Field Methods for Hydrologic and Environmental Studies

Chapter 3

Biological Data Collection

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Ecology and Biological Monitoring

Goals for Class

Look at stream from biologist's point of view

Explore some biological sampling techniques with focus on biological assessment of water quality using fish and benthic macroinvertebrates.

Ecological Units of Organization

Individual

single organism or unit

Population

group of organisms of one species, occupying a defined area and usually isolated to some degree from similar groups

Community

Assemblage of species that co-occur in the same habitat or area and interact through trophic and spatial relationships; typically characterized by reference to one or more dominant species

Properties:

- richness
- diversity (relative composition of species abundance)
- morphological and physiological attributes
- trophic structure

Ecosystem

community of organisms and their physical environment (abiotic such as climate, soil) interacting as an ecological unit

Taxonomy

Science of classification and naming

Phylogeny

Study of evolutionary history of and relationship among taxonomic groups.

Taxonomic Hierarchy Example 1 (caddisfly)

Kingdom:	Animalia	animals
Phylum:	Arthropoda	"jointed legs"
Class:	Insecta	insect
Order:	Trichoptera	caddisfly
Family	Hydropsychidae	net-spinning caddisfly
Genus species	*Hydropsyche morosa*	

Taxonomic Hierarchy Example 2 (Largemouth bass)

Kingdom:	Animalia	animals
Phylum:	Chordata	animals with backbones
Class:	Osteichthyes	bony fishes
Order:	Perciformes	basses, sunfishes, walleye, darters
Family:	Centrarchidae	sunfishes, basses
Genus species:	*Micropterus salmoides*	Largemouth bass

Aquatic Ecosystems

Marine

Brackish
Freshwater

Freshwater Systems

Lentic
standing water (lakes and ponds)

Lotic
flowing water (rivers and streams)

Aquatic Communities

Benthos
collectively all organisms that live on or in the bottom, e.g. worms, insects, diatoms, protists

Plankton
organisms that are suspended in the water column; movement depends on water currents, includes Phytoplankton (plants), Zooplankton (animals)

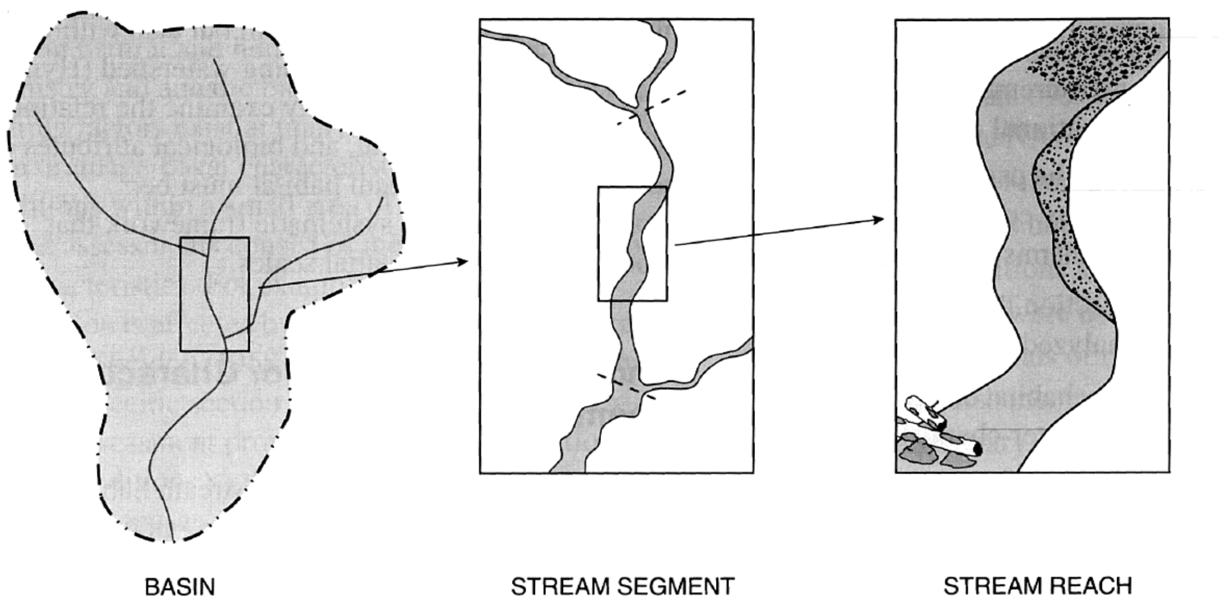
Nekton
free swimming organisms, e.g. fish, snakes, diving beetles, newts

Neuston
organisms that live on water surface; never break surface tension, e.g. water striders,

Madricoles
organisms that live on rock faces in waterfalls or seepages

Hierarchical Nature of Stream Systems (figure from Fitzpatrick and others, 1998)

- Basin
- Segment
- Reach



Lotic Habitat Types (figure from Fitzpatrick and others, 1998)

Riffle
    faster flowing, well-oxygenated water, coarse sediments
Run
    Intermediate characteristics
Pool
    slower currents, deeper water, and finer, more homogeneous sediments

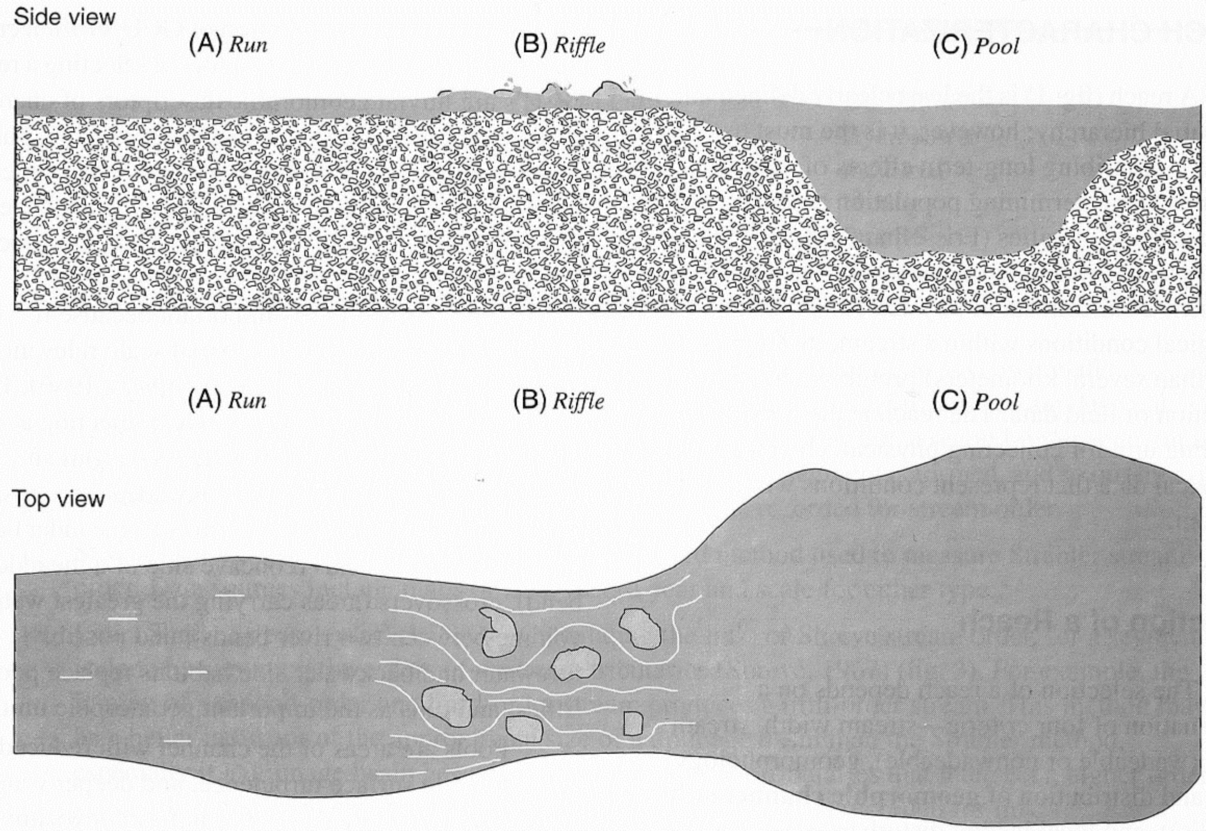


Diagram of the three main geomorphic channel units. (A) Run—A slow moving, relatively shallow body of water with moderately low velocities and little or no surface turbulence; (B) Riffle—A part of the stream where the water flows swiftly over completely or partially submerged obstructions to produce surface agitation; (C) Pool—A part of the stream with reduced velocity, commonly with deeper water than surrounding areas (modified from Bisson and others, 1982).

Biological monitoring

Systematic use of biological resources to evaluate changes in the environment with the intent to use this information in a quality control program. The primary objective of the National Clean Water Act (CWA) is to "restore and maintain the chemical, physical and biological integrity of the nation's waters".

In a multimetric evaluation, reference conditions are used to scale an assessment to the "best attainable" situation. A station of interest is classified on the basis of its similarity to expected conditions (reference condition), and its apparent potential to support an acceptable level of biological health.

Outside the scope of this class are toxicological studies and bioassays. These studies are traditionally laboratory studies where the response of a test organism is measured after exposure to a chemical or effluent.

Factors that effect biological communities

Water Quality
- temperature
- turbidity
- dissolved oxygen
- acidity
- alkalinity
- organic and inorganic chemical
- heavy metals
- toxic substances

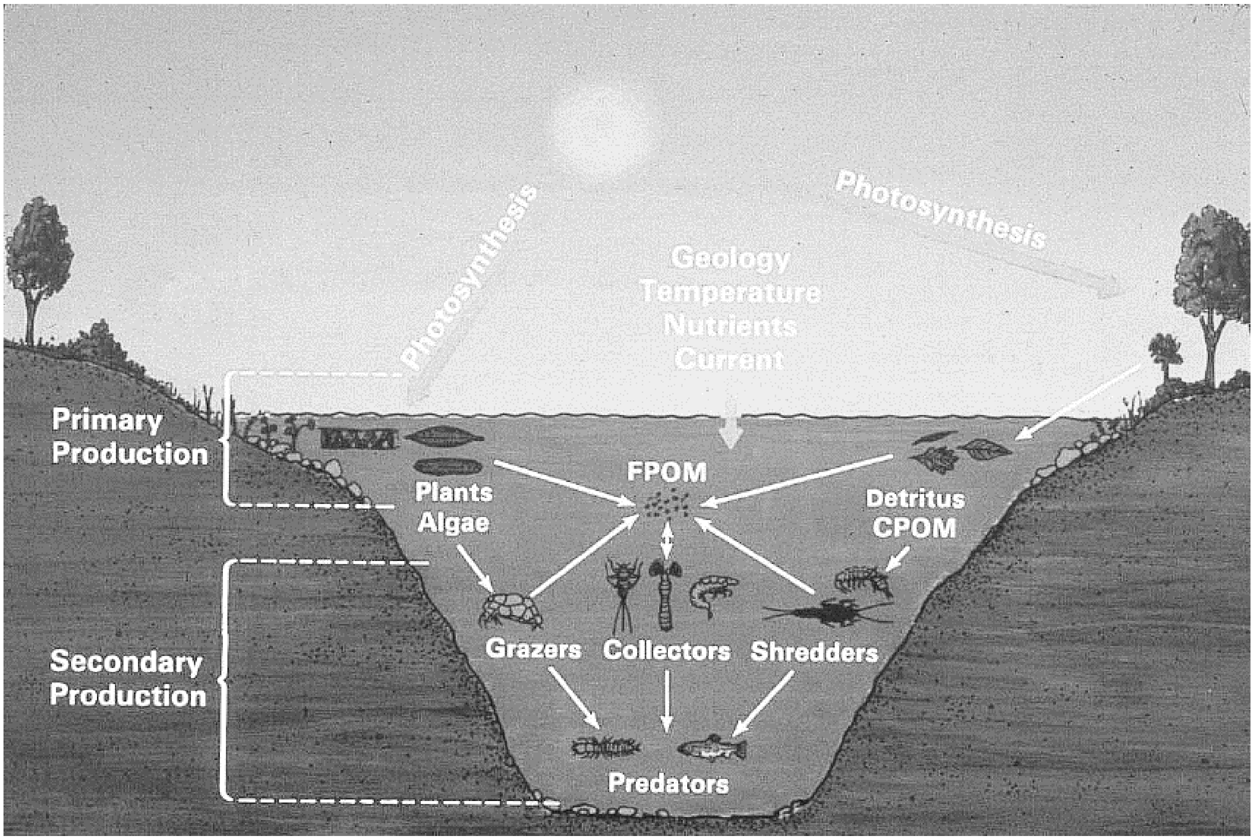
Habitat structure
- substrate type
- water depth and current velocity
- spatial and temporal complexity of physical habitat
- flow regime
- water volume
- temporal distribution of flows

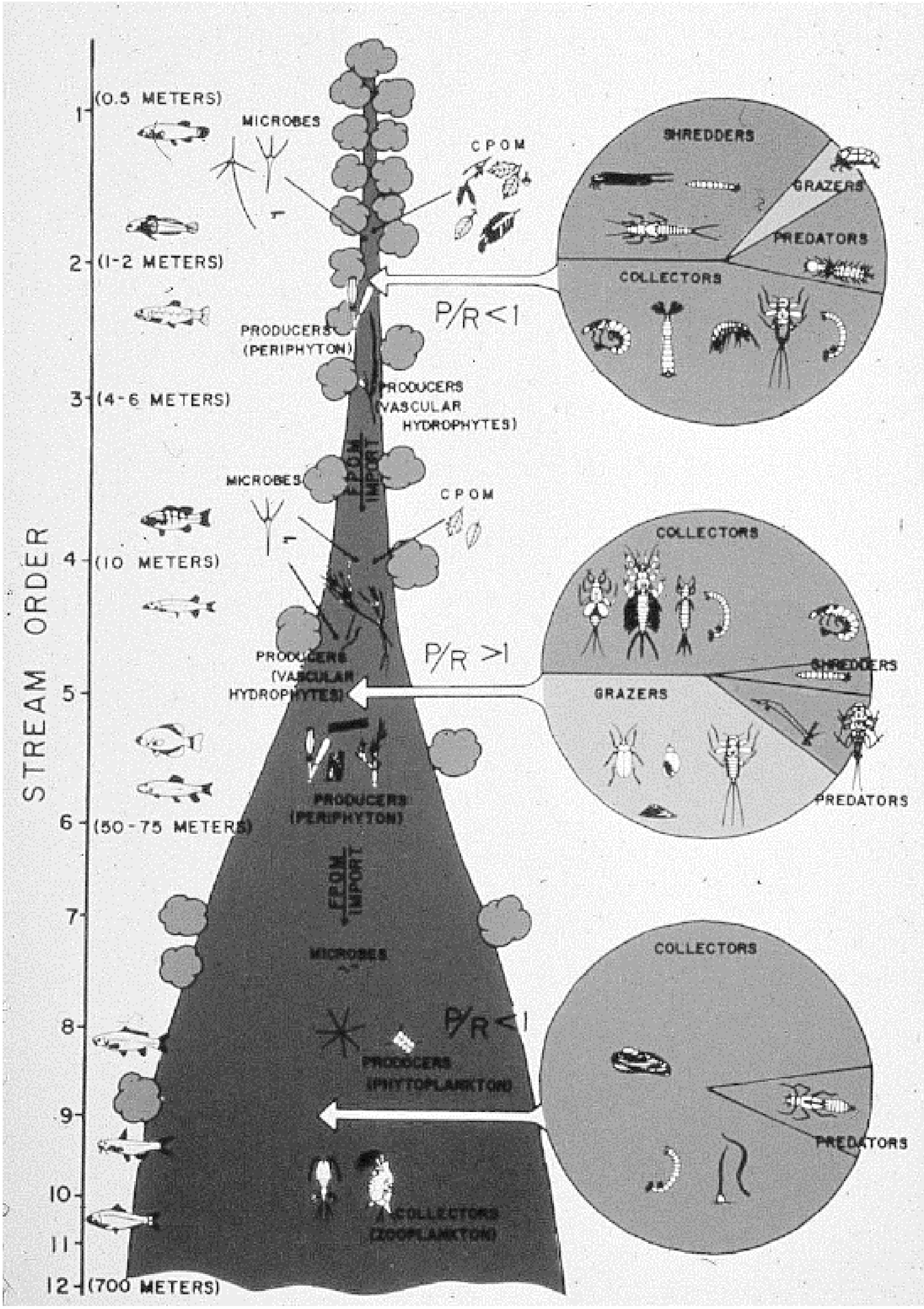
Energy source
- type, amount, and particle size of organic material entering stream
- seasonal pattern of energy availability

Biotic interactions
- competition
- predation
- disease
- parasitism
- mutualism

Food Web

Functional description of a community. Study of organic matter processing and community interactions. (Figure is adapted from “The Living Stream,” a slide show by Bert Cushing, North American Benthological Society <www.benthos.org/info/conserv/consslides.htm>).




STREAM ORDER
1 (0.5 METERS)
2 (1-2 METERS)
3 (4-6 METERS)
4 (10 METERS)
5
6 (50-75 METERS)
7
8
9
10
11
12 (700 METERS)
MICROBES
CPOM
PRODUCERS (PERIPHYTON)
PRODUCERS (VASCULAR HYDROPHYTES)
FPOM IMPORT
P/R<1
P/R >1
SHREDDERS
GRAZERS
PREDATORS
COLLECTORS
PRODUCERS (PHYTOPLANKTON)
COLLECTORS (ZOOPLANKTON)

River Continuum Concept

Describes changes in structure and function of a stream along a longitudinal gradient. (Figure is adapted from The Living Stream," a slide show by Bert Cushing, North American Benthological Society <www.benthos.org/info/conserv/consslides.htm>).

Changes are a function of changes in geomorphic, physical, and biotic variables such as:

- stream flow
- channel morphology (especially width and depth)
- organic matter transport
- use of energy by the streams functional feeding groups
- thermal regimes
- autotrophic production
- nutritional sources

Sampling Considerations

- quantitative
  - #/area
  - relative abundance (%)
- qualitative
  - presence/absence

Communities vary in space and time

- spatial variation
- temporal variation (seasonal and annual)

Life History

events that govern the survival and reproduction of a species or population

Exotic (nonnative) Species

organism that is outside its native range

Endangered or Threatened Species

legislative designation for a species that is threatened with extinction or extirpation

Commonness and Rarity

Fish

A. Some Common Groups of Fishes
B. Habitat, Sampling Methods, Variables
C. Sample Analyses and the Index of Biotic Integrity (IBI)

A. Some Common Groups of Fishes (Page and Burr, 1991)

"Ancient Fishes"

Lampreys, sturgeons, gars, paddlefish, bowfin, shad, eel. An artificial collection of orders and families of fishes that are unrelated to each other. There are a number of interesting and distinctive species in these groups. These orders are evolutionarily older than others that we will look at.

Salmoniformes

Salmonidae (salmon, trout, whitefish). Live in cool streams, many commercially important species. Recognized by fleshy adipose fin.

Esocidae (pickerel, muskellunge). Elongate, predatory fish, with "duck bill" mouth.

Cypriniformes

Cyprinidae (minnows and carps). Minnows are largest family (have the most species) of freshwater fishes. Varied both ecologically and morphologically.

Catostomidae (suckers). Suckers have a small mouths and large thick lips which are used in most species to "vacuum" invertebrates from stream and lake bottoms. Many suckers are large in size and they are usually abundant, so in many water bodies suckers account for the largest biomass of any group.

Siluriformes

Ictaluridae (catfishes, bullheads, madtoms). These fish are recognized by having no scales, four pairs of barbels, an adipose fin, and fins with spines. Madtoms feed on aquatic invertebrates and tend to be found in clean, flowing water. Madtom fin spines have a mild venom (watch out for these when collecting!).

Perciformes

Centrarchidae (sunfishes, basses, crappies). These are laterally compressed fishes. They have two joined dorsal fins, the first with spines and the second with rays. Many popular sportfishes are in this family. Centrarchids typically construct circular nests in the gravel, where the male guards the eggs

Percidae (walleye, sauger, yellow perch, darters). The second most diverse freshwater fish family in North America (after Cyprinidae). All but a few species in this family are darters. Darters do not have swim bladders, and they frequent the bottom of riffles where they ingest insects and crustaceans. Breeding males can be colorful.

B. Habitat, Sampling Methods, Variables

Variables that effect what you fish you find
- geographic location, fish distribution
- stream size and depth
- habitat
  - margin, substrate size
- stream morphology
- pools, run, riffle

Factors Responsible For Disappearance Of Native Fish Species (Smith, 1971)
- Excessive siltation
  - loss of water clarity, disappearance of aquatic vegetation, deposition of silt over rock or sand substrates
- Drainage
  - loss of wetlands
- Desiccation
  - lowering of water table causes small streams, seeps, and spring to dry up, and relatively larger rivers become smaller
- Species interaction
  - introduced species, ecologically labile native species
- Pollution
  - industrial, domestic, agricultural
- Dams and impoundments
  - habitat loss, blocking migration
- Temperature
  - higher temps due to channelization, loss of riparian vegetation

Sampling Methods
- seine
- electrofishing
- net
- visual (snorkling, SCUBA)
- toxicants
- hook and line

C. Sample Analyses and the Index of Biotic Integrity (IBI)

Properties of fish community
- Richness
  - number of species
- Diversity
  - relative composition of species abundances
- Trophic structure
- Morphological and physical attributes

Table: Fish trophic structure

Multimetric indexes

An index created from multiple measures or metrics. Different metrics are sensitive to different perturbations. For example, municipal effluents may alter the trophic structure of a community, while habitat modifications may first effect the darters.

Metrics used in the Original Index of Biotic Integrity (Karr and others, 1986)

Species Richness and Composition Metrics

1. Total number of fish species
2. Number of darter species
3. Number of sunfish species
4. Number of sucker species
5. Number of intolerant species
6. Percent green sunfish

Trophic Composition Metrics

7. Percent omnivores
8. Percent insectivorous cyprinids
9. Percent piscivores (top carnivores)

Abundance and Condition Metrics

10. Number of individuals
11. Percent hybrids
12. Health and condition: percent individuals with disease, tumors, fin damage, skeletal anomalies

Invertebrates

A. Identification
B. Sampling
C. Sample Processing, Analyses, and Assessment

A. Identification

Life Cycle (of an insect)

- eggs
- larvae (multiple instars)
- pupae (in holometabolous orders)
- adults

Identification of Macroinvertebrates

Taxonomy can be at any level, but should be consistent among samples. **Genus/species** will provide more accurate information on ecological/environmental relationships and sensitivity to impairment. Most organisms are identified to the lowest practical level (generally genus or species) by a qualified taxonomist using a dissecting microscope. Midges (Diptera: Chironomidae) are mounted on slides in an appropriate medium and identified using a compound microscope. **Family** level will provide a higher degree of precision among samples and taxonomists, requires less expertise to perform, and accelerates assessment results.

Representative Invertebrates

Phylum
- **Class**
  - Order

Porifera — sponges

Platyhelminthes
- **Turbellaria** — flatworms

Mollusca
- **Gastropoda** — snails
- **Bivalvia** — clams, mussels

Annelida
- **Oligochaeta** — aquatic worms
- **Hirudinea** — leeches

Arthropoda
- **Insecta** (approximate number of aquatic and semiaquatic species in North America north of Mexico) (McCafferty, 1981)
  - Ephemeroptera (700) — mayflies
  - Odonata (450) — damselflies, dragonflies
  - Plecoptera (500) — stoneflies
  - Hemiptera (400) — water bugs
  - Megaloptera (50) — fishflies, dobsonflies, alderflies
  - Neuroptera (6) — spongillaflies
  - Trichoptera (1200) — caddisflies

Coleoptera (1000)	beetles
Lepidoptera (50)	aquatic moths
Diptera (350)	midges, mosquitoes, aquatic gnats and flies

Malacostracta

Amphipoda	scuds, sideswimmers
Isopoda	aquatic sow bugs
Decapoda	crayfish, shrimps

B. Sampling

Habitat Types (Barbour and others, 1999)

The major stream habitat types used here are in reference to those that are colonized by macroinvertebrates and generally support the diversity of the macroinvertebrate assemblage in stream ecosystems. Some combination of these habitats would be sampled in a multihabitat approach to benthic sampling.

Cobble (hard substrate) - Cobble is prevalent in the riffles (and runs), which are a common feature throughout most mountain and piedmont streams. In many high-gradient streams, this habitat type will be dominant. However, riffles are not a common feature of most coastal or other low-gradient streams. Sample shallow areas with coarse (mixed gravel, cobble or larger) substrates by holding the bottom of the dip net against the substrate and dislodging organisms by kicking the substrate for 0.5 m upstream of the net.

Snags - Snags and other woody debris that have been submerged for a relatively long period (not recent deadfall) provide excellent colonization habitat. Sample submerged woody debris by jabbing in medium-sized snag material (sticks and branches). The snag habitat may be kicked first to help dislodge organisms, but only after placing the net downstream of the snag. Accumulated woody material in pool areas is considered snag habitat. Large logs should be avoided because they are generally difficult to sample adequately.

Vegetated Banks - When lower banks are submerged and have roots and emergent plants associated with them, they are sampled in a fashion similar to snags. Submerged areas of undercut banks are good habitats to sample. Sample banks with protruding roots and plants by jabbing into the habitat. Bank habitat can be kicked first to help dislodge organisms, but only after placing the net downstream.

Submerged macrophytes - Submerged macrophytes are seasonal in their occurrence and may not be a common feature of many streams, particularly those that are high-gradient. Sample aquatic plants that are rooted on the bottom of the stream in deep water by drawing the net through the vegetation from the bottom to the surface of the water (maximum of 0.5 m each jab). In shallow water sample by bumping or jabbing the net along the bottom in the rooted area, avoiding sediments where possible.

Sand (and other fine sediment) - Usually the least productive macroinvertebrate habitat in streams, this habitat may be the most prevalent in some streams. Sample banks of unvegetated or soft soil by bumping the net along the surface of the substrate rather than dragging the net through soft substrates; this reduces the amount of debris in the sample.

Some important variables influencing invertebrate distribution.

permanence of aquatic habitat
size of habitat
water depth
presence vegetation for protection and habitat
bottom composition
current
water temperature
food
predators

Videotape: Sampling Aquatic Insects (Resh and others, 1990)

Devices that can be used for sampling aquatic insects in lotic and lentic habitats are demonstrated in this video. This provides an introduction to the process of selecting samplers for aquatic insect studies. The appropriate habitat and methods of operation for the various samplers are discussed. In designing a research project or sampling program, the overall study design, appropriate statistical analyses, as well as the advantages and limitations of specific samplers should be given careful consideration.

The following samplers are demonstrated in video:

In-Flow

These samplers utilize the current to carry organisms into a net. Typically they are used in riffles in shallow streams.

Surber Sampler
Hess Sampler
T- Sampler
Kick Screen

Multihabitat

D-frame net

The D-frame dip net can be used in many habitats and can be used like a kick net or by “jabbing”, “dipping”, or “sweeping”. It is often useful for qualitative collecting. Dimensions of frame are 0.3 m width and 0.3 m height and shaped as a “D” where frame attaches to long pole. Net is cone or bag-shaped for capture of organisms.

Drift

A net suspended in the water column may sample drift, an activity where organisms enter the water column and are transported downstream. Studies of drift may examine macroinvertebrate colonization and dispersal.

Drift Net

Hyporheic

Many invertebrates spend some or all of their lives beneath the stream bottom substrate.

Hyporheic Corer

Lentic, Deep water
Grab samplers are used in lentic and deep-water habitats, and typically have jaws that snap shut.

Ekman Grab
Ponar Grab

Vegetation
Typically, vegetation is a difficult habitat to sample.

Pull-up Vegetation Sampler
Moosejaw Vegetation Sampler

Mosquito

Mosquito Dipper

Visual

Benthic View Box

Artificial Substrates
These samplers provide a standard substrate for sample comparison. They must be left in the stream for a colonization period.

Clay Quarry Tiles
Substrate Implants
Hyporheic Pot Sampler

Adult Insects
These samplers are used to sample the adult stages of aquatic insects. Adult stages of insects are usually easier to identify than immature stage. These samplers are used for studies of reproductive behavior, dispersal, and species distribution.

Sweep Net
Beating Sheet
Pan Trap
Pyramid Emergence Trap
Pheromone Trap
Malaise Trap
Light Trap

C. Sample Processing, Analyses, and Assessment

Sample Processing

Sorting
Identification

Metrics (measures) used for Benthic Macroinvertebrate Communities (Barbour and others, 1999)

Metrics used in multimetric indices evaluate elements and processes within a macroinvertebrate assemblage. Metrics and protocols need to be calibrated for different regions, and sometimes, for different impact types (stressors) and metrics are typically evaluated with respect to reference conditions.

Taxa richness, or the number of distinct taxa, reflect the diversity of the aquatic assemblage. Taxa richness usually consists of species level identifications but can also be evaluated as designated groupings of taxa, often as higher taxonomic groups (i.e., genera, families, orders, etc.) in assessment of invertebrate assemblages. Increasing diversity correlates with increasing health of the assemblage and suggests that niche space, habitat, and food source are adequate to support survival and propagation of many species. Measures of *composition* (or relative abundance) provide information on the make-up of the assemblage and the relative contribution of the populations to the total fauna. The premise is that a healthy and stable assemblage will be relatively consistent in its proportional representation, though individual abundances may vary in magnitude.

Tolerance/Intolerance measures are intended to be representative of relative sensitivity to perturbation and may include numbers of pollution-tolerant and -intolerant taxa or percent composition. Tolerance may or may not be focused on a specific type of stressor, such as organic pollution or sedimentation.

Example: Hilsenhoff Family Biotic Index

$$(1/N) * \bullet n_i t_i$$

N - number of individuals in sample
n - number of individuals in family
t - tolerance score of family

Feeding measures or trophic dynamics, provide information on the balance of feeding strategies (food acquisition and morphology) in the benthic assemblage. Invertebrates are classified by their feeding orientation into functional feeding groups (scrapers, shredders, gatherers, filterers, and predators). Invertebrates may also be classified by their food types, including the relative abundance of herbivores, carnivores, omnivores, and detritivores. Without relatively stable food dynamics, an imbalance in functional feeding groups will result and reflect stressed conditions.

Table: Invertebrate trophic relations

Algae

Algae (Alga – singular; algae – plural) is an umbrella term for a number of groups of photosynthetic organisms. These groups include diatoms (Bacillariophyta), green algae (Chlorophyta), blue-green algae (Cyanophyta or Cyanobacteria), yellow-green algae (Chrysophyta) and red algae (Rhodophyta). Algae are found on almost any surface receiving light including rocks (epilithic), plants (epiphytic), wood (epidendric), fine sediment (epipelic), sand (epipsammic), and animals (epizooic). Benthic algae take on a variety of sizes and growth forms. As primary producers they form a base of the aquatic food chain.

Periphyton (attached algae) are primary producers and are sensitive indicators of environmental change in lotic waters. Because periphyton is attached to the substrate, this assemblage integrates physical and chemical disturbances to the stream reach. The periphyton assemblage serves as a good biological indicator because of naturally high number of species and a rapid response time to both exposure and recovery. Diatoms in particular are useful indicators of biological condition because they are ubiquitous and found in all lotic systems. In addition, most periphyton taxa can be identified to species by experienced biologists, and tolerance or sensitivity to specific changes in environmental condition are known for many species. By using algal data in association with macroinvertebrate and fish data, the strength of biological assessments is optimized. The objectives of periphyton sampling could include assessment of biomass (chlorophyll *a* or ash-free dry mass), species composition, and biological condition of periphyton assemblages (Barbour and others, 1999).

Other photosynthesizing groups are phytoplankton (algae suspended in water column) and aquatic vascular plants.

Habitat Assessment and Physicochemical Parameters

(Adapted from Barbour and others, 1999)

An evaluation of habitat quality is critical to any assessment of ecological integrity and should be performed at each site at the time of the biological sampling. In the truest sense, "habitat" incorporates all aspects of physical and chemical constituents along with the biotic interactions. Often the definition of "habitat" is narrowed to the quality of the instream and riparian habitat that influences the structure and function of the aquatic community in a stream. The presence of a degraded habitat can sometimes obscure investigations on the effects of toxicity and/or pollution. The assessments performed by many water resource agencies include a general description of the site, a physical characterization and water quality assessment, and a visual assessment of instream and riparian habitat quality. Some states include quantitative measurements of physical parameters in their habitat assessment. Together these data provide a comprehensive and integrated picture of the biological condition of a stream system.

Habitat assessment is defined as the evaluation of the structure of the surrounding physical habitat that influences the quality of the water resource and the condition of the resident aquatic community. For streams, an encompassing approach to assessing structure of the habitat includes an evaluation of the variety and quality of the substrate, channel morphology, bank structure, and riparian vegetation. Habitat parameters pertinent to the assessment of habitat quality include those that characterize the stream micro-scale habitat (e.g., estimation of embeddeddness), the macro-scale features (e.g., channel morphology), and the riparian and bank structure features that are most often influential in affecting the other parameters.

When streams lose their ability to dissipate flow energy, there will be accelerated rates of channel erosion. The stability of channel morphology is influenced by these interrelated factors: channel width, channel depth, flow velocity, discharge, channel slope, roughness of channel materials, sediment load and sediment particle size distribution. Some of the habitat structural components that function to dissipate flow energy are sinuosity, roughness of bed and bank materials, presence of point bars (slope is an important characteristic), vegetative conditions of stream banks and the riparian zone, condition of the floodplain (accessibility from bank overflow and size are important characteristics).

Two types of habitat assessment approaches have been developed. The first type provides a relatively comprehensive characterization of the physical structure of the stream sampling reach and its surrounding floodplain by measuring various features of the instream, channel, and bank morphology. An example of this type of assessment are the methods used by the U.S. Geological Survey National Water Quality Assessment Program (Fitzpatrick and others, 1998). The second type is a more rapid and qualitative habitat assessment approach that was developed to describe the overall quality of the physical habitat. In this rapid assessment approach all parameters are evaluated and scored. The totals for a sampling reach are compared to a reference condition to provide a final habitat ranking. An example of this type of assessment may be found in the U.S. EPA Rapid Bioassessment Protocols (Barbour and others, 1999).

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