Macroinvertebrates and the Assessment of Water Quality

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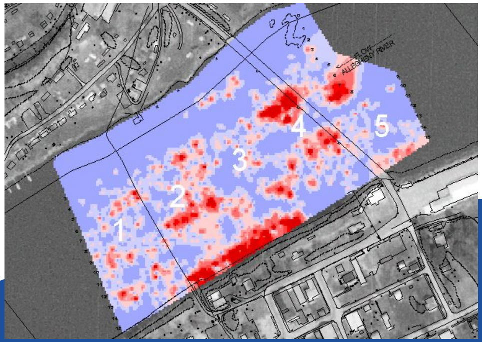
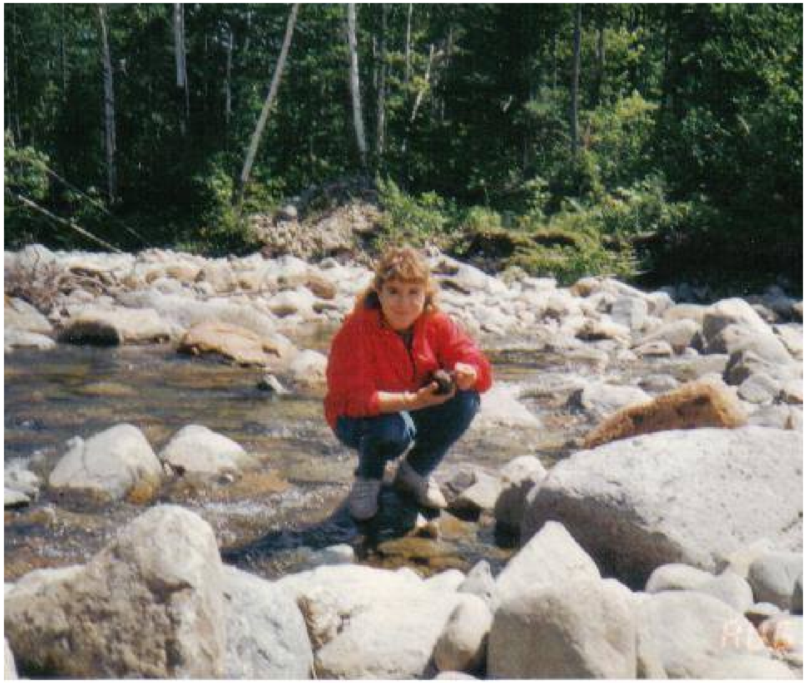
EnviroScience, Inc.

- Ecological services firm based in northern Ohio
- >100 biologists, environmental scientists and engineers specializing in aquatic biomonitoring, aquatic toxicity testing, wetland/stream restoration, invasive species, restoration and regulatory compliance
- Existing clients include State, federal and local governmental agencies (WV DOT, OH, FL, PennDOT, U.S.EPA, US Army Corp of Engineers), major industries and corporations across the U.S. (CSX, AEP, Reliant Energy, Mittal Steel) and many of the Nation’s largest engineering firms (Leidos, TetraTech, Arcadis and others)



Effective Tools to evaluate the Quality of effluents-

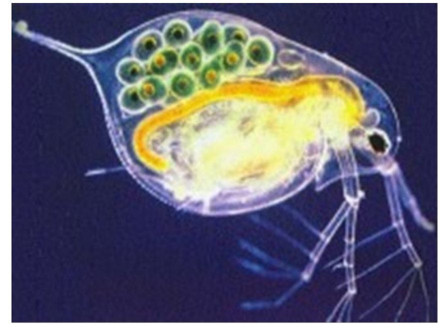


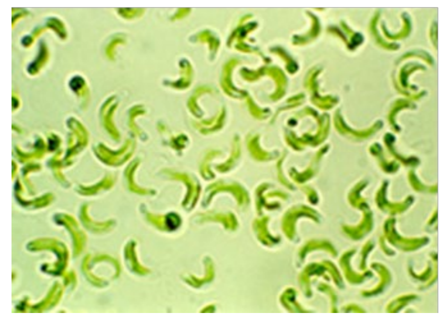
- Chemical testing
- Toxicity Testing
- Biological – Aquatic communities

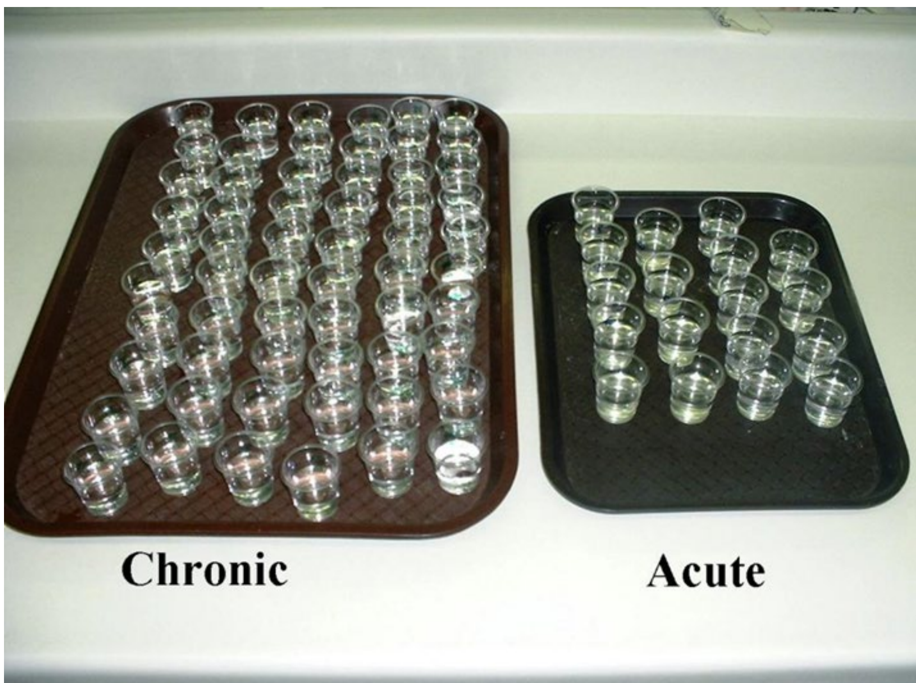
Whole Effluent Toxicity Testing

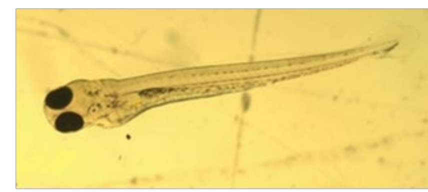
- Whole Effluent Toxicity (WET) Testing - surrogate laboratory species
- WET testing – mimics what is occurring in the stream by testing effluent with the receiving water in a controlled laboratory setting

WET Testing Overview









What does WET testing accomplish?

- Addresses unknown combinations of toxicants
- Predicts the potential for an effluent to have an adverse effect on the in-stream aquatic population. Acute and Chronic values

Limitations: This tool is restricted to laboratory tests on surrogate species

Traditional Methods - Limitations

- Chemical Water Sampling and WET tests
  - Snap shot in time (TDS, BOD, metals, etc.)
- Sediment Sampling (Chemical and toxicity)
  - Delineates specific areas, but not entire system

The Role of Aquatic Ecology in Environmental Assessments to Evaluate Water Quality



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Aquatic Ecology

- Is the study of relationships between organisms in (freshwater) ecosystems

  - Streams
  - Rivers
  - Lakes

  - Macroinvertebrates
  - Fish
  - Algae
  - Periphyton
  - Amphibians
  - Mussels

- Studying these factors to evaluate the health of a body of water is called biological assessment

Biocriteria

- Support the goals of the Clean Water Act to provide for the protection and propagation of fish, shellfish, and wildlife, and to restore and maintain the chemical, physical, and biological integrity of the Nation's waters
- Narrative and Numeric Biocriteria Standards developed by states

Biocriteria make up the Cornerstone of Aquatic Environmental Assessments

- **Biocriteria are Numeric expressions describing the biological condition of aquatic communities inhabiting waters of a designated aquatic life use.**
  - **Mandated by the USEPA - each state must have a form of Biocriteria**
  - **Each state differs from the next on scale, organisms and methodology**

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Value of Biocriteria

- Assess the biological resources that are at risk from chemical, physical or biological impacts
- Biocriteria may detect water quality problems that other methods may miss
- Biocriteria can be used to determine to what extent current regulations are protecting a water body's use attainment

Three Main Focus Groups for Biocriteria

Macroinvertebrates

Fish

Habitat

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What are Aquatic Macroinvertebrates?

- Animals without backbones, large enough to be seen by the unaided eye, and live at least part of their life cycles within a waterbody
- Crayfish, snails, clams, aquatic worms, and larval forms (and some adults) of several insect orders

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Why Macroinvertebrates?

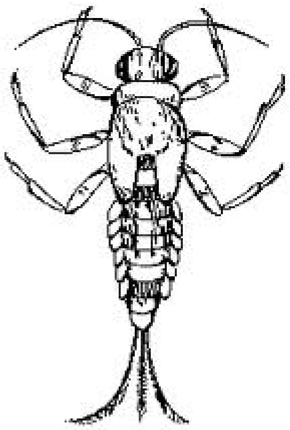
- They form semi-permanent, relatively immobile stream communities
- They can be easily collected in large numbers
- Acute and Chronic reactions to environmental changes
- Occupy all stream habitats and display a wide range of functional feeding preferences
- They inhabit the middle of the aquatic food web and are a major source of food for fish and other aquatic and terrestrial animals.

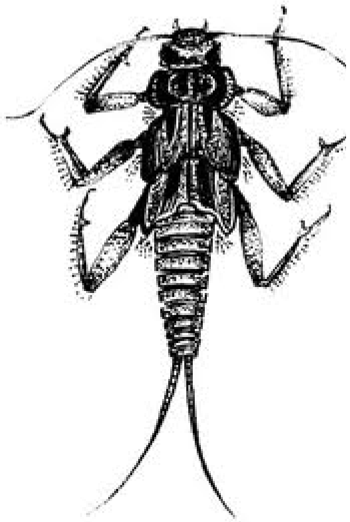
Advantages of using macroinvertebrates to directly monitor the aquatic community (as opposed to fish):

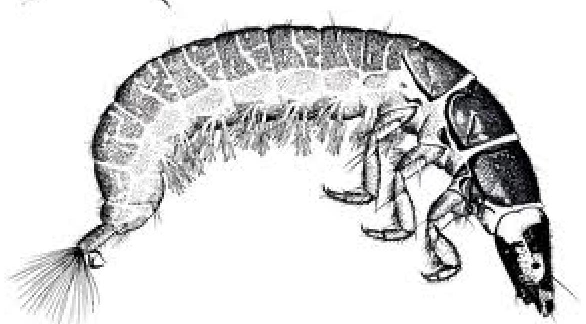
- Obstructions to the habitat like dams may limit where fish are located
- Fish have the ability to swim away from the effects of a pollutant
- Fish communities in northern streams and rivers are often not very diverse, limiting the amount of information that can be gained by collecting them

Intolerant Organisms

- EPT Taxa – most are considered “intolerant” of environmental pollution
  - Ephemeroptera (Mayflies)
  - Plecoptera (Stoneflies)
  - Trichoptera (Caddisflies)







Mayflies (Ephemeroptera)

Stoneflies (Plecoptera)

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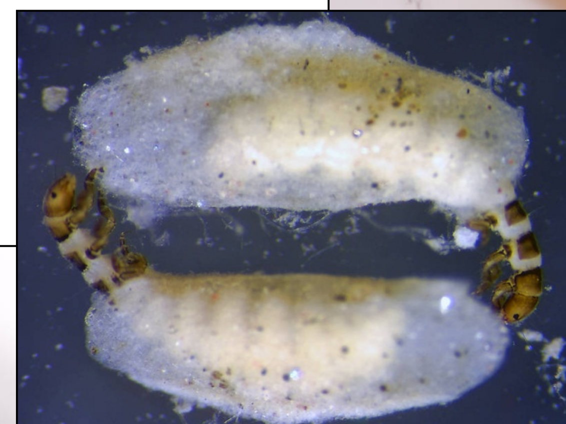
Caddisflies (Trichoptera)



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Tolerant Organisms

- Some organisms, such as certain fly larvae (Diptera), aquatic worms (oligochaetes) and leeches are indicative of polluted conditions and are considered “tolerant organisms”

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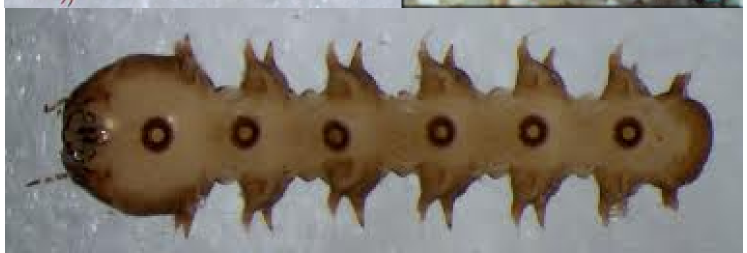
Other Organisms



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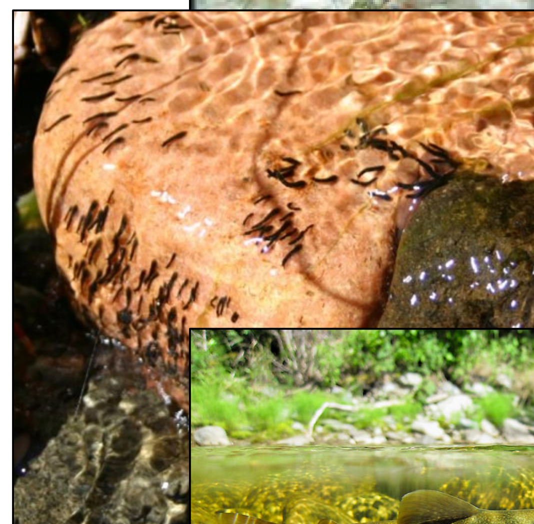
Biotic community in a stream

- A group of interacting organisms inhabiting a given area
- The community is more than just a mix of species (biological structure). It is also influenced by the physical features of the **biotic** and **abiotic** (physical structure) components

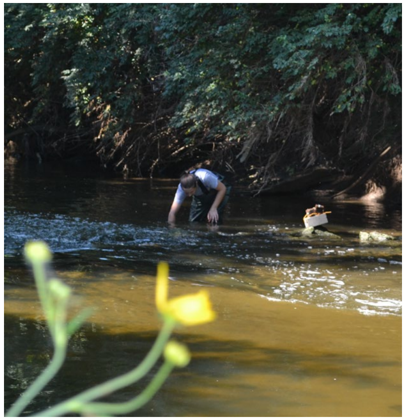


Sampling Macroinvertebrates in Ohio

- Biological Surveys conducted using Ohio EPA methodology
- Credible Data is suitable for regulatory uses
  (TMDLs, use designations, water quality standards, etc.)
- Macroinvertebrates, fish, habitat, chemistry
- All sampling must be conducted or directly supervised by a Level 3 Qualified Data Collector (QDC) for each specialty
- Must have an OEPA approved Study Plan before beginning work

Field Sampling Season



- Sampling season for macroinvertebrates is from June 15th – September 30th
- Until October 15th for fish

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Macroinvertebrate Methodology

- Macroinvertebrates are collected with quantitative and qualitative methods
  - Quantitative: Hester-Dendy multiple-plate artificial substrate samplers - 6 week colonization period

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Macroinvertebrate Methodology

- Qualitative: multi-habitat composite samples are collected from all available macrohabitats (riffles, pools, margins, etc.)
  - D-frame net, visual inspections, and hand-picking
- If there is insufficient stream flow or depth for Hester-Dendy deployment then only a qualitative sample will be collected

Additional Field Methodology

- Fish sampling conducted at the same sites as macroinvertebrate sampling
- Measure stream flow, in-field water chemistry
  - pH, temperature, specific conductance, DO
- May include analytical sampling
- Habitat Characterization – QHEI (Qualitative Habitat Evaluation Index)

Laboratory Processing

- Samples collected in the field preserved with 95% ethanol
- Sub-sampling
- Benthic macroinvertebrates sorted from debris and identified to genus/species

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Data Analysis

- Macroinvertebrate data collected from HD samplers are analyzed by using Ohio EPA's methods for calculating the Invertebrate Community Index (ICI)
- When HDs are not collected, qualitative samples are analyzed using Qualitative community metrics

Biological Assessments

- Identify impairments from point and nonpoint sources
- Early assessments focused on conventional pollutants with target of BOD reduction
- Ex. Hilsenhoff Biotic Index

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Other Measurements

- % of Certain groups of organisms (% Tanytarsini midges)
- Dominance of a particular type of organism (Orthocladiinae midges)
- Loss of a particular group of organisms found in other stream reaches (Heptageniidae mayflies)

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Water Pollution

- Any chemical, biological or physical change in water quality that has a harmful effect on living organisms
- Makes water unsuitable for desired uses

Seven Major Categories of Water Pollutants Which Affect Macroinvertebrates

- Oxygen demanding wastes
- Infectious agents
- Inorganic chemicals
- Organic chemicals
- Plant nutrients
- Sediments
- Heat

Oxygen Demanding Wastes

- Material that can be decomposed by aerobic (oxygen-demanding) bacteria
- Major sources: Sewage, animal feedlots, paper mills
- Large populations of bacteria deplete the water of dissolved oxygen which affects fish and other aquatic organisms – best measured by BOD (biological oxygen demand)

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Infectious agents

- Major sources: Human and animal waste
- Coliform bacteria is a good indicator:
- Number of colonies per 100 ml sample of water

Inorganic Chemicals

- Acids
- Toxic metals (lead, arsenic, mercury, selenium)
- Sources: Surface runoff, industrial effluents

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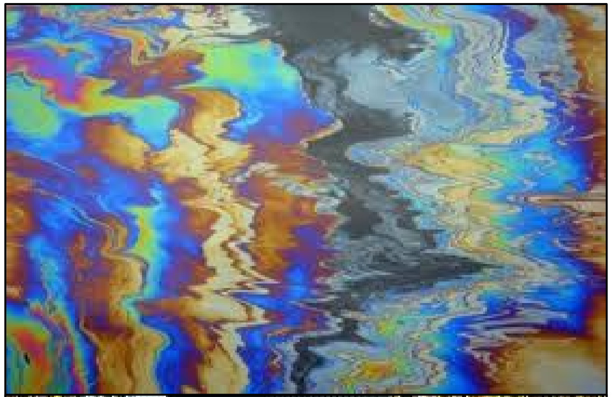
Organic Chemicals

- Oil and gasoline
- Pesticides
- Cleaning solvents
- Detergents
- Sources: Industrial effluents, household cleaners, surface runoff from farms and yards



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Plant Nutrients

- Nitrates, phosphates, and ammonium
- Results in excess growth of algae
- Sources: Runoff from agricultural and urban fertilizers

Sediments

- Addition of excess soil and silt
- Cloud water, destroys fish feeding and spawning grounds and carry harmful substances
- Major source: land erosion

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Thermal (Heat)

- Increased heat lowers dissolved oxygen levels causing stress to aquatic organisms
- Thermal shock: Abrupt changes in water temperatures will kill aquatic organisms

Macroinvertebrate Communities Respond to Habitat Quality

- High Quality Habitat – Provides more niches for organisms to inhabit
- Communities will have increased diversity, with abundance evenly distributed

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Poor Habitat Quality

- Poor habitat – fewer microhabitats – lack of heterogeneity of substrate
- Community diversity reduced, abundance values skewed
- Community will resemble an impacted community regardless of the water quality

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BIOLOGICAL ASSESSMENTS

- Identify the effects of altered physical habitat
  - Sedimentation from stormwater runoff, agriculture, construction
  - Physical or structural habitat alterations – dredging, channelization

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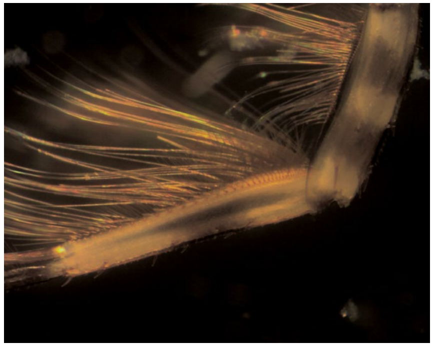
Response To Organic Loading

- Proliferation of certain types of organisms that can exploit the resource – filter-feeding macroinvertebrates



Severe Dissolved Oxygen Depletion

- In cases of extreme loading, only those organisms that can tolerate reduced DO concentrations can survive

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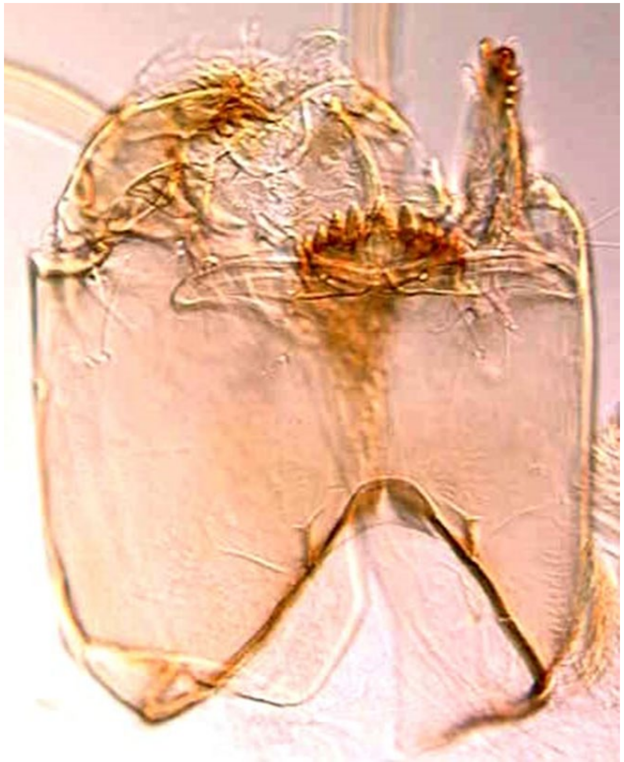
Can Individual Organisms Tell Us Anything About Water Quality?

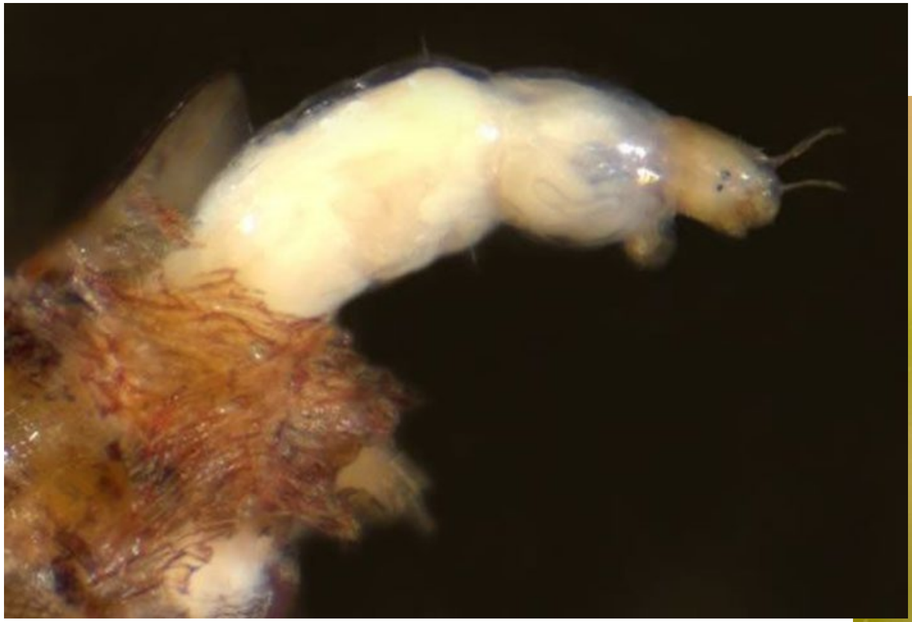
Micropsectra polita

- Indicator of agricultural run-off (nutrients)



Rheotanytarsus

- High levels of plankton and TSS



Cricotopus bicinctus

- Tolerant of toxic substances, such as metals

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Chironomus

- Indicator of organic waste/low DO
- Also can indicate poor habitat quality

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Eukiefferiella brehmi

- Indicator of pristine sites with elevated water quality

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Response of Macroinvertebrate Communities to Pollution

- Macroinvertebrates respond differently and (often) predictably to various forms of toxic pollutants
- Sensitivity to contaminants varies among species.
- Response is on an individual level, but measured in an overall community response.

Types of Responses to Disturbance

- <u>Pulse disturbance</u> - relatively instantaneous alteration of the densities of certain selected species, after which the system "relaxes" or recovers to its previously defined state. Results in individual mortality and a <u>**temporary**</u> reduction of numbers and diversity of stream macroinvertebrates.
- Example: ethanol, ammonia

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Acute Toxic Response (Pulse)

- Widespread immediate reduction in the numbers and types of organisms
- Sensitive taxa lost
- Only very tolerant taxa remain
- Communities often rebound quickly
- *Examples*: Chemical spill from a carrier (truck, train…), accidental release of chemicals

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Acute Response Example – Ethanol spill
Massive Fish Kill

- Approximately 40 miles downstream


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Communities immediately monitored to assess acute impact, which was found to be severe

- Aquatic communities immediately affected – massive loss of aquatic resources
- Ethanol does not bioaccumulate – rapid biodegradation in the aquatic environment

Follow up:

- Community soon rebounded through recolonization of pioneer species

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Result – Loss of natural resources for one year, during which time the stream made a full recovery

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Types of Responses to Disturbance

- Press disturbance - **Long-term chronic effects**, such as those caused by heavy metals, are characteristic of toxins that accumulate and become concentrated in the food chains. Long-term chronic toxins result in decreased reproduction, impaired behavioral responses, and disease in the macroinvertebrate community. Examples: PCBs, PAHs, Metals

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Chronic Toxic Response (Press)

- Gradual reduction in the numbers and types of more sensitive organisms
- Measurable decrease in community health
- Community becomes dominated by organisms that can tolerate the source of the contamination
- Community does not rebound to original condition
- Contaminants will restructure communities, with sensitive species replaced by tolerant species.

Chronic (Press) Response Example - Metals

- EPT taxa are almost exclusively absent from community
- Overall reduction in numbers and diversity

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Chronic Response Example - Metals

- Predictable groups of organisms (those that can tolerate metals) will be present




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Groundwater Contamination

- Macroinvertebrate communities were used to detect widespread groundwater contamination through standard bioassessment techniques
- Quality of the impact site was found to be severely degraded, with stream organisms typically associated with poor water quality

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Widespread Groundwater Contamination

- A macroinvertebrate survey **upstream** of the AOC, however, revealed chronic metal contamination throughout the entire stream system (above and below the site), as evidenced by the presence of numerous indicator groups for metals, and the complete absence of metal sensitive taxa.

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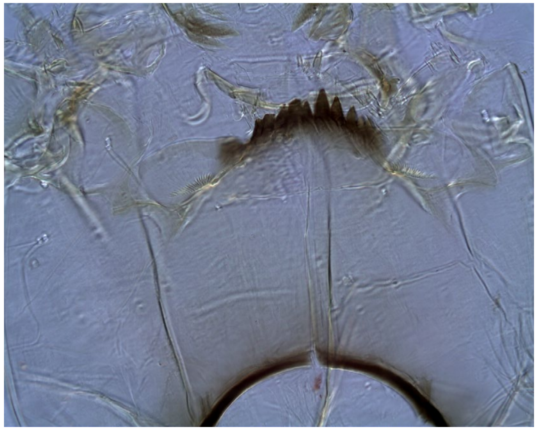
The use of macroinvertebrates to evaluate physical barriers to impacted sediments

- Anacostia River – Widespread sediment contamination throughout River: elevated concentrations of polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), pesticides, lead and other trace elements (NOAA 2003).

Chronic Response Example - Sediments

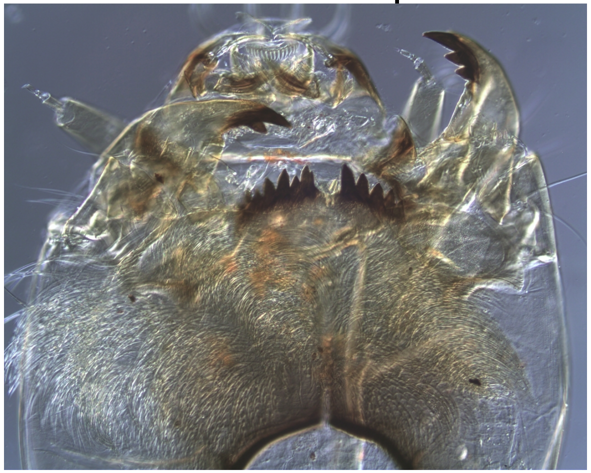
- Morphological mouthpart deformities in midges - typically associated with elevated concentrations of metals, PCBs, PAHs, etc. in sediments

Normal *Chironomus* Mentum



Fluctuating Asymmetry of the Mentum

Köhn Gap



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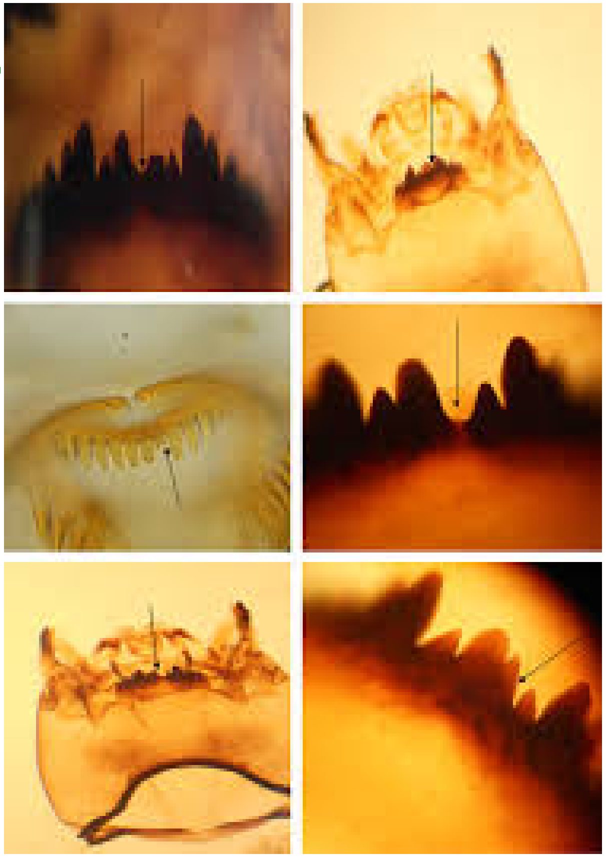
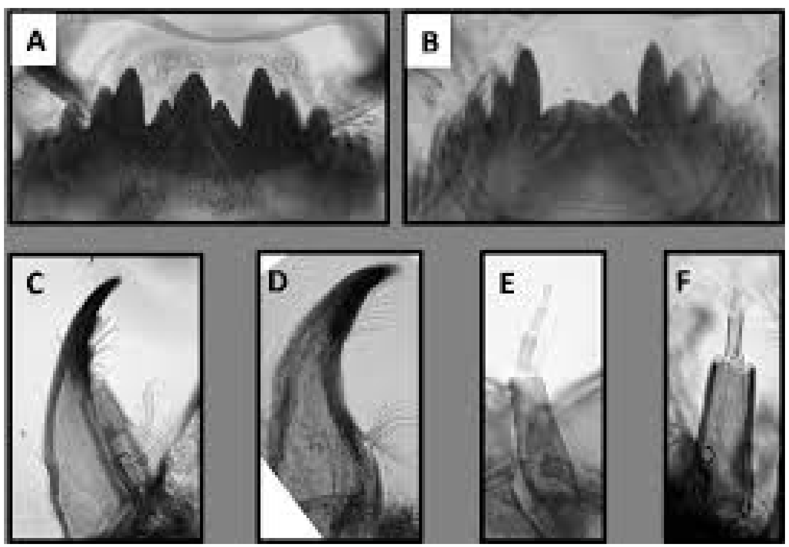
Mouthpart Deformities in Midges Indicate Sublethal Effects

- Cumulative sublethal pollution - Multiple impacts over time or continuous low level stress that periodic chemical sampling is unlikely to address





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Baseline Study – High prevalence of mouthpart deformities present throughout AOC

- Addition of clean sand layer

Follow-up sampling – mouthpart deformities completely absent in clean sand

Conclusion – sand layer acts as an effective barrier to the river's historically impacted sediments, based upon the absence of mouthpart deformities

Effect of TDS/Conductivity

- TDS – total quantity of dissolved material, organic and inorganic, ionized and unionized in a water sample
- Salinity – measure of inorganic salts only
- Conductivity – measure of the ability of water to conduct electrical current, so it is therefore a measure of the ionic material

TDS and conductivity often correlate closely in waters where most of the dissolved material is ionic

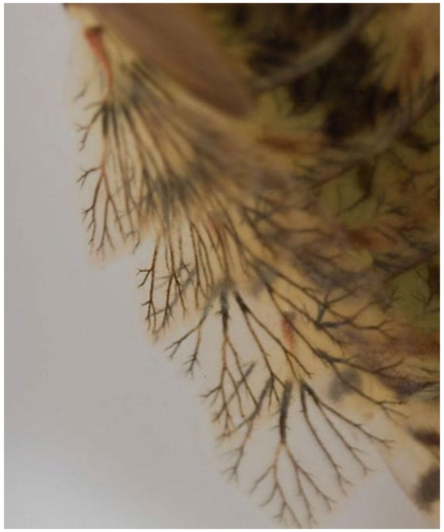
- Most common cations: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+})
- Most common anions: **bicarbonate** (HCO_3^{-}), carbonate (CO_3^{2-}), chloride (CL^{-}) and **sulphate** (SO_4^{2-})
- Most research has been conducted by USEPA in the coal-mining regions of Appalachia

Mayflies Are Most Sensitive

- Extirpated at lower conductivity levels than other taxonomic groups
- *Cinygmula*: 230 µS/cm
- *Epeorus:* 307 µS/cm
- *Drunella:* 297 µS/cm
- *Ephemerella*: 299 µS/cm
- *Baetis:* 1396 µS/cm
- *Caenis:* 3,923 µS/cm

Reasons for Sensitivity

- Gill surfaces are important sites for ion exchange – respiratory surfaces are very sensitive to environmental contaminants
- Excess ions can affect an insect's ability to osmoregulate, especially those with larger gills.



USEPA Conductivity Study

- Based on a study of an EPA Region 3 data set, at conductivity levels exceeding 1,500 µS/cm, 81% of streams lacked mayflies.
- Ephemeroptera are **present** where conductivity is **low** even when other stressors are present.
- Ephemeroptera are frequently **absent** where conductivity is **high**, even when other stressors are absent.

USEPA. (2011). *A Field-Based Aquatic Life Benchmark for Conductivity in Central Appalachian Streams*. EPA/600/R-10/023F. 276 pages.

Questions

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