrates (Winterbourne 1985), but the most commonly used are the kick-net and Surber sampler (or some variant thereof). The Surber sampler provides a quantitative estimate of the number of individuals of each taxa within a known area of stream bed, but less information about the total number of taxa present in the wider stream. The kick-net provides a qualitative list of the taxa present, but limited information about the relative abundance of those taxa. However, Surber samples may be used to estimate the richness of taxa by deploying an appropriate number of replicates and kick-netting may be standardised to provide semi-quantitative community composition data.

Sample replication

Sample size and sample replication are dictated by the desired sensitivity and outcomes of a monitoring program. Reliable estimates of macroinvertebrate community parameters can usually be achieved by sampling less than 1 m^2 of stream bed. The degree of replication may also vary depending on context; however, common practice requires that kick-nets (0.5 mm mesh) over 0.5 m^2 of stream bed or between 3 and 6 Surbers (area 0.1 m^2, 0.5 mm mesh) are collected (Boothroyd & Stark 2000).

Sample processing

Sample processing for macroinvertebrates is also dependent on the objectives of the study and available resources. Three methods are in common usage in New Zealand:

- Coded abundance
- Fixed count (with scan for rare taxa)
- Full counts (with the option of sub-sampling abundant taxa)

These methods each permit the assembly of a species list and the calculation of many biotic indices available to characterise macroinvertebrate communities. An evaluation of benthic macroinvertebrate community metrics for use in assessing effects of known human stressor gradients is provided by Schallenberg et al. (2011). The primary difference between the sample processing methods is the way in which the abundance of taxa is recorded and increasing effort and cost involved. Coded abundance produces a rapid approximation of actual abundance by assigning taxa to one of five abundance codes (rare, common, abundant, very abundant, very very abundant). The method is commonly used with samples collected by kick-net and results are consequently dependent on sampling effort as abundance increases with area sampled. Fixed count methods involve the identification and counting of a pre-defined number of animals in a sample (100–500) and is used to process both standardised kick-net and Surber samples. A scan for rare taxa completes the species list. Full count methods provide the most accurate estimates of

the abundance of individuals in a stream. This method is only used in conjunction with quantitative Surber sampling and generally requires replicate Surbers. All individuals in the sample are enumerated and the results describe the density of individuals/taxa per unit area. Options for the most appropriate counting methodology to use with your chosen sampling regime are given in the 'Decision tree'. Interpretation of the data will vary according to the data itself, your objectives and the metrics/indices you choose to calculate. Use Table 1 in conjunction with the 'Decision tree' to decide which types of data processing and analytical techniques best match your objectives.

Table 1. Guide to the most appropriate types of data and analytical approaches to address the objectives outlined in these protocols. Use this table in conjunction with the 'Decision tree'. As data becomes more intensive and objectives more specific (down the table) new indices and methods are added. The indices on the previous level of the table may still be calculated, but do not fully utilise your data.

Objectives/type of monitoring	Data	metrics/indices/analyses
Inventory	presence/absence	taxa richness
	coded abundance	MCI
		% EPT taxa
		multivariate stats
Ecosystem condition	coded abundance	SQMCI
	fixed count	% EPT abundance
		community composition
Threatened species or restoration monitoring and research	full count	density
		QMCI

Quality control

A final consideration when providing samples for laboratory processing is the level of quality control which is required. The current macroinvertebrate sampling protocols (Stark et al. 2001) recommend a hierarchy of quality control depending on the sample and processing methods. For coded abundance processing, 10% of sorted samples should be re-examined by another sorter. On average the number of taxa identified as different between the two sorters should be < 10%. Missed taxa must not be in the 'Abundant', 'Very abundant' or 'Very very abundant' categories and on average the total number of taxa re-allocated to an abundance category differing by greater than one abundance category must not be > 10% of the total number of taxa allocated an abundance code during the first sort. Quality control for fixed count processing also requires 10% of samples to be re-sorted. This protocol requires examination of the sample residue (Were all rare taxa removed?) and the sorted residue (Were any animals missed during the collection of the 200+ sub-sample?). Differences between the first and second sort must not differ by more than 10%. Finally, full count processing of Surber samples requires 10% of samples to be re-sorted and that

taxonomic and sorting accuracy between the first and second sort do not differ by more than 10%. Options for the appropriate intensity of quality control are given in the decision tree.

Habitat assessment

Habitat assessment alongside biota collection is an integral part of any final assessment. The alteration of the physical structure of the habitat is one of the major factors from human activities that degrade aquatic resources and habitat; instream and surrounding topographical features are a major determinant of aquatic communities. Both the quality and quantity of available habitat affect the structure and composition of macroinvertebrate communities. Effects of such features on biological assessment results can be minimised by sampling similar habitats at all sites being compared. However, when all sites are not physically comparable, habitat characterisation is particularly important for proper interpretation of survey results. Harding et al. (2009) provide a comprehensive guide and protocols for habitat assessment in wadeable New Zealand streams and rivers.[1] A minimum requirement habitat assessment field sheet is provided with these protocols (see 'Stream habitat assessment field sheet'—docdm-761873).

For a more thorough assessment of habitat, the protocols described in Harding et al. (2009) should be applied. The choice of protocol to use in conjunction with your chosen sampling regime is provided in the 'Decision tree' and Table 2. The physical characteristics of a stream are determined by the interaction between a range of factors operating at a multitude of scales. Topography, climate, geology and land use are factors operating at a larger scale to influence the mosaic of habitat types found at lesser scales. Accordingly, factors that define the physical habitat of a stream can be described hierarchically beginning at the catchment scale through bank and floodplain characteristics, riparian zones and finally in-stream conditions. The scale and precision of habitat data collected will be defined by the objectives of the study.

Table 2. Stream monitoring objectives and appropriate habitat assessment protocols. Reproduced from Harding et al. (2009).

Application	**Protocol**
Site selection/scouting	Desktop + H1
State of the Environment (SOE) reporting	Desktop + H1
Assessment of Environmental Effects (AEE)	Desktop + H2
Consent and compliance monitoring	Desktop + H2
Assessment of restoration efforts	Desktop + H2/H3
Fish, macroinvertebrate, algae predictive modelling	Desktop + H3
Ecological research	Desktop + H2/H3

[1] http://www.cawthron.org.nz/coastal-freshwater-resources/downloads/stream-habitat-assessment-protocols.pdf

Decision tree

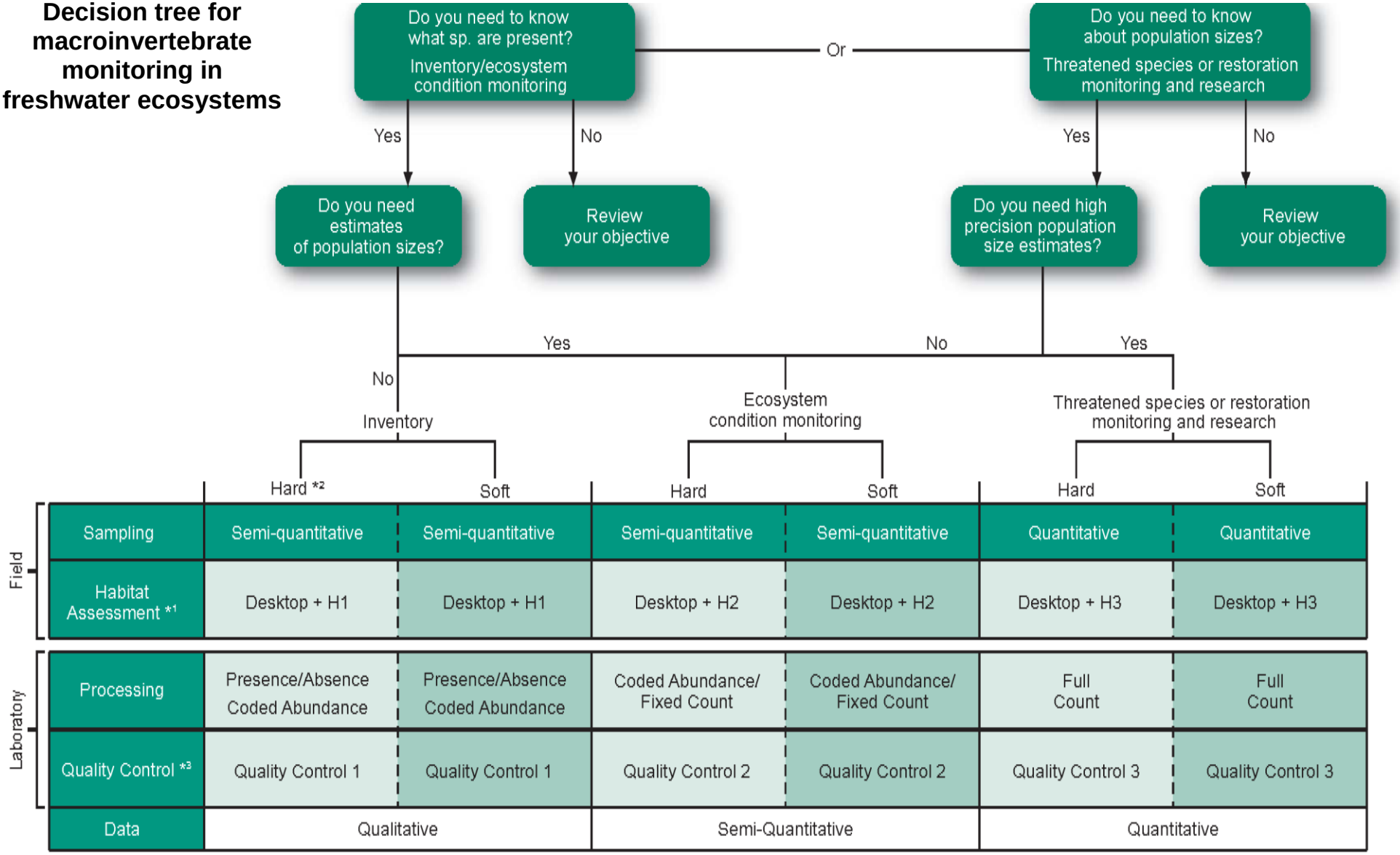
This introduction should enable you to navigate the decision tree and decide upon the appropriate sampling and processing regime for your objectives. It is a good idea to write an investigation plan which outlines the objectives of your study and the protocols you have chosen to address those objectives. If there is any doubt consult a TSO or freshwater ecologist to confirm your choices. Essentially, you must choose between methods for hard- and soft-bottomed streams and techniques that are quantitative or semi-quantitative.

The methods for macroinvertebrate monitoring in freshwater ecosystems are:

- Freshwater ecology: quantitative macroinvertebrate sampling in hard-bottomed streams (docdm-724830)
- Freshwater ecology: semi-quantitative macroinvertebrate sampling in hard-bottomed streams (docdm-722563)
- Freshwater ecology: quantitative macroinvertebrate sampling in soft-bottomed streams (docdm-724884)
- Freshwater ecology: semi-quantitative macroinvertebrate sampling in soft-bottomed streams (docdm-724926)

A final point to remember is that the majority of time and cost is expended in the laboratory. If in doubt it is better to collect more information in the field and not process it, than to have an initial data set that is inadequate to address your objectives.

Decision tree for macroinvertebrate monitoring in freshwater ecosystems



*1 These habitat assessment protocols are recommended by Harding et al. (2009); however, a bare minimum qualitative habitat assessment should always be carried out at all sites (see 'Stream habitat assessment field sheet'—docdm-761873). Note: p1, p2...in Harding et al. (2009) are analogous to h1, h2 used here.

*2 Hard-bottomed streams are defined as those whose substrate is dominated by particles of gravel size or over (i.e. < 50% sand/silt).

*3 These quality control protocols are recommended by Stark et al. (2001) but should be discussed with your sample processing provider. They may have their own systems in place.

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Appendix A

The following Department of Conservation documents are referred to in this method:

docdm-724830	Freshwater ecology: quantitative macroinvertebrate sampling in hard-bottomed streams
docdm-722563	Freshwater ecology: semi-quantitative macroinvertebrate sampling in hard-bottomed streams
docdm-724884	Freshwater ecology: quantitative macroinvertebrate sampling in soft-bottomed streams
docdm-724926	Freshwater ecology: semi-quantitative macroinvertebrate sampling in soft-bottomed streams
docdm-761873	Stream habitat assessment field sheet