Turning Data into Knowledge:
Using Indices for Bioassessments

GRADES: Highschool

TIME FRAME: 75 minutes

SETTING: Indoors

MATERIALS: calculators, chart or scrap paper, printed data sheets

LEARNING OBJECTIVES:

- To understand the importance of the data evaluation step in a research project
- To critique methods of data evaluation and choose the most appropriate
- To define “bioassessment” and “index”
- To explain how we can use data from the biotic elements of a habitat to draw conclusions about abiotic factors in the community

OVERVIEW:

Students will define and explore the purpose of a mathematical index for evaluating data in a biological stream assessment. They will explore how indices look in other bioassessments and discuss how different mathematical formulas can change the information drawn from collected data. Small groups of students will get two data sets from simulated stream surveys, with the challenge of creating an index that can be used for macroinvertebrates, then compare them to and learn about the most commonly used indices.

NJ SCIENCE STANDARDS:

HS-LS2-2 Ecosystems: Interactions, Energy, and Dynamics - Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.

PREPARE AHEAD:

Have lab sheets printed for each group of 3-5 students. Each group needs a copy of the Lichen Field Example Sheet, the Meet Your Macros Data Sheet, and the Stream Collections Data Sheet.

BACKGROUND:

With increasing awareness of water pollutants in the mid-20th century, scientists developed bioassessment methods to monitor stream health in the 1960s. These bioassessments were based on the presence of certain aquatic benthic macroinvertebrates (macros). With this new method, anyone who could learn to identify these stream creatures could assess water quality without expensive chemical test kits. Macroinvertebrates are effective indicators, as they are sensitive to the amount of oxygen in their habitats, which is altered by pollution. They cannot easily relocate to a healthier habitat if theirs becomes degraded, so their presence or absence can tell us about the area they are in.

Oxygen in streams is depleted by several types of pollutants in different ways. Organic pollutants like sewage, agricultural runoff, and food waste decrease oxygen because microbes use it in breaking down these organic compounds. Nutrients like phosphates and nitrates can also deplete dissolved oxygen because they create excessive algae that dies and is decomposed by microbes. Oxygen can also be depleted by rising water temperatures, increased salinity, and reduced flow rate. These issues are caused by humans through development, construction, and climate change.

Macroinvertebrate tolerance to low oxygen levels varies greatly. These creatures are taxonomically diverse and have developed a variety of adaptations to living in streams. For example, Diptera (flies), an order with many tolerant species, may have breathing tubes that allow them to attain oxygen from the air, making them less dependent on dissolved oxygen in the water. On the other hand, Plecoptera (stoneflies) have gills that process enough oxygen only under high concentrations, making them very sensitive. The diversity in macroinvertebrate adaptive strategies is incredible, making them both exciting to study and useful in creating a spectrum of water quality levels in streams.

The way scientists develop a water quality assessment from a collection of macro is with a biotic index. They create calculations from extensive research in testing water quality and surveying macros, take the data from the macro survey and formulate a stream quality result. Depending on the audience, location, and resource constraints, they use different indices. On the table below, you can see some of the common indices, each having their own benefits and drawbacks.

The purpose of this lesson is to teach students about the common stream assessment indices and have them think about the decisions that scientists make every time they evaluate their data. The scientific process is often perceived as imitative and rigid, but like any discipline, it was created by humans and requires a creative and thoughtful approach if one is to find true and relevant information during their research. Results are only as good as the methods used, and the way the data is evaluated is just as critical as the way it is collected. Scientific innovation rests in the development of its processes; so learning to be critical and creative when engaging in STEM activities will help students to think and engage more deeply with their own ideas about what they learn.

Common Biotic Indices for Macroinvertebrates

Index Description	Citation
Total taxa - measures the total number of macroinvertebrate taxa (diversity or different kinds) collected in the sample. In general, total taxa increases with improving water quality.	Plafkin et al., 1989
Percent EPT – EPT stands for the three most pollution sensitive families of macros: mayflies, stoneflies, and caddisflies. Percent EPT is calculated by comparing the number of EPT species found to the total number of other families found.	Plafkin et al., 1989
Percent Chironomidae – Chironomidae is the midge family, one of the most pollution tolerant families of macros. Calculated like percent EPT, this index compares the total number of midges found to the total number of other families found.	Plafkin et al., 1989
Hilsenhoff's Biotic Index (HBI) - Each species is given a tolerance value on a 0 to 10 scale, and both the number of species found and the tolerance values are considered in the calculation to come up with a water quality value.	Hilsenhoff, W. L. 1977

Family Level Biotic Index (FBI): Hilsenhoff developed a similar metric to his BI above but using the family level instead of species, making identification more practical.	Hilsenhoff, W. L. 1988
Average Score per Taxon (ASPT): takes the average of the tolerance scores of all individuals collected	Armitage, P.D. D. Moss, J.F. Wright & M.T. Furse, 1983.
Functional Feeding Groups Abundance Ratios: compares feeding groups of the collected organisms using ratios, to understand the ecological community that can be altered by levels of nutrient availability in the water	Merritt, R.; Cummins, K., Berg, M., Novak, J., Higgins, M., Wessell, K., & Lessard, J. (2002).

ENGAGE:

Depending on what experience your class has with biotic stream assessments, you can shorten or expand to certain areas. Ask students to discuss what they already know about stream assessments and water quality determinations. Students might not spend much time discussing the data evaluation step, so be sure to introduce it as the topic of this activity.

Discuss how a stream assessment is a type of scientific procedure, known as a bioassessment, that can be done in a variety of habitats. The way a scientist goes from a bunch of data to a conclusion is the critical step of data evaluation, and in a bioassessment the evaluation step is done using a biotic index. Define these two terms on the board and discuss them.

Bioassessment: a scientific method used to evaluate the health of an ecosystem by examining the organisms that live there.

Index: a formula or calculation that uses the collected organism data points to create a result that tells you the condition of the habitat

PROCEDURE:

1. Lichen Index Example: If you've done stream assessments with your students, these concepts are not new to them but be sure to have this valuable conversation to set them up for the group challenge. Explain how some scientists use bioassessments to monitor air quality using lichens. Use this model, outlined on the lab sheet, to discuss an example. How does this formula compare the lichens that were found to come up with an air quality assessment?

2. Group Challenge: Propose the question: where did this biotic index come from? Do your favorite short discussion activity, allowing students to talk with their peers before coming back to the class and sharing as a group. Discuss with them about how just like the method of collecting data is designed into a study, so is the method of evaluating data. This is something a scientist must think critically about, as the results they get are only as good as their data collection and evaluation. Put students into groups of 3 or 4, and give the following instructions:
   - Your group will be given a data sheet with several data points on 28 species of macroinvertebrates. How you use this information, and what you use, is up to you.
   - Your task is to come up with a biotic index that takes a list of 100 macros found in a stream sample and converts it into an assessment of stream quality.
   - Work with your team to determine some possible formulas or calculations that you think could work as a biological index.
   - After 20 minutes, you'll be given two stream sample data sets for you to test and refine your indices. Your goal is to end up with one that you think is the most accurate and practical for a biological stream assessment. **Stress these terms, tell them to keep them in mind as*

*they work, write them on the board. Let them know you'll be discussing these terms more thoroughly later**

Distribute macroinvertebrate data sheets, scrap paper, and calculators. You can give each group large chart paper to assist collaboration. After around 20 minutes, distribute the stream sample data. Let them work for 20-30 more minutes.

3. Culmination: Have groups present their indices, explain how they came to it and any they think it would be an accurate and practical method of evaluation. They can write on the board or just speak about it.

4. Wrap Up: Share the table of common indices for streams. Either pass this out to groups, or project it on the board. Give groups a few minutes to read over and discuss what these indices are based on. Challenge them to come up with 3 benefits and 3 downsides of any of the methodologies. Then, share and discuss as a class. Use some questions below to spur conversation, but also let the students ask their own questions and share observations about the indices and data evaluation in general.

Some Wrap Up Discussion Points:

- How can scientists ensure their indices are both accurate and practical? *Perfect accuracy might require something like sampling all of the macros in a stream, which is not at all practical. Scientists can test methodologies that are practical for field use by comparing them with more thorough methods.*
- Why did Hilsenhoff create the Family Biotic Index (FBI)? *William Hilsenhoff's first biotic index required a stream surveyor to identity macros to species level, which is very accurate, but not always practical, as it takes a lot of skill and time. He tested this new index, which requires less time and skill for identification, and found it to be very close to the same accuracy of his original BI.*
- What might be different about the information we get about the stream when using the Percent EPT versus the Percent Chironomidae indices? *A*

high percentage of the most intolerant species (EPT) will show that a stream must not be highly polluted, but a high percentage of the most intolerant species (Chironomidae) may indicate that something is wrong, but is not a direct indicator of pollution, as they can theoretically tolerate a range of water quality, unlike the EPT species.

- How can scientists get the most accurate picture of a stream they're surveying with such a variety of indices? *Using several! Many stream programs incorporate several indices into their data evaluation process to get as complete of a picture of the water quality as they can.*

REFERENCES:

Lichen Index Example: https://www.apis.ac.uk/sites/default/files/downloads/A4-Guide%20to%20the%20lichen%20based%20nitrogen%20air%20quality%20index_0.pdf

Dissolved Oxygen Information: https://cdn.cyfoethnaturiol.cymru/media/692076/new-information-note-dissolved-oxygen.pdf

Biotic Index Overview: Plafkin, JL., Barbour, M.T., Porter, K.D., Gross, S.K., and Hughes, R.M.. 1989. Rapid Bioassessment Protocols for use in Streams and Rivers: Benthic Macroinvertebrates and Fish. U.S. Environmental Protection Agency. EPA 440/4-89/001. 8 chapters, Appendice

Hilsenhoff's Biotic Index and Family Biotic Index

BI: https://search.library.wisc.edu/digital/AHCLDETM7D4AT282

FBI: https://www.webpages.uidaho.edu/fish415/Wilhelm%20files/2435%201988%20Hilsenhoff.pdf

Field Example of a Biotic Index

Scientists have developed an index for determining air quality based on the lichens found growing on tree bark. Let’s break down the process into the data collection method and the data evaluation method.



Data collection method: 5 trees are randomly selected. The researcher identifies the lichens on the West, South, and East sides of each of the trees and writes down the number of species present that are either sensitive or tolerant of air pollution.

Data evaluation method: To turn the collected data into a result, the below biotic index is used. All the sensitive species are added and averaged by the number of trees, and then the same to the tolerant species. The lichen indicator score then is calculated by subtracting the tolerant average from the sensitive average. The LIS is compared to the score table to get the air quality reading, an essential part of every biotic index.

	Tree 1			Tree 2			Tree 3			Tree 4			Tree 5			Count	Average
Aspect	W	S	E	W	S	E	W	S	E	W	S	E	W	S	E		= Count / no. trees (5)
N-sensitive	1	0	1	1	1	1	1	0	0	0	1	0	1	0	1	9	1.8
N-tolerant	0	0	0	1	0	0	1	1	1	1	0	0	0	0	1	6	1.2
Lichen indicator score (LIS) = (Average N-sensitive) – (Average N-tolerant)																	**0.6**

Lichen Air Quality Index

LIS Score:

Clean: 0-0.5 | At Risk: 0.51-0.85 | Polluted: 0.86-1.25 | Very Polluted: >1.25

Meet Your Macros Data Sheet

Macroinvertebrate	Level of Disturbance Tolerance	Tolerance Value	Functional Feeding Groups
Keys:	Low – Intolerant Pollution Medium – Can tolerate some pollution High: Tolerant of pollution	0 – Intolerant of Pollution 10- Tolerant of Pollution	prd: predator, feed on living prey such as other macroinvertabrates scr: scraper, feed on biofilms like a snail does shr: shredders, feed on large organic matter such as dead leaves c-f: collectors & filter feeders, feed in organic matter floating in water c-g: collectors & gatherers, feed on organic matter mixed with sediment
Brush-Legged Mayfly Isonychiidae	Low	2	c-f
Minnow Mayfly Baetidae	Low	3	c-g
Spiny-Crawler Mayfly Ephemerellidae	Low	1	c-g

Burrowing Mayfly Ephemeridae	Medium	4	c-g
Little Brown Stonefly Nemouridae	Low	2	shr
Giant Stonefly Pteronarcyidae	Low	0	shr
Winter Stonefly Taeniopterygidae	Low	2	shr
Case-Building Caddisfly Phryganeidae	Medium	4	prd
Net-Spinning Caddisfly Hydropsychidae	Medium	4	c-f
Free Living Caddisfly Rhyacophilidae	Low	1	prd

Club-Tailed Dragonflies	Medium	4	prd
Broad-Winged Damselflies Calopterygidae	Medium	6	prd
Riffle Beetle Gomphidae	Medium	4	scr
Whirligig Beetle Gyrinidae	Medium	4	prd
Water Penny Psephenidae	Medium	4	scr
True Bugs Corixidae	Medium	5	prd
Dobsonflies Corydalidae	Medium	4	prd
Alderflies Sialidae	Medium	4	prd
Non-biting Midges	High	8	prd

Chironomidae			
Black Flies Simuliidae	Medium	6	c-f
Crane Flies Tipulidae	Low	3	c-g
Horseflies Tabanidae	Medium	6	prd
Crayfish Decapoda	High	8	prd
Scuds Amphipoda	Medium	6	c-g
Sow Bugs Isopoda	High	8	c-g
Aquatic Worm Oligochaeta	High	9	c-g
Leeches Hirudinea	High	10	prd

Flat Worms Planariidae	Medium	6	prd
Clams Corbiculidae	Medium	6	c-f

Stream Collections Data Sheet

Stream 1 Clean, headwater stream through a forest	Stream 2 Large, polluted river through a city
Burrowing Mayfly	Crayfish
Dobsonfly	Broad-Winged Damselfly
Brush-Legged Mayfly	Non-biting Midge
Water Penny	Crayfish
Crayfish	Burrowing Mayfly
Burrowing Mayfly	Crayfish
Free Living Caddisfly	Crayfish
Dobsonfly	Clam
Water Penny	Flat Worm
Case-Building Caddisfly	Crayfish
Brush-Legged Mayfly	Crayfish
Dobsonfly	Burrowing Mayfly
Crane Fly	Burrowing Mayfly

Brush-Legged Mayfly	Non-biting Midges
Lunged Snail	Broad-Winged Damselfly
Crayfish	Non-biting Midge
Free Living Caddisfly	Non-biting Midge
Broad-Winged Damselfly	Crayfish
Brush-Legged Mayfly	Clam
Brush-Legged Mayfly	Flat Worm
Broad-Winged Damselfly	Broad-Winged Damselfly
Flat Worm	Crayfish
Brush-Legged Mayfly	Flat Worm
Crane Fly	Burrowing Mayfly
Lunged Snail	Non-biting Midge
Crane Fly	Non-biting Midge
Free Living Caddisfly	Burrowing Mayfly
Broad-Winged Damselfly	Clam

Flat Worm	Clam
Dobsonfly	Flat Worm
Broad-Winged Damselfly	Crayfish
Water Penny	Broad-Winged Damselfly
Crane Fly	Flat Worm
Giant Stonefly	Flat Worm
Case-Building Caddisfly	Clam
Water Penny	Flat Worm
Brush-Legged Mayfly	Burrowing Mayfly
Flat Worm	Crayfish
Broad-Winged Damselfly	Non-biting Midge
Free Living Caddisfly	Flat Worm
Crane Fly	Burrowing Mayfly
Dobsonfly	Flat Worm
Dobsonfly	Non-biting Midge

Water Penny	Non-biting Midge
Broad-Winged Damselfly	Crayfish
Giant Stonefly	Non-biting Midge
Case-Building Caddisfly	Crayfish
Case-Building Caddisfly	Clam
Crayfish	Flat Worm
Crane Fly	Flat Worm