Simulating Biomagnification to Illustrate Trophic Pyramids in the Middle School Classroom

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ABSTRACT

Biomagnification influences the movement of environmental contaminants and relates to food chains and the transfer of matter in ecosystems, concepts that are found in the Next Generation Science Standards. Consequently, we developed a hands-on, discussion-based activity for the middle school science classroom to demonstrate biomagnification and connect it to food webs and trophic pyramids. Each student represents an aquatic organism, and together students simulate the consumption and excretion processes in an aquatic food chain. This simulation demonstrates how certain environmental contaminants accumulate within organisms and ultimately become concentrated in predators at the top of the food chain.

Key Words: biomagnification; food web; aquatic; simulation; pollution.

Introduction

Students often confuse bioaccumulation and biomagnification. Bioaccumulation is the process by which some environmental contaminants collect in organisms; biomagnification refers to the transfer of contaminants from organism to organism up the food chain, resulting in the concentration of the contaminant in top predators. Because this process governs a major way in which humans impact their environment, education about biomagnification is crucial for developing students’ understanding of how we affect our planet (Kim & Kim, 2013). Moreover, biomagnification relates clearly to the Next Generation Science Standards core idea of “Ecosystems: Interactions, energy, and dynamics,” as well as the cross-cutting concept of “Energy and matter: Flows, cycles, and conservation” (National Science Teachers Association, 2013). Consequently, biomagnification could serve as a helpful and relevant example of the movement of matter through ecosystems.

We therefore developed an activity that demonstrates biomagnification and connects it to food webs and trophic pyramids through a hands-on thought experiment and class discussion. This lesson plan is based on active learning principles, allowing students to engage with the material by making observations, developing predictions, and drawing conclusions with feedback from their instructor.

Intended Audience and Prior Knowledge

This activity was intended for a seventh grade science classroom and was conducted in one 40-minute class period. Students should be familiar with food webs, as well as the shape of the trophic pyramid and why higher trophic levels have fewer organisms. We have provided a food web graphic as a starting point for the activity (Figure 1).

Materials

Assuming a class size of 25 students, the instructor will need:

- 15 small disposable cups labeled with “zooplankton,” “copepod,” or another primary consumer
- 7 medium-sized disposable cups labeled with “mummichog” or another secondary consumer
- 3 large disposable cups labeled with “striped bass” or another tertiary consumer
- 1 even larger cup (optionally labeled with “human”)
- 1–2 bowls of water
- 25 pennies (1 per student)
- 1 cup of Cheerios or other cereal

To simulate a food web, each student is given one disposable cup, labeled with the name of a local aquatic organism that it represents. For this activity, we focused on organisms common to the Chesapeake Bay. The size of the cup corresponds to the organism’s place in the food chain; small cups represent zooplankton or copepods (primary consumers and herbivores), medium cups represent mummichogs (secondary consumers and omnivores),
and large cups represent striped bass (tertiary consumers and carnivores). The relative abundances of the organisms should be chosen to approximate the shape of the trophic pyramid, e.g., in a class of 25 students, 15 students might represent zooplankton or copepods, seven students mummichogs, and three students striped bass.

Safety Concerns
There are typically no safety hazards associated with this activity, though cereal choice may be changed if some students have severe allergies to certain food products.

○ Procedure
Detailed instructions are provided in Appendix 1.

Ingesting Pollutants
Students are first asked to brainstorm things that organisms need to survive. When a student provides the answer water, the students are instructed to quench their organisms’ thirst by filling their cups roughly halfway with water from a bowl representing the Chesapeake Bay or other local body of water. This body of water also contains pennies representing methylmercury pollution. The students are asked what might happen when their organisms live in and drink from a polluted water source. Once a student correctly identifies that the organisms should have pollution in them as well, each student is given one penny to place in their cup, representing the methylmercury that their organism has ingested.

Ingesting Plant Material
Students are again asked to suggest things that organisms need to survive, and this time responses are discussed until a student provides the answer food. The class should then discuss the diets of their various organisms, particularly distinguishing among the diets of herbivores, omnivores, and carnivores. The class then begins to simulate a food chain using the students’ organisms. First, students representing zooplankton, copepods, and mummichogs will receive a few cereal pieces to add to their cups to represent the algae and plant material that they have consumed.

Simulating Bioaccumulation
The instructor points out that the zooplankton and copepods are almost full and asks the students what organisms do when they are full of food and water. Students should be able to identify that organisms excrete waste. Students representing zooplankton and copepods then simulate this process by carefully pouring some—but not all—of the contents of their cups back into the common body of water. Students are then asked to observe the cups and share their observations. Students can use the Observation Worksheet (see Supplemental Materials) to record their observations throughout the activity. Students should observe that, although water and cereal, or “food,” were lost in the excretion process, the pennies, or “methylmercury,” remain in the cups. This simulation demonstrates bioaccumulation: the accumulation of a toxin within individual organisms that cannot excrete it as quickly as they consume it.

Simulating Biomagnification
Next, students are asked whether mummichogs eat anything other than plants. Once they have identified that omnivores like mummichogs also eat herbivores like zooplankton, the students simulate this consumption by pouring the contents of several zooplankton or copepod cups into each mummichog cup. Students then examine their cups and share their observations. Students should identify that the mummichogs now contain more methylmercury. Because the mummichogs are now almost full, the students with mummichog cups then “excrete waste” as before by pouring some of the contents of their cups back into the common body of water.

Proceeding up the food chain, the students are then asked what the striped bass eat. Students should identify that striped bass eat mummichogs. The striped bass will then do so as before, by transferring the contents of the mummichogs’ cups into their own. Students are then asked to share their observations of their cups and identify that the striped bass now contain much more methylmercury.

Finally, students are asked to predict what would happen if a human caught and ate these striped bass. Students should expect that the methylmercury load of the striped bass would transfer to the human. As before, this consumption is simulated by emptying the striped bass cups into a larger cup held by the instructor, who represents a human. Students are asked to share their observations of the “human” and should identify that the human now contains all of the original pollution. This simulation demonstrates
biomagnification, the magnification of concentrations of toxins as they move up the food chain.

○ Class Discussion

Remaining class time can be used to conduct a class discussion about biomagnification. Students might work in groups to complete an Observation Worksheet on the lesson’s main concepts (see Supplemental Materials), and then the class can discuss their answers together.

○ Possible Alterations

To extend the lesson for a longer period of time or a more advanced grade level, connections could be made to human physiology through the health effects of biomagnifying substances like methylmercury and PCBs (EPA, 2016a, 2016b). Discussing different biomagnifying substances could also provide classes the opportunity to discuss how different substances accumulate in different body tissues and what the implications of these differences in bioaccumulation might be. Higher grade levels could also practice scientific literacy and data interpretation by examining case studies of biomagnification (e.g., Bargagli et al., 1998, Strandberg et al., 1998).

This lesson plan can also accommodate classes of different sizes. For a class of seven to 24 students, instructors can simply place fewer students at each level of the food chain, as long as each secondary consumer can still eat at least two zooplankton, and each tertiary consumer can eat at least two secondary consumers. For a class of greater than 25 students, instructors might consider breaking the class into two groups.

Although zooplankton and copepods are found in essentially all aquatic ecosystems, our choices of secondary and tertiary consumers are relatively specific to the Chesapeake Bay. Consequently, these elements of the lesson could be adapted to other locally relevant aquatic ecosystems. For example, in freshwater ecosystems, minnows, herring, or shad could be substituted for the secondary consumer, and bass, trout, or salmon for the tertiary consumer. For saltwater ecosystems, minnows, mackerel, and sardines might be more relevant secondary consumers, and salmon or tuna could serve as the tertiary consumer. However, in adapting this lesson to other ecosystems, it is important not to conflate secondary consumers with omnivores or tertiary consumers with carnivores; for example, while mummichogs and minnows are omnivores, herring and shad are not and should therefore not consume plant material in the second stage of the lesson.

○ Classroom Observations

When we field-tested this activity in a middle school classroom, students remained engaged and were particularly excited to consume their classmates and excrete the waste. Moreover, based on responses to the Post-Activity Worksheet (see Supplemental Materials), the lesson was successful at conveying the main concepts of biomagnification, particularly in relation to the food chain and as distinct from bioaccumulation.

○ Acknowledgments

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References


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APPENDIX: Instructor’s Guide

Preparation

- Fill a common bowl (or multiple bowls, if more convenient for classroom setup) with water.
- Place pennies in bowl(s) of water. Make sure there are enough pennies for each student using the bowl to have one.
- Give each student one cup, each labeled with the name of an organism in a local food web (copepod, mummichog, or striped bass in our example). Thus, each student represents an organism in that food web. (The instructor can hold onto the large “human” cup.)

Procedure Details: Instructions For Instructors And Students

Discussion prompts are printed in italics.

Ingesting Pollutants (~5 minutes)

What do organisms need to survive?

- Students should eventually provide the answer water.
- Students use the bowl(s) of water to fill their cups roughly halfway with water.

What do you think will happen when these organisms live in and drink from a polluted water source?

- Students should identify that the organisms will have pollution in them as well.
- Instructor drops one penny into each student’s cup to represent the methylmercury that they have ingested.
- It may help to explain that each penny represents a relatively small amount of methylmercury—not enough to cause any negative health effects for the organisms. This clarification should prevent students from panicking that their organisms are dying of mercury poisoning.

Ingesting Plant Material (~5 minutes)

Other than water, what do organisms need to survive?

- Students should eventually provide the answer food.
- Zooplankton and copepods eat algae and phytoplankton (microscopic aquatic plants).
- Mummichogs eat both plant and animal material (e.g., algae, plants, zooplankton, copepods, insects, insect larvae, worms, and small crustaceans, mollusks, and fish).
- Striped bass eat smaller fish (e.g., mummichogs), as well as eels, crabs, mollusks, and other aquatic animals.

Instructor places a few cereal pieces into the cups of each student holding a zooplankton, copepod, or mummichog cup. This cereal represents the algae that these organisms have consumed.

Simulating Bioaccumulation (~5 minutes)

The zooplankton and copepods are almost full of food and water. What organisms do when they are full?

- Students should identify that organisms excrete waste.
- Students with zooplankton and copepod cups “excrete waste” by carefully pouring some of the contents of their cups back into the bowl(s) of water.

Do you get rid of all the water in your bodies when you go to the bathroom?

- The zooplankton and copepods also shouldn’t lose all of their water when they excrete waste.
- Emptying the cups only partway allows the pennies to remain in the cups, while water and cereal are lost.
- Students observe the zooplankton and copepod cups and record their observations (Observation Worksheet).
- Students should observe that the methylmercury remains in the zooplankton and copepods, even when regular food and water are excreted.
Bioaccumulation: the accumulation of substances inside living organisms, when those substances are ingested faster than they are excreted.

- It may help to break down this term into its word parts: accumulation, or the gathering together of a substance, and bio-, or life.
- It is also important to note that, although some pollutants like methylmercury bioaccumulate, many others do not.

Simulating Biomagnification (~10 minutes)

Do mummichogs eat anything other than plants?
- Mummichogs also eat animal matter, like zooplankton and copepods.
- Each student with a mummichog cup “consumes” a few zooplankton and copepods by transferring the contents of the zooplankton and copepod cups into their own.

Would mummichogs eat just part of a zooplankton or copepod, or the entire thing?
- They would eat the entire thing, so the students with zooplankton and copepod cups should pour the entire contents of their cups into the mummichog cups.
- Students observe the mummichog cups and record their observations (Observation Worksheet).
- Students should observe that the mummichogs now contain several times as much methylmercury as before.

The mummichogs are now almost full. Remind me: what do organisms do when they are full?
- Students should identify the mummichogs’ need to excrete waste.
- Students with mummichog cups should “excrete waste” by pouring some of the contents of their cups back into the bowl(s) of water.

The striped bass have not eaten yet. What do they eat?
- The striped bass eat mummichogs and other animals.
- Each student with a striped bass cup “consumes” a few mummichogs by transferring the entire contents of the mummichogs’ cups into their own.
- Students observe the striped bass cups and record their observations (Observation Worksheet).
- Students should observe that the striped bass now contain many times as much methylmercury as they did originally.

What if a human caught these striped bass and ate them?
- Students should predict that the methylmercury in the striped bass would transfer to the human.
- Students with striped bass cups empty their cups into the largest cup held by the instructor, who represents a human.
- Students observe the human cup and record their observations (Observation Worksheet).
- Students should observe that the human now contains all of the methylmercury.

Biomagnification: the process by which environmental contaminants are concentrated in living organisms at the top of the food chain.
- Again, this term can be broken down into its parts: magnification, or getting bigger or more concentrated, and bio-, or life.