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INQUIRY & INVESTIGATION

Stability & Change in a Freshwater Ecosystem: A Blooming Mess

RECOMMENDED FOR *AP Biology*

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Abstract

A report by the U.S. Environmental Protection Agency found 46% of rivers and streams and 21% of lakes are in poor biological condition (EPA, 2017). In this 5E standards-based inquiry lesson, students actively engage with the natural phenomena of algal blooms through the introduction of the harmful algal bloom (HAB) that occurred in Lake Erie's western basin in the summer of 2011. Students make sense of relationships within aquatic ecosystems, using microcosms (miniature ecosystems) containing phytoplankton and zooplankton, and then communicate their findings through a scientific manuscript. This lesson engages students in the three-dimensional learning identified in the Next Generation Science Standards (NGSS) under the standard of HS-LS2, Ecosystems: Interactions, Energy, and Dynamics. More specifically, students address the expectation of HS-LS2-6 when they make sense of how the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, while changing conditions may result in new ecosystems. This long-term scientific investigation also provides students with opportunities to make sense of aspects of the nature of science, while increasing their science content knowledge and understanding of the practices of science. Evaluation of student work occurs at all stages of the lesson.

Keywords: *Investigation, ecosystem, zooplankton, phytoplankton, anthropogenic, algal bloom.*

○ Introduction

In line with the Next Generation Science Standards (NGSS), high school students learn about organization levels—cells, tissues, organs, organisms, populations, communities, and ecosystems—of living systems (NGSS Lead States, 2013). Making sense of the relationships among the various levels of organization in an ecosystem is the focus of NGSS-HS-LS.2: Ecosystems: Interactions, Energy, and Dynamics. Ecosystems include close interactions among both biotic and abiotic factors, with a delicate balance between these factors in determining an ecosystem's success or failure. While students may be familiar with top-down, predator-controlled ecosystems such as that of the reintroduced wolves in Yellowstone National Park, students may be less familiar with slowly escalating events that result in significant changes in an ecosystem, such as increasing agricultural use of fertilizers and pesticides. These slowly escalating events can cause a bottom-up control where organisms at higher trophic levels are controlled by those at the bottom, resulting in a producer-controlled ecosystem. When the initial negative environmental effect is on the primary producers, the "effect" has the potential to impact the upper trophic levels, causing a trophic cascade.

The *National Rivers and Streams Assessment 2008-09* found that "46% of river and stream miles are in poor biological condition." The *National Lakes Assessment 2012* identified 21% of lakes sampled in the United States as hypereutrophic (characterized by abnormally high algal activity); they are, therefore, also classified in poor biological condition (EPA, 2017). This 5E lesson focuses on the crosscutting concept of stability and change through the lesson's driving question, How do anthropogenic factors affect relationships in an aquatic ecosystem?

Throughout the lesson, students explore anthropogenic influences on inland water bodies as they plan and carry out investigations on microcosms (miniature ecosystems). Then, using data from their microcosm, students engage in the scientific practice of arguing from evidence. To strengthen students' science literacy skills, this lesson explicitly addresses both the use of scientific models, as students design and create miniature ecosystems susceptible to potential algal blooms, and the empirical nature of science, as they collect and analyze data. Evaluation of student work occurs at all stages of the lesson.

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○ Background

Aquatic ecosystems located around areas of agriculture are commonly affected by anthropogenic (human-caused) stressors that can include habitat fragmentation due to land use changes, loss of surrounding habitat, or chemical pollution (Piggott et al., 2015). Transport of chemical stressors (pesticides and fertilizers) is facilitated by drainage systems (Blann et al., 2009). Consequently, pesticides have been found in 97% of U.S. streams in agricultural areas (Dalton et al., 2015). In addition, eutrophication (excessive nutrient buildup leading to dense phytoplankton growth) is among the top causes of water quality impairment for water bodies across the United States (EPA, 2017). Cultural eutrophication is specifically caused by excessive inputs of chemicals, mainly phosphorus (P) and nitrogen (N) compounds, from human activities like farming and the water runoff it produces, and it occurs at a much faster rate than natural eutrophication. Eutrophication has multiple negative effects on aquatic ecosystems, which can include increased biomass of phytoplankton, oxygen depletion, fish kills, and shifts of phytoplankton into bloom-forming species that can be inedible or toxic for zooplankton (Carpenter et al., 1998).

Algae are aquatic organisms that contain chlorophyll but lack true stems, roots, leaves, and vascular tissues. They include both single-cell organisms such as phytoplankton and multicellular organisms such as seaweed. Due to their trophic location in an aquatic food web, algae play an important part in the services they provide to zooplankton and other trophic level organisms. For example, through photosynthesis, phytoplankton release oxygen into their environment and transform solar energy into energy-rich organic molecules. Planktonic communities can, in the presence of anthropogenic inputs, shift from primarily green algae to different forms of primary producers, such as *Anabaena* spp., that are less edible and can produce toxins (Chia et al., 2018). This change in planktonic communities can alter other communities at higher levels of the food chain through bottom-up control (de Bernardi & Giussani, 1990).

Zooplankton (primary consumers) serve as a conduit in aquatic ecosystems as energy is transferred from primary producers to secondary consumers. Zooplankton are sensitive to the effects of anthropogenic inputs either from direct exposure by insecticides or indirectly from herbicidal effects on algae. Environmental stress can also affect zooplanktons' ability to reproduce efficiently through parthenogenesis or cause them to induce ephippia (resting egg) production (Kleiven et al., 1992).

The effects of anthropogenic activities on nearby water bodies can serve as a learning tool to evaluate our role, as humans, in an ecosystem. Harmful algal blooms (HABs) are often a result of anthropogenic events that have caused negative impacts on freshwater ecosystems. In 2011, Lake Erie's western basin had its largest HAB in recorded history, with its peak algal density being three times greater than any previous year. The western basin covers nearly 7 million acres, with 75% of the land used in agricultural production. During the spring of 2011, large storm runoff events occurred between February 17 and June 8 that exceeded the 99.8th percentile for the Maumee River daily discharge. Additionally, dissolved reactive phosphorus loading that was four times that of the Sandusky River drained into the western basin (Michalak et al., 2013). This historic event serves as the anchoring phenomenon for the lesson.

○ Engage: Lake Erie Algal Bloom Activity

As an introduction to the lesson's anchoring phenomenon, students watch a two-minute video about the Lake Erie harmful algal bloom of 2011 (https://www.youtube.com/watch? v=oZ_Xpetc0o4). The news clip shows the HAB, the reasons believed to cause the event, and the dangers posed to animals and humans. Students are tasked to compose three questions as they watch the video. In small groups, students discuss all group members' questions and then collaboratively identify and rank their top three questions in order of their group's interest.

During a whole-class discussion, each small group adds their three questions to a driving question board, then the class works together to sort the questions into categories based on theme similarities. These similarities may include causes of the algal bloom, effects on relationships in the ecosystem, use of chemicals such as herbicides and fertilizers, anthropogenic impacts on the algal bloom, the greater impacts of the algal bloom, or improving the algal bloom issue. Guided by the teacher, the class chooses one overall driving question for the lesson, How do anthropogenic factors affect relationships in aquatic ecosystems?

○ Explore: Aquatic Ecosystem Microcosm Investigation

During the Explore phase, students engage in the science practice of planning and carrying out an investigation as they construct microcosms and collect data to begin to figure out the lesson's driving question, How do anthropogenic factors affect relationships in aquatic ecosystems? To address the driving question, student groups design investigations to answer the questions they wrote in the Engage phase. Students explore the impacts of varying amounts of chemicals, potentially introduced by humans through agricultural runoff, on algal growth and zooplankton life.

Special note: At least three weeks before conducting this lesson, experimental organisms (algae and zooplankton) are cultured to ensure proper density for students' experiments (see Supplemental Material available with the online version of this article).

With guidance from the teacher, students complete the Microcosm Lab Planning form (available in the Supplemental Material online) to design their investigations. Using peer-reviewed sources, the Explore phase begins with students conducting background research about the two species to be studied (algae and zooplankton) and the anthropogenic factors that have been shown to contribute to algal blooms, specifically agricultural inputs. To further prepare for their experimentation, students research the trophic contributions of photosynthesis and cellular respiration on algal growth, and the impacts of agricultural fertilizers. Literature findings prepare students to select their experimental variables and controls, write research questions and detailed experimental procedures, and generate hypotheses. Examples of student hypotheses include "Increases in Roundup will cause a decrease in algal growth, which will lower total offspring in *Daphnia*" and "Increases in fertilizer will cause algal growth to increase and will cause higher total *Daphnia* offspring in those treatments." For their independent variable, students may choose from a variety of possible anthropogenic inputs such as pesticides or fertilizers; the independent variable can be a pesticide or fertilizer and can vary in amount (see the Supplemental Material online).

Students create three replicates of the control group and three replicates of each treatment group, using transparent containers larger than 3 ounces. Using green algae, blue-green algae, and live *Daphnia magna* (zooplankton available from biological supply companies), students fill their microcosms with spring water that has been treated with either a fertilizer or an herbicide that they selected to model anthropogenic inputs, 4 mL of algae, and one adult *Daphnia*. While algae serve as a food source for *Daphnia* in the microcosm, algal blooms can also be detrimental to *Daphnia* populations. All student groups use *Daphnia* that are approximately the same age, to control effects (size, fecundity, and likelihood of survival) that can be more potent at different life stages. Potency can change depending on *Daphnia*'s age, due to factors such as lower fat content and size in newborns (Xiang et al., 2010). Neonates (newborns) are removed from their microcosm each day so that the adults continue to only reproduce through parthenogenesis (asexual reproduction through forming of embryos without fertilization). Each day for 9 to 12 days, students gently stir the contents (algae, *Daphnia*, and water) of their microcosm before measurements are taken, to ensure there is homogeneity in the container. Daily, students collect data that can include, but are not limited to, the following: the pH, using a pH sensor, to check for evidence of the algae carrying out photosynthesis and cell respiration (lowered pH indicates higher carbon dioxide levels resulting from cellular respiration, and raised pH indicates that carbon dioxide has been used up in photosynthesis); the verification of live/dead *Daphnia* adults; the count of *Daphnia* neonates; algal cell counts (using a hemocytometer); and Secchi stick readings for water turbidity to indicate algal density (Figure 1). Students should wear goggles and gloves for protection from the chemicals in fertilizers and herbicides and also to prevent contamination of the microcosms.

At the end of the data collection period, students organize their data into appropriate tables and graphs. Using Excel or Google Sheets, students transfer their data into a spreadsheet and use that spreadsheet to create appropriate graphical representations of their data. Students use scatterplots and line graphs to show change over time, and bar graphs like the one in Figure 2 to compare groups of data. These tables and graphs are used in the Explain phase.

○ Explain: Aquatic Ecosystem Microcosm Investigation Lab Manuscript Writing

In the Explain phase, students write a lab manuscript as a mechanism for explaining the impact that changing conditions, caused by anthropogenic inputs, can have on an aquatic ecosystem. The purpose of the lab manuscript is for students to engage in argument from evidence as they support a claim that addresses their investigation's research question.

Students use a lab manuscript template to create their lab manuscript, which answers their group's research question from the microcosm investigation (see slides and other materials in the Supplemental Material online). Lab manuscripts begin with an introduction that provides background information pertaining to the investigation, such as the zooplankton and algae species used in students' investigations. The introduction also identifies students' research question and hypothesis. The methods section describes the procedures used to construct, maintain, and monitor the microcosms and identifies the experimental variables, including the dependent and independent variables. The results section includes clearly labeled tables and graphs to display their

Figure 1. During the microcosm investigation students use a microscope and hemocytometer to count cells, transfer *Daphnia* neonates to separate containers, and use a Secchi stick to measure turbidity.

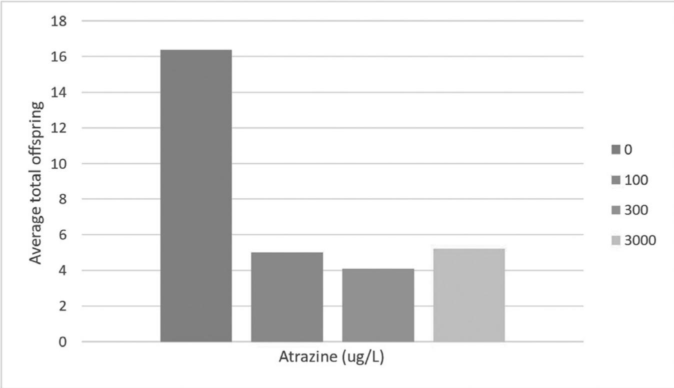

Figure 2. Sample results from a group using varying concentrations of atrazine (an herbicide) as the independent variable.

findings, with each supported by a descriptive narrative. The discussion section addresses the NGSS performance expectation HS-LS2-6 as it includes a thorough explanation of the changing relationships in the ecosystem based on evidence obtained from students' experimental findings. Using the CER format—claim, evidence, reasoning—students analyze their results as they attempt to address their research questions. Students cite the sources for their research, using in-text citations, and provide a reference list in MLA format. A grading rubric is provided in the Supplemental Material online.

○ Elaborate: Lake Erie Harmful Algal Bloom Long-Term Effects Research and Presentation

During the Elaborate phase, students connect changes to effects: changes in an ecosystem that resulted from anthropogenic influence to societal effects (commercial fishing decline, tourism decline, toxic drinking water). As students read the Alliance for the Great Lakes article titled "Five Years Later: Lessons from the Toledo Water Crisis," they highlight specific societal impacts of the algal bloom. Questions such as the following engage students in a whole-class discussion: What were some ways the surrounding communities relied on the lake? How did the algal bloom impact resources the lake provided to the communities? How did the effects of the algal bloom change everyday life for surrounding communities?

Next, students are placed in groups and assigned topics, which were generated from the article and are related to societal effects of HABs. These topics may include drinking water availability, impacts to tourism, and impacts to commercial fishing. Students conduct literature reviews on their topic and create a slide presentation to share with the class. Presentations describe the HAB, the level of impact of the HAB effect on society, if something specific is causing the HAB effect, and whether the HAB can be remediated. Presentations are five to seven minutes in length.

Following class presentations, students are tasked to write a (1-page) paper on how human activities can cause changes to an aquatic ecosystem and how those changes in turn negatively impact human society. To ensure all aspects of the lesson are included in their written statement, students incorporate the following key terms: *anthropogenic, cultural eutrophication, algal bloom*, and *zooplankton*.

○ Evaluate

The lesson includes multiple opportunities for assessment to monitor students' understanding of both science content knowledge and scientific practices. In the Explore phase, students demonstrate their ability to design and conduct an experiment using a microcosm, with each student group's investigation addressing some aspect of how anthropogenic factors can affect aquatic ecosystems. Students also collect data and organize their data into tables and graphs, which are later used in the Explain phase when they write their lab manuscript and engage in supporting their claims during the discussion section. As the lesson's summative assessment, students write a reflection on how human activities may lead to changes in aquatic ecosystems and how those changes may in turn impact human society. This array of assessments is designed to meet the needs of students' diverse academic strengthens.

○ Conclusion

Throughout the lesson, students actively engage with the natural phenomena of algal blooms as they address all three NGSS dimensions (Table 1). Starting with the introduction of the 2011 HAB in Lake Erie's western basin, students make sense of relationships found in aquatic ecosystems and the impacts anthropogenic activities like agriculture have on those ecosystems. Students very often have difficulty understanding ecosystem relationships because they have never seen these relationships for themselves. The lesson supports students' growth in the skills of the NGSS practice of "planning and carrying out an investigation" as they construct models of microcosms (miniature ecosystems) that contain phytoplankton and zooplankton. Students further gain valuable laboratory experience collecting and analyzing data to provide evidence of relationships that exist between these two aquatic species exposed to herbicides or fertilizers. This lesson supports students' writing and argumentation skills as they write a lab manuscript that concludes with evidence to support claims made about the impacts of anthropogenic activities on aquatic organisms. These skills are further strengthened during the final assessment when students demonstrate their understanding of the connections between human activities and aquatic ecosystems. Throughout this lesson, students actively engage in some of the same practices as scientists who investigate HABs that harm aquatic systems and ultimately human society.

References

Blann, K. L., Anderson, J. L., Sands, G. R., & Vondracek, B. (2009). Effects of agricultural drainage on aquatic ecosystems: A review. *Critical Reviews in Environmental Science and Technology*, *39*(11), 909–1001. https://doi.org/10.1080/10643380801977966

Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications*, *8*(3), 559–568. https://doi.org/10.1890/1051-0761(1998)008[0559: NPOSWW]2.0.CO;2

Chia, M. A., Jankowiak, J. G., Kramer, B. J., Goleski, J. A., Huang, I.-S., Zimba, P. V., do Carmo Bittencourt-Oliveira, M., & Gobler, C. J. (2018). Succession and toxicity of *Microcystis* and *Anabaena* (*Dolichospermum*) blooms are controlled by nutrient-dependent allelopathic interactions. *Harmful Algae*, *74*, 67–77. https://doi.org/10.1016/j.hal.2018.03.002

Table 1: Next Generation Science Standards.

NGSS	HS-LS2. Ecosystems: Interactions, Energy, and Dynamics
Performance Expectation	**HS-LS2-6.** Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions but changing conditions may result in a new ecosystem.
Science and Engineering Practice	**Planning and Carrying Out an Investigation.** Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters. **Engaging in Argument from Evidence.** Argumentation is the process by which explanations and solutions are reached.
Disciplinary Core Ideas	**HS-LS2.C: Ecosystem Dynamics, Functioning, and Resilience.** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.
Crosscutting Concept	**Stability and Change.** For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

Dalton, R. L., Boutin, C., & Pick, F. R. (2015). Nutrients override atrazine effects on riparian and aquatic plant community structure in a North American agricultural catchment. *Freshwater Biology*, *60*(7), 1292–1307. https://doi.org/10.1111/fwb.12563

de Bernardi, R., & Giussani, G. J. H. (1990). Are blue-green algae a suitable food for zooplankton? An overview. *Hydrobiologia, 200*(1), 29–41. https://doi.org/10.1007/BF02530326

EPA. (2017). *National water quality inventory: Report to Congress*. https://www.epa.gov/waterdata/2017-national-water-quality-inventory-report-congress

Fox36. (n.d.) *Lake Erie algae* [Video]. YouTube. https://www.youtube.com/watch? v=oZ_Xpetc0o4

Kleiven, O. T., Larsson, P., & Hobæk, A. (1992). Sexual reproduction in *Daphnia magna* requires three stimuli. *Oikos*, *65*(2), 197–206. https://doi.org/10.2307/3545010

Michalak, A. M., Anderson, E. J., Beletsky, D., Boland, S., Bosch, N. S., Bridgeman, T. B., … Zagorski, M. A. (2013). Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. *Proceedings of the National Academy of Sciences USA, 110*(16), 6448–6452. https://doi.org/10.1073/pnas.1216006110

NGSS Lead States. (2013.) *Next Generation Science Standards: For States, By States*. National Academies Press.

Piggott, J. J., Townsend, C. R., & Matthaei, C. D. (2015). Reconceptualizing synergism and antagonism among multiple stressors. *Ecology and Evolution*, *5*(7), 1538–1547. https://doi.org/10.1002/ece3.1465

Xiang, F., Yang, W., Chen, Y., & Yang, Z. (2010). Acute toxicity of nitrite and ammonia to *Daphnia similoides* of different developmental stages: Using the modified Gaussian model to describe. *Bulletin of Environmental Contamination and Toxicology, 84*(6), 708–711. https://doi.org/10.1007/s00128-010-0017-x

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