The EcoCasting Project: Ecological Forecasting: Framework to Evaluate the Effects of Multiple Stresses on Lake Michigan Food Webs and Guide Remediation is supported in part by the National Oceanic and Atmospheric Administration under grant NMFS-HCPO-2009-2002033 to Kimberly Gray. However, any opinions, findings, conclusions, and/or recommendations are those of the investigators and do not necessarily reflect the views of the Administration.

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Teacher Overview
Answer Key
Student Guide
Student Response Sheet
Overview

The Office of STEM Education Partnerships (OSEP) at Northwestern University has created these materials to help students learn about the scientific observations, measurement techniques, and computer models used in an ongoing National Ocean and Atmospheric Administration (NOAA) Ecological Forecasting project. This curriculum is based on research conducted in Calumet Harbor, Illinois, where a NOAA team is developing more precise food web models to better predict PCB toxin levels in Great Lakes fish.

The EcoCasting Project is a set of hands-on inquiry activities focused on ecosystems, food webs, and bioaccumulation designed for use in environmental science and biology classes in grades 9-12. The curriculum is aligned to Illinois state standards, the College Readiness Standards, and the National Science Education Standards. It addresses the following objectives:

- Using ecological models to investigate food web complexity
- Investigating PCB toxins and how they move through an ecosystem
- Investigating invasive species and how they disrupt ecosystems and change bioaccumulation patterns

EcoCasting is comprised of four major investigations, which may be done as stand-alone lessons or as parts of a larger unit. Investigation I is an introductory activity that will help the students to see relevance of the unit through a connection with a major current event, the 2010 BP oil spill in the Gulf of Mexico.

In Investigation II, students will be introduced to the concepts of trophic levels, predator-prey interactions, food chains and food webs. Students will use the NetLogo Aquatic Food Chain model to explore population changes among the primary species of the Calumet Harbor food web.

The objective of Investigation III is to familiarize students with bioaccumulation, persistent organic pollutants (POPs), polychlorinated biphenyls (PCBs), and the dangers these pollutants pose to living organisms. Students will quantitatively model bioaccumulation and biomagnification using the NetLogo Aquatic Bioaccumulation model and create tables and graphs to analyze their data.

Investigation IV explores how the introduction of a new species into a food web can change feeding relationships amongst the native organisms, and how such invasions can alter the process of PCB bioaccumulation in the food web. Students will use the NetLogo Aquatic Invasive Species model to detect any cause-and-effect relationships focused around the invasion of a new species into an already established environment.

More information on the scientific research cited in EcoCasting can be found in Chemical Amplification in a Invaded Food Web: Seasonality And Ontogeny In A High-Biomass, Low-Diversity Ecosystem published in Environmental Toxicology and Chemistry, Volume 27, No. 10.
EcoCasting: an Ecological Forecasting Curriculum

Science Summary for Teachers

What is Ecological Forecasting?

The term ‘ecological forecasting’ refers to a way of modeling ecosystems that allows scientists to predict how a particular ecosystem will respond to disturbances. Ecological forecasting models incorporate information about biotic (food web dynamics) and abiotic (environmental) ecosystem components. By incorporating many different facets of an ecosystem, these models can produce more reliable ‘forecasts’ of change at a whole ecosystem level, instead of considering the future of a single species or pollutant.

Invasive Species in the Great Lakes

According to the State of the Great Lakes 2009 report, published by the U.S. EPA and Environment Canada, there are currently 185 non-native aquatic species and 157 non-native terrestrial species in the Great Lakes region. A non-native species is any species that has been introduced or spread to a region outside its natural range. More than 10 percent of the non-native species in the Great Lakes region have become invasive species, which means that their “presence in the environment causes economic or environmental harm or harm to human health” (EPA 2009). Human activity has had by far the most influence on the spread of invasive species to the Great Lakes. The shipping, home aquarium, and fish-bait industries all contribute to the spread of invasive species in the Great Lakes. Ballast, the water that ships pump into and out of their hulls to control buoyancy, is an extremely efficient vector for the transport of species from one location to another. The Welland Canal, which was built between Lake Ontario and Lake Erie in 1919, connects the lower and upper Great Lakes and has allowed several species, such as alewives and sea lampreys, to invade the lakes further inland.

The invasive species explored in this curriculum are the round goby (Apollonia melanostoma), the zebra mussel (Dreissena polymorpha) and the quagga mussel and (Dreissena bugensis). All three of these organisms are native to the Ponto-Caspian region in eastern Europe (parts of Ukraine and western Russia; see map).
The zebra mussel has become an invasive species because of its significant economic and environmental impacts to the Great Lakes region. Zebra mussels were first noticed in Lake St. Clair (near Detroit) in 1988. They have since colonized bottom sediments in all of the Great Lakes and displaced native benthic species, which are organisms living in or on sediments at the bottom of a lake or river. Zebra mussels form thick beds along the inside of water intake pipes, which can pose a serious economic problem as these organisms are very difficult and costly to remove. Additionally, they filter a huge volume of water – up to one gallon of water per day per mussel. This improves water clarity in the shallow zones the mussels typically colonize, but in doing so it reduces the amount of food available to native species. Because the zebra mussels remove the bulk of the phytoplankton from the water column, less energy from primary productivity is available for zooplankton. This dramatically alters the food web.

Quagga mussels, more recent newcomers to the Great Lakes ecosystem, pose similar threats but because they are able to colonize both soft and hard substrates they have succeeded, or out-competed, zebra mussels as the dominant invasive species in many areas. Often, invasive species are much more abundant in their “new” environments because they lack sufficient competitors and predators to keep their populations in check. More than 99 percent of the mussel species native to the Great Lakes have disappeared as a result of the invasion by the zebra and quagga mussels.

The third invasive species addressed in this activity is the round goby. The round goby is a small brown fish that is native to the same bodies of water in Eurasia as the zebra and quagga mussels. These fish prefer shallow waters and perch themselves on rocks using their small, front fins; however, they can travel to deeper waters to feed. Round gobies are aggressive eaters who enjoy diets of smaller fish, fish eggs and fry (early life stage of fish), aquatic insects, and zebra mussels. They can out-compete for food with native species within an ecosystem because they have the ability to feed in total darkness (USGS 2010). Just like the zebra and quagga mussels, the round goby was introduced to the Great Lakes waterways via the ballast water found inside of freighter ships from Europe and/or Asia. They were first found within the Great Lakes near the Michigan-Ontario, Canada border in 1990. By 1994 the round goby had been detected in southern Lake Michigan, and they can now be found in all five of the Great Lakes. Round gobies are voracious eaters and consume large quantities of zebra mussels and fish eggs, both of which can be highly contaminated with biomagnifying toxins. (NOTE: biomagnification is different from bioaccumulation. Bioaccumulation is the increasing concentration of contaminants from any source within an individual organism over time. Biomagnification is the increasing concentration of contaminants in organisms at successive trophic levels.) Round gobies are, in turn, predated by sport fish such as walleye and smallmouth bass; thus, the presence of the round goby in the food web increases toxin transfer to humans who eat these fish.

Chemical Contamination in the Great Lakes

In addition to the many environmental stresses caused by invasive species, the Great Lakes have a long history of anthropogenic (caused by human activity) chemical
contamination. While contaminant releases have declined substantially in the last few decades, the Lakes are still subject to contaminant loading from industrial wastewater, air pollution, contaminated sediments, surface runoff, and plumes of polluted groundwater. Contaminated sediments can return pollutants to the food web when they are disturbed (during dredging, for example) and via direct contact with primary producers such as periphyton. Since periphyton are at the base of the food chain, this initiates the process of biomagnification. Many industrial pollutants, such as PCBs, are lipophilic, or fat-soluble and they are easily stored in fatty body tissues of organisms in the environment. While the concentrations of these chemicals in open waters are generally quite low, there are several localized coastal areas where the level of contamination remains very high. The EPA has designated these as Areas of Concern.

**History of the EcoCasting project**

The combined effects of zebra and quagga mussel invasions have contributed to the benthification of Calumet Harbor (Chicago, IL). The term benthification refers to “a shift in nutrients and energy from the water column to the sediment-water interface” (Ng, et al. 2008), which means that most of the biomass and transfers of energy occur at the bottom of the lake. For the most part, this is due to the sprawling populations of mussels on the lake bottom. Because these prolific invasive species have out-competed native species, the Calumet Harbor ecosystem is now dominated by a small number of invasive species, which has led to a reduction in biodiversity.

A team of researchers began studying Calumet Harbor in order to understand the impacts of invasive species and industrial pollution on the structure and function of this newly altered food web. The study of the impacts and spread of chemical contaminants is called environmental toxicology. The scientists began research in 1998-1999, collecting initial data to develop a food web model. They returned to the field site to collect further data in 2005, and made additional discoveries about the complexities of this food web. The following text summarizes the published findings: “Ng, et al. 2008. Chemical amplification in an invaded food web: seasonality and ontogeny in a high-biomass, low-diversity ecosystem. *Environ. Toxicol. Chem.* 27: 2186-2195.”

**The Food Web Model**

The scientific article on which the EcoCasting curriculum is based presents an ecological forecasting model of energy transfer and PCB biomagnification through the Calumet Harbor food web. The model incorporates stable isotope data, bioenergetic rates, diet information, and PCB concentrations in the organisms studied. Stable isotope analysis is frequently used to determine the trophic position of organisms within a food web. This model uses the ratio of $^{15}$N:$^{14}$N among the major organisms in the food web. The $\delta^{15}$N ratio, as it is called, increases with trophic level by about 3.4‰ (parts per thousand) from prey to predator. This occurs because $^{15}$N conserved in body tissues, whereas $^{14}$N is more readily excreted from the body (as urea, for example). Bioenergetic rates, the next parameter, measure the energy budget of an organism. Since energy is conserved, the total
energy consumed by an organism must therefore equal the sum of all other energy that is used for growth, reproduction, respiration, or that leaves the organism as waste.

Determining Trophic Level

The authors of this study designated zebra mussels, at trophic level 2, as the ‘baseline’ species for this model and measured the trophic level of other organisms in the food web against that of zebra mussels. They chose to do this because seasonal variability in δ\(^{15}\)N ratio is less in primary consumers than in primary producers. Trophic level (P) is calculated using the difference in δ\(^{15}\)N ratio between organisms in the following formula:

\[
P_i = \frac{\delta^{15}N_i - \delta^{15}N_0}{3.4} + P_0
\]

where \(P_0\) is the trophic level assigned to the zebra mussels (baseline species), and \(\delta^{15}N_0\) is the ratio for zebra mussels. \(\delta^{15}N_i\) is the ratio measured for species \(i\), and \(P_i\) is the trophic level calculated for species \(i\).

Results

Trophic Levels

Figure 1. Trophic position of organisms in Calumet Harbor ecosystem. Reproduced from Ng, et al. 2008. Chemical amplification in an invaded food web: seasonality and ontogeny in a high-biomass, low-diversity ecosystem. Environ. Toxicol. Chem. 27: 2186-2195.
Figure 1 shows the trophic levels of the major organisms in this ecosystem. The trophic level ($P$) of periphyton was determined to range from 1-2.8, which is an unusually large range. Typically, $P = 1$ for primary producers because they are at the base of the food web. It can be difficult, however, to obtain a sample that includes only the algae components. Usually there is a significant amount of detritus that is mixed in with the periphyton sample. This causes substantial contamination because the $\delta^{15}N$ ratio of detritus reflects the organism from which it came. The largest contributors to the detritus pool in Calumet Harbor are mussels and the round goby, simply because they make up the most biomass to the ecosystem. Thus, the range of $P$ for periphyton reflects the detritus contributed by these organisms at higher trophic levels.

There is also measurable variation in the trophic levels of round gobies (Figure 1). This is a result of the feeding habits of this organism. During spawning season the round goby predates on the eggs of smallmouth bass and other round gobies. The sampling for this project took place during round goby spawning season (May-August), and this feeding behavior is reflected in the higher trophic level of some round gobies sampled. In addition to these seasonal changes in diet, however, there is an additional quirk to these results. The researchers discovered that it is only the smaller round gobies that are able to invade the nests of other fish to predate their eggs; therefore, it is only the smaller gobies that are populating the higher trophic levels. The scientists entered this information into their model, and produced the following figure, with distinct size classifications (Figure 2).

![Figure 2](image)

**Figure 2.** Trophic position of organisms in Calumet Harbor ecosystem with small (S), medium (M) and large (L) size classifications. Reproduced from Ng, et al. 2008. Chemical amplification in an invaded food web: seasonality and ontogeny in a high-biomass, low-diversity ecosystem. *Environ. Toxicol. Chem.* 27: 2186-2195.
During the months of the year when there is no spawning occurring, \( p=3 \) for the round goby because it is not consuming the fish eggs that elevate its trophic level. The feeding behavior of round gobies runs counter to traditional food web dynamics. Eggs, which contain high levels of lipids, are significant sources of lipophilic toxins such as PCBs. Because small round gobies are consuming more of this PCB-rich food source than large round gobies, it is the smaller fish that have the highest toxin concentration. Thus, during spawning season, round gobies do not fit into the traditional model of bioaccumulation.

Round gobies also undergo **ontogenetic** diet changes, or changes in feeding habits due to life stage, or size. The round goby undergoes such changes even when there is no spawning occurring. Small gobies, <70mm, consume nonmussel invertebrates such as amphipods. Medium-sized gobies, 70-100mm in length, consume amphipods and mussels, and large gobies, greater than 100mm, consume mussels only. They eat both zebra and quagga mussels. Similarly, smallmouth bass undergo diet changes according to size. While this study did not measure these changes, it is known from other studies that they transition from invertebrates to crayfish to fish as they grow.

**A Revised Model**

Having learned all of this, the researchers returned to their model and added their new data about ontogenetic and seasonal diet changes. Thus, their final model reflects considerable changes from the original (see Figure 3).

![Diagram](https://example.com/diagram.png)

**Figure 3.** (a) Foodweb diagram showing simple predator-prey interactions. (b) Foodweb including seasonal and life-stage feeding habits. Reproduced from Ng, et al.

In Figure 3, black arrows reflect energy transfer from a lower trophic level to a higher one; red dashed arrows represent predation at equal or higher trophic levels. This creates a positive feedback effect because it raises the trophic position of the predator from its traditional level. As Ng, et al (2008) described, “Consumption of detritus and fish eggs links predators to prey items at equal or higher trophic positions than their own, creating a positive feedback effect.”

Species Succession in Calumet Harbor

The authors returned to Calumet Harbor in 2005 to collect samples in order to validate the predictions of their model. They analyzed tissue samples from round gobies and found that, on average, PCB concentrations were 3 times lower than they had been in 1999. In addition, they observed that quagga mussels had become the dominant mussel species in the harbor during the intervening time. This species had also become the primary food source for the round goby. The scientists proposed that quagga mussels, which can live on sandier bottoms where there is less PCB bound to the sediment, bioaccumulate fewer toxins than the zebra mussels and therefore pass on lower toxicity levels to round gobies. While this outcome made model validation difficult for the scientists, it does provide more insight to the ecological consequences of invasive species.

Conclusions

In this study, small round gobies comprised roughly 20-40% of the smallmouth bass diet. Other studies of smallmouth bass, however, suggest that the abundance of round goby in this ecosystem is changing the feeding habits of smallmouth bass, encouraging young bass to begin piscovory (a fish-only diet) earlier. Since small round gobies, the new prey of young smallmouth bass, are the most highly contaminated, this could potentially increase the toxin transfer to bass. The positive feedback loops described in this research demonstrate the importance of cleaning up the sediments of polluted harbors to protect the health of the top consumers in this ecosystem, humans.
1. Is Fish Safe To Eat, Or Is It a Toxic Risk?

Teacher Overview
Answer Key Parts 1 & 2
Student Guide Part 1: K-W-L Chart
Student Guide Part 2: Toxic Fish in the News
Student Response Sheet: Part 1
Student Response Sheet: Part 2
Investigation I: Is Fish Safe To Eat, Or Is It A Toxic Risk?

Purpose
The purpose of this activity is to prepare students to learn about the dynamics of food chains and webs, bioaccumulation vs. biomagnification of a toxin within a food web, and how the introduction of an invasive species can affect all of the above.

Overview
This introductory activity will help students to see the relevance of the unit through a connection with a major current event. They will first be asked to consider the driving question of the activity by using a K-W-L chart to brainstorm how eating fish could be considered dangerous to humans. Students will then be asked to read a news article regarding the Gulf oil spill and how it is projected to impact marine food webs within that region. Students will be asked to complete reading comprehension questions at the end of the article.

Student Outcomes Specific to this Investigation

National Research Council’s (NRC) National Science Education Standards for grades 9-12

- Humans have a major effect on other species. For example, one influence of humans on other organisms occurs through land use—which decreases space available to other species—and pollution—which changes the chemical composition of air, soil, and water.

Time
Part 1: KWL chart – one 45 minute class period
Part 2: Reading “Toxic Fish in the News” – one 45 minute class period

Level
Secondary (9-12)

Materials and Tools

- White board/dry erase markers (or any other tool used for large group visual display such as GoogleDoc, SmartBoard, etc.)
- Yahoo!News Associated Press article
- Student Guide and Student Response Sheets

Preparation
Make copies of article and Student Guide as necessary
Prerequisites
None

Background
The food web that is being focused on in this unit is found in the Calumet Harbor in Chicago, Illinois (Figure 1). It is a part of the Port of Chicago, which is found along the southern portion of Lake Michigan, and is dominated mainly by invasive species. Most of the life that exists within the harbor consists of zebra mussels, quagga mussels, and the round goby—all organisms considered invasive aquatic species in the Great Lakes. To a lesser degree, native organisms such as smallmouth bass and crayfish have also been found within the harbor. Besides being so inundated with non-native life, the harbor is also considered to be heavily polluted with several toxins, one being polychlorinated biphenyls (PCBs). This is due to the industrial activity associated in and around the Port of Chicago over time.

Teaching Notes

Part 1: the KWL Chart
A K-W-L chart is a visual tool to help students organize their previous knowledge/misconceptions about a topic (K), questions or ideas that they’re interested in learning more about in regards to a topic (W), and what new information they’ve learned or walked away with from the lesson in regards to a topic (L). Some teachers may also call this type of chart a “What do I know/What do I want to know/What have I learned” chart. To get the activity started, construct a large K-W-L chart on a white board like the one shown below and allow the students to fill in the “K” and “W” columns.
<table>
<thead>
<tr>
<th>What do we already know?</th>
<th>What do we want to know more about?</th>
<th>What have we learned?</th>
</tr>
</thead>
</table>

You can revisit the “L” portion of the chart at the end of the reading assignment, or at the end of the unit to help summarize the information collected by the students.

**Part 2: Reading “Toxic Fish in the News”**
It is suggested that the article chosen for this investigation should be reviewed ahead of time to check for any vocabulary that may prove challenging to your students.
Investigation I: Is Fish Safe To Eat, Or Is It A Toxic Risk?

Part 1: K-W-L

<table>
<thead>
<tr>
<th>What do we already know?</th>
<th>What do we want to know more about?</th>
<th>What have we learned?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student answers will vary</td>
<td>Student answers will vary</td>
<td>Student answers will vary – should be revisited and filled out at the end of the unit/investigations</td>
</tr>
</tbody>
</table>

Part 2: Toxic Fish in the News

Q1. Before reading through the article, how do you think the oil spill in the Gulf of Mexico will affect the organisms that call it home? Will humans end up feeling the effects of these changes? Explain.

*Students should suggest that the oil will have polluted the water, making it difficult for some organisms to survive in their natural habitats. They may suggest that this will affect humans who depend on this natural resource for food (fish, shrimp and other shellfish) and those who visit the beaches. Students may also predict that this spill may cause drilling regulations to become stricter in the coming years, affecting oil supply in the U.S.*

Q2. How will the already visible impacts of oil contamination to a few organisms, such as pyrosomes and young crabs, have larger side effects?

*The loss of pyrosomes will affect the endangered sea turtle population and the young crabs now holding oil under their shells will affect fish, turtles, and shorebird populations.*

Q3. What is the prediction for the seafood industry following this spill? Has this prediction been backed up by any evidence yet?

*It is predicted by some that the seafood industry will be impacted by the oil spill as predators eat contaminated marine life, possibly tainting seafood. It is also predicted*
that the organization of sea life in the Gulf will be reshuffled, or changed, and that this could negatively impact the ecosystem and the fishing industry over time. No evidence had been found at the time of the article to support these predictions.

Q4. How has the base of the food web in the Gulf of Mexico already been changed by the oil spill? Is this a good change for the food web or a bad one? Explain.

Oil and natural gas consuming bacteria have been found to be thriving in the Gulf waters. This is not projected to be a good change for the food web as it can impact fishing and introduce contaminants into the food web.

Q5. How is phytoplankton being impacted by the oil spill? Will this change in conditions necessary for phytoplankton survival have a large side effect? Explain.

The surface slick of oil is preventing sunlight from passing through to the phytoplankton, which need sunlight to survive (for photosynthesis). If the numbers of phytoplankton decrease, this could negatively impact smaller fish populations, such as the menhaden, that feed on the phytoplankton. If the menhaden fish population drops, this could impact the tuna, red snapper, and other fish populations as well.

Q6. Are the conditions of the aquatic ecosystem of the Gulf of Mexico expected to return to normal over time or not? How so?

Yes, it is predicted that the conditions of the ecosystem will rebound over time. Scientists expect that fish and other organisms living in untainted waters (and those that left the spill area for uncontaminated waters immediately after the spill) could eventually return to the impacted areas to repopulate them after the oil is cleaned up.
Investigation I: Is Fish Safe To Eat, Or Is It A Toxic Risk?

Well...what do you think? Is fish safe to eat, or is it a toxic risk? Have you ever considered that when eating that tuna fish sandwich for lunch or enjoying a dinner of locally caught trout? Can what you eat make you sick? How can this happen? This unit will hopefully help you to answer some of these questions by the end.

In Part 1 of this Investigation, you will be asked to think about how fish can be considered "toxic" and what can possibly lead them to be described as so. You'll brainstorm individually and share with your classmates information that you may already know about this topic, as well as some questions you hope to have answered by the end of the unit.

In Part 2 of this Investigation, we'll look at a recent environmental catastrophe that will help us better set the stage for some of the upcoming investigations. The Gulf of Mexico oil spill that has finally come to an end will unfortunately impact the marine ecosystems of the region for many years to come. You will be asked to read a news article describing how scientists predict the oil spill will affect aquatic organisms within the Gulf.
Part 1: K-W-L

In this section you will fill out the following K-W-L chart with your classmates about the driving question to this Investigation. First, think about what you already know about fish being described as “toxic”. What would cause us to be able to describe them as such? How could they become “toxic”? Put your answers to these questions in the first column. Then, come up with some questions about the overall theme to the unit that you’d like to have answered and put them in the second column. We will leave the “L” portion of the chart blank until the end of the Investigation to see what questions you were able to actually answer and what new information you learned.

<table>
<thead>
<tr>
<th>What do we already know?</th>
<th>What do we want to know more about?</th>
<th>What have we learned?</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Investigation I: Is Fish Safe To Eat, Or Is It A Toxic Risk?

Part 2: Toxic Fish in the News

On April 20, 2010 the Deepwater Horizon oil rig owned by BP exploded and sank into the Gulf of Mexico. During the months that followed, an estimated 207 million gallons of crude oil were released into the water. Fortunately, the leaking well was capped on July 15th and stopped releasing oil into the Gulf. However, the impacts of such a large amount of oil being spilled into such a biologically diverse body of water will last for a long time.

In this part of the Investigation, you will be asked to read the following Associated Press article from early on in the spill to understand how scientists predict the oil spill will impact the marine ecosystems that exist in the Gulf of Mexico.

Question:
Q1. Before reading through the article, how do you think the oil spill in the Gulf of Mexico will affect the organisms that call it home? Will humans end up feeling the effects of these changes? Explain.
Scientists say Gulf spill altering food web

By MATTHEW BROWN and RAMIT PLUSHNICK-MASTI, Associated Press Writers

This June 15, 2010 photo provided by the University of California Santa Barbara, shows pyrosomes - cucumber-shaped, gelatinous organisms fed on by endangered sea turtles, pulled up after a deep cast in the vicinity of the oil spill in the Gulf of Mexico. Scientists are seeing early signs that the massive Gulf spill is altering the food web, by killing or tainting creatures that form the foundation of marine life and spurring the growth of others more suited to a fouled environment. (AP Photo/David L. Valentine, Department of Earth Science, University of California Santa Barbara)

Wed Jul 14, 9:04 am ET

NEW ORLEANS – Scientists are reporting early signs that the Gulf of Mexico oil spill is altering the marine food web by killing or tainting some creatures and spurring the growth of others more suited to a fouled environment.

Near the spill site, researchers have documented a massive die-off of pyrosomes — cucumber-shaped, gelatinous organisms fed on by endangered sea turtles.

Along the coast, droplets of oil are being found inside the shells of young crabs that are a mainstay in the diet of fish, turtles and shorebirds.

And at the base of the food web, tiny organisms that consume oil and gas are proliferating.
If such impacts continue, the scientists warn of a grim reshuffling of sealife that could over time cascade through the ecosystem and imperil the region’s multibillion-dollar fishing industry.

Federal wildlife officials say the impacts are not irreversible, and no tainted seafood has yet been found. But Rep. Ed Markey, D-Mass., who chairs a House committee investigating the spill, warned Tuesday that the problem is just unfolding and toxic oil could be entering seafood stocks as predators eat contaminated marine life.

"You change the base of the food web, it's going to ripple through the entire food web," said marine scientist Rob Condon, who found oil-loving bacteria off the Alabama coastline, more than 90 miles from BP's collapsed Deepwater Horizon drill rig. "Ultimately it's going to impact fishing and introduce a lot of contaminants into the food web."

The food web is the fundamental fabric of life in the Gulf. Once referred to as the food chain, the updated term reflects the cyclical nature of a process in which even the largest predator becomes a food source as it dies and decomposes.

What has emerged from research done to date are snapshots of disruption across a swath of the northern Gulf of Mexico. It stretches from the 5,000-feet deep waters at the spill site to the continental shelf off Alabama and the shallow coastal marshes of Louisiana.

Much of the spill — estimated at up to 182 million gallons of oil and around 12 billion cubic feet of natural gas — was broken into small droplets by chemical dispersants at the site of the leaking well head. That reduced the direct impact to the shoreline and kept much of the oil and natural gas suspended in the water.

But immature crabs born offshore are suspected to be bringing that oil — tucked into their shells — into coastal estuaries from Pensacola, Fla., to Galveston, Texas. Oil being carried by small organisms for long distances means the spill's effects could be wider than previously suspected, said Tulane professor Caz Taylor.

Chemical oceanographer John Kessler from Texas A&M University and geochemist David Valentine from the University of California-Santa Barbara recently spent about two weeks sampling the waters in a six-mile radius around the BP-operated Deepwater Horizon rig. More than 3,000 feet below the surface, they found natural gas levels have reached about 100,000 times normal, Kessler said.
Already those concentrations are pushing down oxygen levels as the gas gets broken down by bacteria, Kessler and Valentine said. When oxygen levels drop low enough, the breakdown of oil and gas grinds to a halt and most life can’t be sustained.

The researchers also found dead pyrosomes covering the Gulf's surface in and around the spill site. "There were thousands of these guys dead on the surface, just a mass eradication of them," Kessler said.

Scientists said they believe the pyrosomes — six inches to a foot in length — have been killed by the toxins in the oil because there have no other explanation, though they plan further testing.

The researchers say the dead creatures probably are floating to the surface rather than sinking because they have absorbed gas bubbles as they filtered water for food.

The death of pyrosomes could set off a ripple effect. One species that could be directly affected by what is happening to the pyrosomes would be sea turtles, said Laurence Madin, a research director at the Woods Hole Oceanographic Institution in Cape Cod, Mass. Some larger fish, such as tuna, may also feed on pyrosomes.

"If the pyrosomes are dying because they've got hydrocarbons in their tissues and then they're getting eaten by turtles, it's going to get into the turtles," said Madin. It was uncertain whether that would kill or sicken the turtles.

The BP spill also is altering the food web by providing vast food for bacteria that consume oil and gas, allowing them to flourish.

At the same time, the surface slick is blocking sunlight needed to sustain plant-like phytoplankton, which under normal circumstances would be at the base of the food web.

Phytoplankton are food for small bait fish such as menhaden, and a decline in those fish could reduce tuna, red snapper and other populations important to the Gulf's fishing industries, said Condon, a researcher with Alabama’s Dauphin Island Sea Lab.

Seafood safety tests on hundreds of fish, shrimp and other marine life that could make it into the food supply so far have turned up negative for dangerous oil contamination.

Assuming the BP gusher is stopped and the cleanup successful, government and fishing industry scientists said the Gulf still could rebound to a healthy condition.

Ron Luken, chief scientist for Omega Protein, a Houston-based company that harvests menhaden to extract fish oil, says most adult fish could avoid the spill by swimming to
areas untainted by crude. Young fish and other small creatures already in those clean waters could later repopulate the impacted areas.

"I don't think anybody has documented wholesale changes," said Steve Murawski, chief scientist for the National Marine Fisheries Service. "If that actually occurs, that has a potentially great ramifications for life at the higher end of the food web."

Questions:

Q2. How will the already visible impacts of oil contamination to a few organisms, such as pyrosomes and young crabs, have larger side effects?

Q3. What is the prediction for the seafood industry following this spill? Has this prediction been backed up by any evidence yet?

Q4. How has the base of the food web in the Gulf of Mexico already been changed by the oil spill? Is this a good change for the food web or a bad one? Explain.

Q5. How is phytoplankton being impacted by the oil spill? Will this change in conditions necessary for phytoplankton survival have a large side effect? Explain.

Q6. Are the conditions of the aquatic ecosystem of the Gulf of Mexico expected to return to normal over time or not? How so?
Investigation I: Is Fish Safe To Eat, Or Is It A Toxic Risk?

Part 1: K-W-L

<table>
<thead>
<tr>
<th>What do we already know?</th>
<th>What do we want to know more about?</th>
<th>What have we learned?</th>
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</table>
Investigation I: Is Fish Safe To Eat, Or Is It A Toxic Risk?

Part 2: Toxic fish in the news?

Q1. Before reading through the article, how do you think the oil spill in the Gulf of Mexico will affect the organisms that call it home? Will humans end up feeling the effects of these changes? Explain.

Q2. How will the already visible impacts of oil contamination to a few organisms, such as pyrosomes and young crabs, have larger side effects?

Q3. What is the prediction for the seafood industry following this spill? Has this prediction been backed up by any evidence yet?

Q4. How has the base of the food web in the Gulf of Mexico already been changed by the oil spill? Is this a good change for the food web or a bad one? Explain.

Q5. How is phytoplankton being impacted by the oil spill? Will this change in conditions necessary for phytoplankton survival have a large side effect? Explain.
Q6. Are the conditions of the aquatic ecosystem of the Gulf of Mexico expected to return to normal over time or not? How so?
2. Aquatic Food Chains, Food Webs, and Modeling

Teacher Overview
Answer Key Parts 1 & 2
Student Guide Part 1:
  Introduction to Aquatic Food Chains and Food Webs
Student Guide Part 2: Aquatic Food Chains, Food Webs, and Modeling
Student Response Sheet: Part 1
Student Response Sheet: Part 2
Investigation II: Aquatic Food Chains, Food Webs, and Modeling

Purpose
During this activity, students will be introduced to and/or review the concepts of trophic levels, biological populations, predator-prey interactions, food chains, and food webs. Students will use the NetLogo Aquatic Food Chain model to explore population changes over time of several aquatic species.

Overview
This activity will serve as an introduction to two other activities in this unit: Bioaccumulation and Invasive Species. Students begin with a review of the various vocabulary terms and concepts used for understanding food chains. They will practice constructing some simple food chains and food webs using interactive online tools. Once students have mastered the concepts, they will use the NetLogo Aquatic Food Chain model to analyze population changes within the Calumet Harbor freshwater community. They will then be asked to predict the effects of changing initial population conditions and feeding relationships and will use the NetLogo Aquatic Food Chain model to test these predictions.

Student Outcomes Specific to this Investigation

College Readiness Standards
• Determine how the value of one variable changes as the value of another variable changes in a complex data presentation

National Research Council’s (NRC) National Science Education Standards for grades 9-12
• A population consists of all individuals of a species that occur together at a given place and time. All populations living together and the physical factors with which they interact compose an ecosystem.
• Populations of organisms can be categorized by the function they serve in an ecosystem. Plants and some microorganisms are producers—they make their own food. All animals, including humans, are consumers, which obtain food by eating other organisms. Decomposers, primarily bacteria and fungi, are consumers that use waste materials and dead organisms for food. Food webs identify the relationships among producers, consumers, and decomposers in an ecosystem.
• Energy flows through ecosystems in one direction, from photosynthetic organisms to herbivores to carnivores and decomposers.
Time
Part 1: Introduction to Aquatic Food Chains and Food Webs – one 45-minute class period
Part 2: Modeling an Aquatic Food Chain Using NetLogo – one 45-minute class period

Level
Secondary (9-12)

Materials and Tools
Part 1: Introduction
• Student Guides – 1 per student
• Computers with Internet access – ideally 1 per student
• Pictures of organisms in a food web – optional
Part 2: Modeling
• Student Guide – 1 per student
• Computers with Internet Access– ideally 1 per student
• NetLogo software or Java-enabled web browser and access to the online Food Chain model: http://ecocasting.northwestern.edu/NetLogo/Food%20Chain.html

Preparation
• If you are using the NetLogo software with the Aquatic Food Chain model:
  – Download the NetLogo software from: http://ccl.northwestern.edu/netlogo/
  – Then, go to: http://ecocasting.northwestern.edu/NetLogo/Food%20Chain.html. Under the model, right-click on “view/download model file” and select “Save Link As…”
  – Save file to a labeled folder that students can access from their computers.
• Or, provide internet access to the NetLogo Aquatic Food Chain model (see address under Materials and Tools)
• Reserve computer lab time if necessary
• Make copies of Student Guides
• Prepare pictures of organisms found in various food webs – optional

Prerequisites
None – although basic understanding of ecology will make introductory activities less time-consuming
Background

Part 1: Introduction
- Food Chain Anticipation/Reaction Guide
- Review of common food chain and ecology terms
- Introduction to the Calumet Harbor aquatic food chain
- Interactive Food Webs [http://www.harcourtschool.com/activity/food/food_menu.html]
- Construction of a food web

Part 2: Modeling
- How to use NetLogo
- Using the NetLogo Aquatic Food Chain model to verify predictions about changing population variables

Teaching Notes

Part 1: Introduction to Aquatic Food Chains and Food Webs

Food Chain Anticipation/Reaction Guide: Have students complete the “Anticipation” side on their own. Remind them that there are no right or wrong answers. Surveying the student responses with a show of hands or a thumbs up (true)/thumbs down (false) is an excellent way of assessing the class’ understanding. Do not give out correct answers until the end of the reading activity. For the “Reaction” side, have students fold back the answers in the “Anticipation” column so their choices will not be influenced by their prior responses. Assess the students’ comprehension by going over the answers and the corrections for the false statements.

NOTE: Depending on the level of detail you want to include in your discussion of this activity, the correct answer to statement #8 may change. The sun is the source of energy in a food web where the primary producers perform photosynthesis. In some ecosystems, however, primary producers perform chemosynthesis, whereby they use chemical compounds (methane, hydrogen sulfide, etc) in their environment to carry out metabolic functions. Chemosynthesis occurs near deep-sea hydrothermal vents and in estuaries, as well as other ecosystems.

Constructing a Food Web: This activity can be accomplished in a variety of different ways. The teacher can prepare sets of cards with pictures of organisms at every trophic level (easily found on the Internet) in an ecosystem and then give these cards to the students to manipulate at their desks. Laminating them and placing them in envelopes means that the materials can be reused multiple times. Different paper labels and arrows can be made to place next to the pictures of the organisms, or standard science lab tables can be drawn on with chalk (the students love this). Alternately, have the students cut out pictures from old magazines (National Geographic, Field and Stream, Smithsonian, etc.) and tape or glue them to their papers. Or, students can draw the organisms or their names on their paper.
are also several websites with interactive food webs that students can construct. Make sure you instruct your students in the way you would like them to do this activity.

**Part 2: Modeling an Aquatic Food Chain Using NetLogo**

**NetLogo Aquatic Food Chain model**: Students will run the model with the pre-set conditions and then analyze the population cycles in the graph. Students will then change some of the initial conditions, predict what will happen to the population numbers, run the program, and then explain how their results compare to their predictions. Encourage the students to manipulate the variables in a variety of ways and to analyze their results.

An explanation of this particular NetLogo model can be found by clicking on the “Information” tab at the top of the screen if you are using the software package. If you are using the online applet version, there is detailed information below the model screen. You can also visit the NetLogo website at [http://ccl.northwestern.edu/netlogo/](http://ccl.northwestern.edu/netlogo/) for more detailed information.

Encourage students to do a Screen Capture of their population graphs and print them out. That will give you a more accurate picture than their hand-drawings and will allow easier assessment of their analyses. Screen Captures can be done in several ways:

- On a PC: fn+insert/prt sc key combination or use the Snipping Tool software found on HP Tablet laptops.
- On a Mac: command+shift+4 will produce a crosshairs symbol; students can then drag the cursor and select the image they would like to save

Students may often find the model behaving in unpredictable ways. Encourage them to explore possible explanations, as well as the limits of a model of this type. Although the initial starting numbers are the same, both the locations of the individual organisms and the interactions between them are randomized for every run.

**Additional Information**

Investigation II activities, especially Part 1, are not essential for every course, depending on the students’ prior knowledge of ecology. They serve as an introduction to food chains, trophic levels, and the NetLogo Aquatic Food Chain model. These activities also provide a foundation for successful completion of the Bioaccumulation and Invasive Species Investigations. Part 1 activities may be shortened or even omitted, depending on the course.

Investigation II: Aquatic Food Chains, Food Webs, and Modeling

Part 1: Introduction to Aquatic Food Chains and Food Webs

Food Chain Anticipation/Reaction Guide

<table>
<thead>
<tr>
<th>Anticipation</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. __________ 1. A simple feeding pattern showing the transfer of energy is a food chain.</td>
<td>1. T</td>
</tr>
<tr>
<td>2. __________ 2. Consumers that eat only plants are called carnivores herbivores.</td>
<td>2. F</td>
</tr>
<tr>
<td>3. __________ 3. Aquatic organisms live on land in water.</td>
<td>3. F</td>
</tr>
<tr>
<td>4. __________ 4. Periphyton are at the base of a food chain.</td>
<td>4. T</td>
</tr>
<tr>
<td>5. __________ 5. There is a relationship between the number of predators and the number of prey.</td>
<td>5. T</td>
</tr>
<tr>
<td>6. __________ 6. In a food chain, arrows point toward the organism being eaten getting the energy/eating.</td>
<td>6. F</td>
</tr>
<tr>
<td>7. __________ 7. Crayfish can be both predators and prey.</td>
<td>7. T</td>
</tr>
<tr>
<td>8. __________ 8. Producers are The sun is the source of all the energy in a food chain (NOTE: see page 3 of Teacher Overview).</td>
<td>8. F</td>
</tr>
<tr>
<td>9. __________ 9. Many food chains in an ecosystem make up a food web.</td>
<td>9. T</td>
</tr>
<tr>
<td>10. __________ 10. When a smallmouth bass eats a crayfish, most about 10% of the energy from the crayfish is transferred.</td>
<td>10. F</td>
</tr>
</tbody>
</table>
The Calumet Harbor Aquatic Food Chain

Questions:

Q1. Describe some of the characteristics or adaptations of both the crayfish and smallmouth bass that help them survive in Calumet Harbor.

*Crayfish:* protective exoskeleton, claws, living near the bottom under rocks, coloration/camouflage, etc.

*Smallmouth bass:* fins for swimming, strong jaws, coloration, ability to hide, etc.

Q2. Check your understanding of the following vocabulary terms by writing your own definitions/explanations and giving an example of each: producer, primary consumer, omnivore, autotroph, trophic level, secondary consumer, prey, heterotroph, predator, carnivore, periphyton.

*Producer:* an organism that can produce its own food using energy from the sun (or inorganic materials such as methane or sulfides) and organic materials in its environment

*Primary consumer:* can be either a herbivore or an omnivore, the first level of consumers above primary producers in a food chain.

*Omnivore:* an organism that eats plants and other animals

*Autotroph:* an organism that can produce its own food using energy from the sun (or inorganic materials) and organic materials in its environment

*Trophic level:* the position occupied by an organism in a food web

*Secondary consumer:* an organism that eats the primary consumer

*Prey:* an organism caught or hunted by another organism for food

*Heterotroph:* an organism that gets its energy by eating other organisms

*Predator:* an organism that hunts other organisms for food

*Carnivore:* an organism that eats only animals for food

*Periphyton:* a combination of algae along with bacteria, protozoa, and the remains of dead organisms (detritus). Serves as the base of the food chain this part of the lake.

Q3. Do any of the terms in Question 2 mean the same thing? If so, which ones?

*Primary and secondary consumer/heterotroph
Producer / autotroph

Q4. How does the energy from the periphyton get “used up” by the crayfish?

*Through its daily activities (swimming, foraging, etc.) and metabolism, much of it is lost as heat.*
Q5. If it takes 3500 extra calories (kilocalories) to gain one pound, and you ate several fast food hamburgers and bags of cookies that added up to 3500 calories, would you gain exactly 1 pound?

No, because you would “burn off” most (about 3150) of those calories doing your everyday activities – moving, breathing, sleeping, etc., only 350 of those calories would be stored in your body and converted into protein and/or fat. Obviously, this is a simplistic explanation.

Q6. Would it be possible to have more smallmouth bass than crayfish? Why or why not? What might happen?

For a short time, yes, but in a “closed” food chain they would run out of prey and the numbers would drop. Once the crayfish have gone locally extinct, the bass would have nothing to eat.

Food Chains to Food Webs

Q7. Trace 2-3 different food chains through this food web. How many trophic levels do they have? Could a food chain have 10 trophic levels? Why or why not? (Hint: Think about what you learned about energy transfer between organisms).

Answers will vary, but food chains are generally limited at 4-6 levels because of the loss of almost 90% of available energy with each successive trophic level.

Q8. Food webs are found in all ecosystems, including in the area where you live. Draw, sketch, use cut-out pictures, etc. a food web from a nearby ecosystem. Make sure to use at least 7-8 different organisms and include arrows. Label the organisms with the following terms: producer, primary consumer, omnivore, autotroph, trophic level, secondary consumer, prey, heterotroph, omnivore, predator, carnivore.

Answers vary – see Teaching Notes for ideas for this activity.
Part 2: Modeling an Aquatic Food Chain using NetLogo

Q1. Record the Setup conditions:

<table>
<thead>
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<th>_______</th>
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</thead>
<tbody>
<tr>
<td>periphyton-start-percentage</td>
<td>______</td>
</tr>
<tr>
<td>crayfish-start-amount</td>
<td>_______</td>
</tr>
<tr>
<td>smallmouth-bass-start-amount</td>
<td>_______</td>
</tr>
</tbody>
</table>

*Answers will vary.*

Q2. Sketch or print out your population graph. Describe the changes in the 3 populations beginning at time 0 and ending at time 500. Be specific about any relationship between the populations.

*Answers will vary, but they should include a description of the change over time and the relationship between the population numbers of the three organisms. Students should notice that the peaks come in a predictable order: periphyton, crayfish, then smallmouth bass.*

Q3. Compare your new population graph to your first one. Are the two the same or different? Why or why not?

*Answers will vary. Although the initial starting numbers are the same, both the locations of the individual organisms and the interactions between them are randomized for every run. Students should notice patterns between repeated runs.*

Q4. What happened to the crayfish you were following? Give an explanation. If it disappeared, what do you think that means?

*If the watched organism disappears, it means that the specific creature has died.*
Q5. Record the new Setup conditions:

periphyton-start-percentage

---
crayfish-start-amount

---
smallmouth-bass-start-amount

---

Rules: ___________________________________________________

_______________________________________________________

_______________________________________________________

Answers will vary. Certain rules are “Biologically Impossible” and will result in the students having to edit their rules. A pop-up screen will indicate this.

Q6. Predict what you think might happen to each of the populations? Why might this happen?

Answers will vary.

Q7. Sketch or print out your population graph. Describe the changes in the 3 populations beginning at time 0 and ending at time 500. Be specific about any relationship between the populations.

Answers should include a description of the change over time and the relationship between the population numbers of the three organisms and any patterns students observe.

Q8. Describe any differences between the populations during this run and your original run. What may be the reasons for these differences? How did these compare to your predictions?

Students should compare their observations to their predictions and explain any differences between the two model runs. They should note that differences could be due to their modification of the rules and the fact that the interactions between the organisms are not exactly the same with each run of the model. For example, observed differences may include steeper (or shallower) curves on the population graph.
Q9. Use the NetLogo model to answer some of the following: Can you get the populations to “crash?” Under what conditions? How long can the model run before a species goes locally extinct? Are there any “rules” that are impossible? Does setting up the same initial conditions guarantee that the model will run the same way? Why or why not?

Encourage the students to explore the possible explanations and to consider the limits of a model of this nature. Students may find the model behaving in unpredictable ways. Some students may be able to crash one of the species populations by changing the model rules. Some rules are “biologically impossible,” such as ‘periphyton eat periphyton’ and ‘periphyton eat smallmouth bass.’

Q10. Using what you have learned about food chains, predators and prey, and food webs, predict what would happen to your populations if another organism was introduced into the ecosystem.

Depending on the trophic level, this could change the population dynamics. Students should write an educated prediction based on what they have learned about food webs during this investigation. This is a leading question for the later investigations.
**Investigation II: Aquatic Food Chains, Food Webs, and Modeling**

**Food Chain Anticipation/Reaction Guide**

**Directions:** Before we begin, in the Anticipation column, mark the statements true (t) or false (f) based on what you think or know now. When we are done, fold over or cover your initial responses in the Anticipation column and mark the statements in the Reaction column incorporating the information you learned. If the answer in the Reaction column is false (f), correct the statement to make it true.

<table>
<thead>
<tr>
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<tbody>
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</tr>
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<td>10. When a smallmouth bass eats a crayfish, most of the energy from the crayfish is transferred.</td>
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</tbody>
</table>
Part 1: Introduction to Aquatic Food Chains and Food Webs

Have you ever heard the expression, “It’s a dog eat dog world?” Is it really? Do dogs go around eating other dogs?!? If they did, we’d probably have few dogs left. In reality, the way organisms eat is more like that old children’s poem, “There Was an Old Lady Who Swallowed a Fly.” In that tale, a woman accidentally swallowed a fly. She then swallowed a spider to eat the fly, then a bird to eat the spider, then a cat to eat the bird, etc., etc., etc.

Living things eat other living things in order to get energy and to survive, but not every organism can eat any other organism. Every living thing has specific feeding requirements. The set of feeding relationships between different populations or organisms in an ecosystem is called a food chain. How much do you know about food chains?

The Calumet Harbor Aquatic Food Chain

The basic food chain in Lake Michigan’s Calumet Harbor consists of 3 trophic (feeding) levels. This ecosystem is experiencing stress from two major types of disturbances: invasive species and industrial pollution. A team of scientists from Illinois, Wisconsin and Michigan is studying this ecosystem to try to figure out how it is responding to these stressors. As you work through the investigations in this unit you’ll learn about the surprising results of their research, but let’s begin by learning about the basic food chain.

At the base of every food chain are producers or autotrophs. These are organisms that usually get their energy from the sun through photosynthesis. Algae, which belong to the Protist Kingdom, are usually the primary producers in aquatic (freshwater) ecosystems. In terrestrial (land) ecosystems, plants serve as the primary producers. Periphyton is a combination of algae along with bacteria, protozoa, and the remains of dead organisms (detritus), and serves as the base of the food chain in this part of the lake.

Periphyton – LakeSuperiorStreams.org
This periphyton coats the bottom of the harbor and clings in various amounts to the rocks and sandy bottom. If you've ever walked into a lake or pond and your feet sink into the “muck,” you have had an experience with periphyton.

The rest of the trophic levels in food chains consist of consumers or heterotrophs. These are organisms that eat other organisms in order to get the energy they need to survive. The first level of consumers are often called the **primary consumers** and are either herbivores (can only digest plants/algae) or omnivores (can digest either plants/algae or other animals). One of the main primary consumers in Calumet Harbor is the Northern Freshwater Crayfish, *Orconectes propinquus*. This is a native species of crayfish commonly found in these waters.

This invertebrate (organism without a backbone) lives at the bottom and feeds primarily on periphyton, but it may feed on other smaller organisms as well. Crayfish are well adapted to living in Calumet Harbor. They are usually found under rocks or other debris. They also are covered by a very tough exoskeleton (outer skeleton) and have enlarged front claws.

An organism that eats the primary consumer is called a **secondary consumer** and is either an omnivore or carnivore (can only digest animals). In this food chain, the main secondary consumer is the smallmouth Bass, *Micropterus dolomieu*.
If you have ever seen one of these fish, you might think its mouth is not very small – especially if you have caught one and have to try to take the hook out of it without getting bit. It is called a smallmouth bass because the hinge of its lower jaw is below and just in front of its eye (a largemouth bass’ jaw extends behind its eye).

This vertebrate (animal with a backbone) lives in rivers, streams and lakes and prefers cool, clear water with rocky or gravel bottoms and protective cover, like logs or large rocks. They are predators (organisms that hunt other organisms), and the crayfish is their prey (organism that is hunted). In Calumet Harbor, these fish are at the top of the natural food chain.

Questions:

Q1. Describe some of the characteristics or adaptations of both the crayfish and smallmouth bass that help them survive in Calumet Harbor.

Q2. Check your understanding of the following vocabulary terms by writing your own definitions/explanations and giving an example of each: producer, primary consumer, omnivore, autotroph, trophic level, secondary consumer, prey, heterotroph, omnivore, predator, carnivore, periphyton.

Q3. Do any of the terms in Question 2 mean the same thing? If so, which ones?
When scientists draw food chains, they “connect” the organisms with arrows as seen below:

You might think that it does not matter which direction an arrow is drawn, but that is incorrect. Arrows always point toward the organism that is doing the eating. If you get confused about which direction to draw the arrow, think of the arrow as meaning, “gives energy to.” So, in the aquatic food chain above, the periphyton “gives energy to” the crayfish, and the crayfish “gives energy to” the smallmouth bass. And remember, the sun is what gives energy to the periphyton and therefore to the entire ecosystem.

When the crayfish eats, about 90% of the energy from the periphyton gets “used up” by the crayfish or released as heat. Only 10% of the energy gets converted into “new” crayfish cells. The same is true when the smallmouth bass eats the crayfish. This fact also affects the number of predators and prey in an ecosystem.

Questions:
Q4. How does the energy from the periphyton get “used up” by the crayfish?

Q5. If it takes 3500 extra calories (kilocalories) to gain one pound, and you ate several fast food hamburgers and bags of cookies that added up to 3500 calories, would you gain exactly 1 pound?

Q6. Would it be possible to have more smallmouth bass than crayfish? Why or why not? What might happen?
**Food Chains to Food Webs**

Most of you have probably realized that there are a lot more organisms that live in any lake, pond, stream, or river than just three types, and that these organisms eat more than one kind of food. They do this because their main food source may not always be available, so they have to eat other organisms to survive. Imagine if you only ate one kind of food, such as pizza. If there was no way to order or make a pizza, you would starve, so you would eat something else – maybe even broccoli!

The way that all of the feeding relationships in an ecosystem are shown is by connecting all the possible food chains into a **food web**. A food web for all of Lake Michigan would look like this:

![Lake Michigan Food Web](image)

As you can see, a food web is highly complicated and has many different connections between organisms.

**Question:**

Q7. Trace 2-3 different food chains through this food web. How many trophic levels do they have? Could a food chain have 10 trophic levels? Why or why not? (Hint: Think about what you learned about energy transfer between organisms).
To practice constructing interactive food webs in 3 different ecosystems, access the Interactive Food Webs tool using the following link:

http://www.harcourtschool.com/activity/food/food_menu.html

**Question:**

Q8. Food webs are found in all ecosystems, including in the area where you live. Draw, sketch, use cut-out pictures, etc. a food web from a nearby ecosystem. Make sure to use at least 7-8 different organisms and include arrows. Label the organisms with the following terms: **producer, primary consumer, autotroph, trophic level, secondary consumer, prey, heterotroph, omnivore, predator, carnivore.**

Now that you have finished this part of Investigation II, check your understanding by completing the “Reaction” column of the **Food Chain Anticipation/Reaction Guide** on page 1. Make sure to cover up your answers in the Anticipation column If one of the answers is “false,” correct the statement to make it true.
Investigation II: Aquatic Food Chains, Food Webs, and Modeling

Part 2: Modeling an Aquatic Food Chain using NetLogo

In this investigation you will be looking at a model of an Aquatic Food Chain to see how the populations of organisms affect each other.

1. Open the Food Chain NetLogo model. This can be done in one of two ways:
   a. Launch the NetLogo software on your computer. Click on File → Open and select the Aquatic Food Chain model from the list.
   b. Or, open your internet browser and type in the following address: http://ecocasting.northwestern.edu/NetLogo/Food%20Chain.html

2. Notice the black box on the right side of the screen. In order to display the organisms that make up the food web in this region, you will need to click the button in the upper left corner of the screen.

   *NOTE:* This button will be helpful as you move through the rest of the investigation as it will always reset your model back to zero when clicked.*

When the data loads, your model should look like this:

![NetLogo Model](image-url)
This model shows the 3 different organisms in the food chain:

periphyton  crayfish  smallmouth bass

The model also shows the initial Setup conditions and a population graph of the ecosystem:

Question:

Q1. Record the Setup conditions:

periphyton-start-amount  ________
crayfish-start-amount  ________
smallmouth-bass-start-amount  ________

3. Click the go/stop button and let the model run for a time interval of at least 500 (the time intervals do not represent any real generation times).

4. Click the go/stop button again to stop the run.
Question:

Q2. Sketch or print out your population graph. (It may look something like this):

![Population Graph Diagram]

Describe the changes in the 3 populations beginning at time 0 and ending at time 500. Be specific about any relationship between the populations.

5. Click the setup button to re-start the run from the beginning. Run the model again for a time interval of 500.

Question:

Q3. Compare your new population graph to your first one. Are the two the same or different? Why or why not?
6. While the model is stopped, Right Click (or command+click on a Mac) on a crayfish and scroll down to the specific crayfish number you have selected.

7. Click on ‘watch a-crayfish’, and the crayfish you chose will be highlighted in the population:

8. Click go/stop and follow what happens to the crayfish.

**Question:**

Q4. What happened to the crayfish you were following? Give an explanation. If it disappeared, what do you think that means?
9. Now it is time to use the NetLogo Aquatic Food Chain model to investigate what happens when certain conditions are changed. This may be done in a variety of ways.

   a) You can change the initial Setup conditions by sliding the *start-amount* buttons one direction or another:

   ![Image of start-amount buttons]

   b) Or, you can change the “rules” by clicking the *Change* button and by typing in a new “rule” into the text box that pops up. When you are done, click *Apply* and *OK*.

   ![Image of Change button and text box]

10. Choose a new set of starting conditions either by changing the start amounts, the rules, or both. Click on the *Setup* button.

Questions:

Q5. Record the new Setup conditions:

   periphyton-start-amount  _______
   crayfish-start-amount  _______
   smallmouth-bass-start-amount  _______
   Rules: ________________________________
   ________________________________
   ________________________________
   ________________________________
Q6. Predict what you think might happen to each of the populations? Why might this happen?

11. Click the go/stop button and let the model run for a time interval of at least 500.

12. Click the go/stop button again to stop the run.

Questions:

Q7. Sketch your population graph below. Or, you can take a screenshot of the plot, save it, and print it out. Describe the changes in the 3 populations beginning at time 0 and ending at time 500. Be specific about any relationship between the populations.

Q8. Describe any differences between the populations during this run and your original run. What may be the reasons for these differences? How did these compare to your predictions?
During any of the runs, you may have a situation where “Bass went extinct locally.” This does not mean that these organisms are truly extinct, but that in this particular area, there are none left.

You can either click the Yes button to add an organism,

![Yes button](image)

or at any time, you can click the buttons to add organisms. Or, click No and see what happens to the ecosystem without adding another bass.

13. Continue changing a variety of conditions in the model to see how changes in initial population numbers or having more members of a species enter a population affect the ecosystem.

14. Answer the final questions on the following page.
Questions:

Q9. Use the NetLogo model to answer some of the following: Can you get the populations to “crash?” Under what conditions? How long can the model run before a species goes locally extinct? Are there any “rules” that are impossible? Does setting up the same initial conditions guarantee that the model will run the same way? Why or why not?

Q10. Using what you have learned about food chains, predators and prey, and food webs, predict what would happen to your populations if another organism was introduced into the ecosystem.
Investigation II: Aquatic Food Chains, Food Webs, and Modeling

Part 1: Introduction to Aquatic Food Chains and Food Webs

Food Chain Anticipation/Reaction Guide

Directions: Before we begin, in the Anticipation column, mark the statements true (t) or false (f) based on what you think or know now. When we are done, fold over or cover your initial responses in the Anticipation column and mark the statements in the Reaction column incorporating the information you learned. If the answer in the Reaction column is false (f), correct the statement to make it true.

<table>
<thead>
<tr>
<th>Anticipation</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ________</td>
<td>1. A simple feeding pattern showing the transfer of energy is a food chain.</td>
</tr>
<tr>
<td>2. ________</td>
<td>2. Consumers that eat only plants are called carnivores.</td>
</tr>
<tr>
<td>3. ________</td>
<td>3. Aquatic organisms live on land.</td>
</tr>
<tr>
<td>4. ________</td>
<td>4. Periphyton are at the base of a food chain.</td>
</tr>
<tr>
<td>5. ________</td>
<td>5. There is a relationship between the number of predators and the number of prey.</td>
</tr>
<tr>
<td>6. ________</td>
<td>6. In a food chain, arrows point toward the organism being eaten.</td>
</tr>
<tr>
<td>7. ________</td>
<td>7. Crayfish can be both predators and prey.</td>
</tr>
<tr>
<td>8. ________</td>
<td>8. Producers are the source of all the energy in a food chain.</td>
</tr>
<tr>
<td>9. ________</td>
<td>9. Many food chains in an ecosystem make up a food web.</td>
</tr>
<tr>
<td>10. _______</td>
<td>10. When a smallmouth bass eats a crayfish, most of the energy from the crayfish is transferred to the bass.</td>
</tr>
</tbody>
</table>
The Calumet Harbor Aquatic Food Chain

Questions:

Q1. Describe some of the characteristics or adaptations of both the crayfish and smallmouth bass that help them survive in Calumet Harbor.

Q2. Check your understanding of the following vocabulary terms by writing your own definitions/explanations and giving an example of each: producer, primary consumer, omnivore, autotroph, trophic level, secondary consumer, prey, heterotroph, omnivore, predator, carnivore, periphyton.

Q3. Do any of the terms in Question 2 mean the same thing? If so, which ones?

Q4. How does the energy form the periphyton get “used up” by the crayfish?
Q5. If it takes 3500 extra calories (kilocalories) to gain one pound, and you ate several fast food hamburgers and bags of cookies that added up to 3500 calories, would you gain exactly 1 pound?

Q6. Would it be possible to have more smallmouth bass than crayfish? Why or why not? What might happen?

Food Chains to Food Webs

Q7. Trace 2-3 different food chains through this food web. How many trophic levels do they have? Could a food chain have 10 trophic levels? Why or why not? (Hint: Think about what you learned about energy transfer between organisms).

Q8. Food webs are found in all ecosystems, including in the area where you live. On the following page, draw, sketch, use cut-out pictures, etc. a food web from a nearby ecosystem. Make sure to use at least 7-8 different organisms and include arrows. Label the organisms with the following terms: **producer, primary consumer, omnivore, autotroph, trophic level, secondary consumer, prey, heterotroph, omnivore, predator, carnivore.**
Investigation II: Aquatic Food Chains, Food Webs, and Modeling

Part 2: Modeling an Aquatic Food Chain using NetLogo

Q1. Record the Setup conditions:
   - periphyton-start-amount
   - crayfish-start-amount
   - smallmouth-bass-start-amount

Q2. Sketch or print out your population graph.

Describe the changes in the 3 populations beginning at time 0 and ending at time 500. Be specific about any relationship between the populations.

Q3. Compare your new population graph to your first one. Are the two the same or different? Why or why not?

Q4. What happened to the crayfish you were following? Give an explanation.
Q5. Record the new Setup conditions:

periphyton-start-percentage _______

crayfish-start-amount _______

smallmouth-bass-start-amount _______

Rules: ____________________________________________
____________________________________________________
____________________________________________________
____________________________________________________
____________________________________________________

Q6. Predict what you think might happen to each of the populations? Why might this happen?

Q7. Sketch or print out your population graph.

Describe the changes in the 3 populations beginning at time 0 and ending at time 500. Be specific about any relationship between the populations.
Q8. Describe any differences between the populations during this run and your original run. What may be the reasons for these differences? How did these compare to your predictions?

Q9. Use the NetLogo model to answer some of the following: Can you get the populations to “crash?” Under what conditions? How long can the model run before a species goes locally extinct? Are there any “rules” that are impossible? Does setting up the same initial conditions guarantee that the model will run the same way? Why or why not?

Q10. Using what you have learned about food chains, predators and prey, and food webs, predict what would happen to your populations if another organism was introduced into the ecosystem.
3. Bioaccumulation and Biomagnification

Teacher Overview
Answer Key Part 1
Answer Key Part 3
Answer Key Part 4
Answer Key Part 5
Answer Key Part 6
Student Guide Part 1
Student Guide Part 2
Student Guide Part 3
Student Guide Part 4
Student Guide Part 5
Student Guide Part 6
Student Response Sheet: Part 5
Student Response Sheet: Part 6
Investigation III: Bioaccumulation and Biomagnification

Purpose

The purpose of this activity is to familiarize students with

- Bioaccumulation and biomagnification
- Persistent organic pollutants (POPs) and dangers they pose to human health
- How humans can be exposed to POPs, and to recognize those pathways in a lake ecosystem
- Develop a working definition of one particular POP: polychlorinated biphenyls (PCBs)

Overview

This investigation explores the concepts of bioaccumulation and biomagnification and the effects of POPs present in an aquatic ecosystem. In Part 1, students will take a self-graded, pre-activity test that will help teachers to determine students’ prior knowledge of these topics. Part 2 is a reading from the U.S. Environmental Protection Agency, "Persistent Organic Pollutants: A Global Issue, A Global Response." The graphic organizer "What is POP (don’t you mean soda)?" may be used to help students organize what they learn from this document. In Part 3, students will work in groups to brainstorm ways that they might be exposed to toxins in their environment and then they will determine which of these pathways could also apply to aquatic organisms. In Part 4, students will read two factsheets published by the U.S. EPA and answer questions about polychlorinated biphenyls (PCBs) and their health effects. This investigation concludes with two modeling activities. Part 5 is a hands-on activity that will introduce students to the concept of bioaccumulation and biomagnification. In Part 6, students will use the NetLogo Aquatic Bioaccumulation model to further explore these concepts in a simulated environment. Students will collect model data and analyze it in table and graph format to answer activity questions.

Student Outcomes Specific to this Investigation

Illinois State Standards for grades 9-12

- Analyze the transmission of genetic traits, disease, and defects

College Readiness Standards

- Understand the methods and tools used in an experiment
• Determine experimental conditions that would produce a specified result

National Research Council’s (NRC) National Science Education Standards for grades 9-12

• Scientists usually inquire about how physical, living, or design systems function

Time

• Part 1: What do I know about pollutants? (pretest) – one 45-minute class period
• Part 2: What is POP (don’t you mean soda)? – one 45-minute class period
• Part 3: How are we exposed to chemicals? – one-half of a 45-minute class period
• Part 4: What is a PCB? – one 45-minute class period
• Part 5: Hands-on Toxicity Modeling Activity – one 45-minute class period
• Part 6: NetLogo Bioaccumulation model – one 45 minute class period

Level

Secondary (9-12)

Materials and Tools

Part 1: What do I know about pollutants? (pretest)

• Pre-/ post-test

Part 2: What is POP (don’t you mean soda)?

• Computers with internet access to EPA website: http://www.epa.gov/international/toxics/pop.html
• Copies of “What is POP (don’t you mean soda)?” graphic organizer – one per student

Part 3: How are we exposed to chemicals?

• White boards and dry erase markers
• Brainstorming worksheets and questions – one each per student
• Four different colors of highlighters – one set per group
Part 4: What is a PCB?

- Computers with internet access to EPA website: 
  http://www.epa.gov/epawaste/hazard/tds/pcbs/pubs/about.htm 
  http://www.epa.gov/epawaste/hazard/tds/pcbs/pubs/effects.htm
- Copies of graphic organizers and questions – one each per student

Part 5: Hands-on Toxicity Modeling Activity

- Copies of activity worksheets – one per group
- Copies of Student Guide – one per student
- 200 Skittles or M&Ms per group
- 100 plastic beads

Part 6: NetLogo Bioaccumulation model

- Computers – ideally one per student
- Internet access and Java-enable web browser or NetLogo model software installed
- Copies of Student Guide and Student Response Sheets – one each per student
- Graph paper

Preparation

Part 1: What do I know about pollutants?

- Copy one test per student

Part 2: What is POP (don’t you mean soda)?

- Download, print, and copy EPA publication cited above or provide internet access to online version
- Copy one graphic organizer per student

Part 3: How are we exposed to chemicals?

- If using white board, divide into 4 squares per lab group (2-3 students each)
- Or, copy brainstorming and question sheets for each student

Part 4: What is a PCB?

- If necessary, schedule time in computer lab
- Ensure student computers can access above EPA site
- Copy one graphic organizer and question sheet per student
Part 5: Candy Bioaccumulation (Hands-on Toxicity Modeling Activity)

- Divide marshmallows into portions of 150 per student group (2-3 students per group)
- Tape large picture of smallmouth bass to whiteboard at the front of the room
- For a video of how this model should work: [http://vimeo.com/20107416](http://vimeo.com/20107416)

Part 6: NetLogo Bioaccumulation model

- If you are using the NetLogo software with the Aquatic Bioaccumulation model:
  - Download the NetLogo software from: [http://ccl.northwestern.edu/netlogo/](http://ccl.northwestern.edu/netlogo/)
  - Then, go to: [http://ecocasting.northwestern.edu/NetLogo/Bioaccumulation.html](http://ecocasting.northwestern.edu/NetLogo/Bioaccumulation.html). Under the model, right-click on “view/download model file” and select “Save Link As...”
  - Save file to a labeled folder that students can access from their computers.
- Or, provide internet access to the NetLogo Aquatic Bioaccumulation model: [http://ecocasting.northwestern.edu/NetLogo/Bioaccumulation.html](http://ecocasting.northwestern.edu/NetLogo/Bioaccumulation.html)
- If necessary, schedule time in computer lab

**Prerequisites**

Part 1: none

Part 2:

- NOAA EcoCasting Investigations I and II and the Investigation III Pre-test (optional)
- Students must understand the definition of a chemical, including being able to define a compound.
- Students have a reading level from the 11-12 grades. Randomly selected paragraphs from this reading were tested using the Flesch-Kincaid method and resulted in a grade level of 12. If students are not at this level you may need to scaffold the reading.

Part 3: Students should be able to define a compound

Part 4: Basic introduction to the terms “persistent organic pollutant (POP)” and “exposure pathway”

Part 5: Parts 1-4 are a useful introduction to the terms and concepts in this exercise

Part 6: Students should be able to:

- recognize a food chain and be able to define the trophic levels within it
- define and qualitatively recognize biomagnification and bioaccumulation
Background

Part 1: N/A

Part 2: Students must have:

- basic knowledge of chemistry
- reading level of grade 11-12; see note in Prerequisites

Part 3: Basic knowledge of chemistry

Part 4: Basic knowledge of chemistry

Part 5: Students should be familiar with the 90:10 rule, i.e. that only 10% of the energy from one trophic level is passed on to the next highest level. The remaining 90% is used up for metabolic function or is lost as body heat

Part 6: Students should be familiar with food chains/webs, POPs, and exposure pathways

Teaching Notes

Part 1: This test can be used as:

- a tool to assess knowledge retention from previous units and adjust the unit accordingly
- part of a pre-/post-test assessment to demonstrate evidence of content learning and/or to assess instruction effectiveness

Part 2: The Persistent Organic Pollutants: A Global Issue, A Global Response booklet is comprehensive. Strategies for maximizing the reading activity include:

**Independent Reading:** Students read independently and are assigned a starting and stopping point for each section of content (i.e., “What are POPs? pp. 2-4) and a purpose for the reading. For example, “While you read determine three characteristics of a POP that you can share with the class.” They should use the graphic organizer to summarize what they read. After completion of the task, the class can have a short oral discussion and then the next section should be assigned. Note: to successfully complete this section of the activity the following sections should be read: What are POPs?, What Domestic Actions Have Been Taken to Control POPs, How Do POPs Affect People and Wildlife?, and The Great Lakes: A Story of Trials and Triumphs.

**Jigsaw:** Split the students into groups and assign each group a section to read. As they read they should add their summaries to the “pop bubbles on the graphic organizer”. Upon completion of the task each group becomes the expert on their section and is required to teach their section to the rest of the class.
Part 3: When students are brainstorming, remind them that we come into contact with liquids, solids, and gases every day.

Part 4: It is suggested that you preview the suggested readings first, as you may need to review vocabulary and/or modify the readings depending on student ability.

Part 5: To assist with developing a definition of biomagnification/bioaccumulation it may be helpful to open the activity by discussing the origin of the terms bioaccumulation and biomagnification.

- **Bio** is Greek in origin and means “life”; hence, biology is the study of life (*logy* refers “to the study of [a certain subject]”).
- **Accumulate** is from the Latin word *accumulātus*, past participle of *accumulāre* to heap up, from *cumulus* a heap. (Source: World English Dictionary, accumulate, http://dictionary.reference.com/browse/accumulate)
- **To magnify** is to increase the apparent size of, especially with a lens; biomagnification is the increase in the concentration of a substance at higher trophic levels.

In the final step of this activity when you feed each group’s crayfish to the smallmouth bass, remember that after each day of feeding the fish will also respire. Make sure the fish is respiring the same amount each day: 20 units of energy should suffice. This way the total number of candy will consistently be higher than the PCB units, but students will still see bioaccumulation and biomagnification occurring.

This lesson is adapted from “Bioaccumulation of Toxins,” produced by PolarTrec Resources, which can be found online at: http://www.polartrec.com/files/resources/lesson/10856/bioaccumulationtoxinsfinal.pdf

This lesson can be modified for students at different learning levels.

**Variation:** Have each group (2-3 students) model one periphyton through 10 days of feeding. Then, have 3 groups join together to feed each of their periphyton to one crayfish. The students will have only 3 days of data for biomagnification, unless you choose to have each initial group model more than one periphyton. From this point, follow the original lesson plan to feed the crayfish to the smallmouth bass at the front of the room.

**Additional Activity:** The activity on page 8 can be used as a vocabulary review at the end of this model. Divide the class into groups of 9. Cut up the following table so that every student has one line. (“I have ‘bioaccumulation’” and “Who as ‘PCBs’”). One student in the group will start by reading their paper aloud. Whoever has the corresponding card (in this case it would be followed by: “I have ‘polychlorinated biphenyls’”) reads their statement aloud. This will continue until all students have read their definitions. The terms in this activity are drawn from Investigations II and III; thus, if you have not done Investigation II with your students, not all of the terms may be familiar to them.
Part 6: It is suggested that you familiarize yourself with the model and the various ways in which it can be manipulated prior to beginning this activity with the class. You can choose to use the NetLogo software—it will need to be installed prior to this class period—or you can use the online version, which requires a Java-enabled web browser.

An explanation of this particular NetLogo model can be found by clicking on the “Information” tab at the top of the screen if you are using the software package. If you are using the online applet version, there is detailed information below the model screen. You can also visit the NetLogo website at http://ccl.northwestern.edu/netlogo/ for more detailed information.

Encourage students to do a Screen Capture of their population graphs, print them out, and attach them to their Student Guides. That will give you a more accurate picture than their hand-drawings and will allow easier assessment of their analyses. Screen Captures can be done in several ways:

- On a PC: fn+insert/prt sc key combination or use the Snipping Tool software found on HP Tablet laptops.
- On a Mac: command+shift+4 will produce a crosshairs symbol; students can then drag the cursor and select the image they would like to save.

Students may often find the model behaving in unpredictable ways. Encourage them to explore possible explanations, as well as the limits of a model of this type. Although the initial starting numbers are the same, both the locations of the individual organisms and the interactions between them are randomized for every run.

Additional Information

You may need to more fully explain the technology, data analysis and graphing, or other aspects of these activities depending on student ability and background.
### Review Activity

<table>
<thead>
<tr>
<th>I have “bioaccumulation”</th>
<th>Who has “PCBs”?</th>
</tr>
</thead>
<tbody>
<tr>
<td>I have “polychlorinated biphenyls”</td>
<td>Who has “the set of feeding relationships between different populations or organisms in an ecosystem”?</td>
</tr>
<tr>
<td>I have “food chain”</td>
<td>Who has “a POP”?</td>
</tr>
<tr>
<td>I have “persistent organic pollutant”</td>
<td>Who has “an organism that can make its own food using energy from the sun and/or chemical compounds in its environment”?</td>
</tr>
<tr>
<td>I have “producer”</td>
<td>Who has “the position in a food chain occupied by a certain organism”?</td>
</tr>
<tr>
<td>I have “trophic level”</td>
<td>Who has “the ratio of energy used for metabolism versus energy stored by an organism”?</td>
</tr>
<tr>
<td>I have “the 90:10 rule”</td>
<td>Who has “an organism that feeds on other organisms to get its energy”?</td>
</tr>
<tr>
<td>I have “consumer”</td>
<td>Who has “increasing concentration of contaminants in animals at higher trophic levels”?</td>
</tr>
<tr>
<td>I have “biomagnification”</td>
<td>Who has “increasing concentration of contaminants from any source within an individual over time”?</td>
</tr>
</tbody>
</table>
### Investigation III: Bioaccumulation

#### Part 1: What do I know about pollutants?

<table>
<thead>
<tr>
<th>What is a POP?</th>
<th></th>
<th>1.</th>
<th>What we eat/drink we eventually digest and then excrete.</th>
</tr>
</thead>
<tbody>
<tr>
<td>F (POPs bioaccumulate in our fat cells)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F (DDE, a metabolite of DDT, has been found in penguin eggs shells in Antarctica)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T (Studied how DDE in the eggs thinned the shell preventing live offspring)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F (It's food)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F (Clint Eastwood starred in Dirty Harry. The Dirty Dozen are the twelve POPs that several countries agreed to eliminate production, use, and/or release of at the Stockholm Convention.)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>How are we exposed to chemicals?</th>
<th></th>
<th>6.</th>
<th>We are exposed to chemicals in the womb before we are born.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What is a PCB?</td>
<td></td>
<td>7.</td>
<td>If we do not wash our hands before we eat we are exposed to chemicals.</td>
</tr>
<tr>
<td>T</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F (PCBs were used in dielectric fluid such as in transformers, capacitors, and coolants.)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>What is bioaccumulation/biomagnification?</th>
<th></th>
<th>8.</th>
<th>PCBs are a group of man-made chemicals.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td></td>
<td></td>
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<tr>
<td>T</td>
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</tbody>
</table>

| 9. PCBs are used in plastic water bottles and when discarded end up in the Great Lakes system. |                                                                 |    |                                                         |
| 10. Longer-lived animals have greater bioaccumulation. |                                                                   |    |                                                         |
| 11. PCBs can be absorbed through the skin into an organism |                                                                   |    |                                                         |
Investigation III: Bioaccumulation

Part 3: How are we exposed to chemicals?

Exposure Pathways Concept Map

- Swimming in the high school pool
- Drinking my morning Redbull
- Eating food in the school cafeteria
- Breathing the air in the weight room
Once the class has shared their brainstorming, complete the following:

Q1. Write the three exposure pathways for humans by your class.

  *eating/drinking* (green)  *inhalation* (blue)  *skin contact/absorption* (yellow)

Q2. Now imagine you’re an organism living in a beautiful lake. Would your exposure pathways change?

  *Aquatic organisms can be exposed to chemicals via the food they eat (trophic transfer) or direct uptake from the water column.*

Q3. Do exposure pathways change according to what type of aquatic organism you are: forage fish, a mussel, or a top predator? Think about where each one lives, what they eat, how they breathe, etc.

  *Mussels are filter-feeders, and will take up toxins present in the water column and in their prey. They will also be exposed to toxins that are bound to sediments. Forage fish will be exposed to toxins via direct contact with water as well as trophic transfer. Top predators, like the smallmouth bass or larger fish in other ecosystems (tuna and swordfish, for example) are likely to be exposed to more toxicity from their prey than from the water column directly. Thus, the exposure pathways do not change entirely for different species, but the portion of toxicity transferred via each pathway will differ.*

Q4. List the generalized exposure pathways for an aquatic organism.

  *Eating & absorption (direct uptake)*
Investigation III: Bioaccumulation

Part 4: What is a PCB?

Q1. What are polychlorinated biphenyls (PCBs)?

*PCBs are a large group of human-made organic chemicals that have a wide range of toxicity and physical characteristics. They can come in several colors and can come in the form of liquids or waxy solids.*

Q2. Why were they once a desirable substance?

*PCBs have chemical and physical properties that can be used in many different industrial applications—from electrical equipment to paper manufacturing to paints and dyes.*

Q3. Name some locations where PCBs may exist in your community:

*Responses may vary but should include: landfills, river or lake sediments, soils, air*

Q4. What is a common trade name for PCBs?

*Aroclor is the most common trade name for a PCB-containing compound.*

Q5. How might PCBs be released?

*Responses should include some or all of the following: leaks from PCB/hazardous waste sites, illegal dumping of PCB waste, leaks from electrical transformers that contain PCBs, improper disposal of PCB-containing products into landfills, municipal or industrial incineration.*
Health Effects of PCB exposure

Answers should include some or all of the following:

<table>
<thead>
<tr>
<th>Immune Effect</th>
<th>Neurological Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>in Rhesus monkeys:</em> significant decrease in size of thymus gland, decreased resistance to Epstein-Barr virus and other infections, increased susceptibility to pneumonia and viral infections, decreased ability to mount primary antibody response and develop protective immunity</td>
<td><em>in newborn monkeys:</em> persistent and significant deficits in neurological development, including visual recognition, short-term memory and learning. Some evidence suggests similar effects in humans</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reproductive Effect</th>
<th>Endocrine Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>in Rhesus monkeys:</em> reduced birth weights, reduced rates of conception and live births; in humans: decreased birth weights, gestational age</td>
<td>can have effects on thyroid hormone levels, which are important for normal growth and development</td>
</tr>
</tbody>
</table>
Q6. What are other names for polychlorinated biphenyls?

*Student answers may vary; some other names include: Pyranol, Inerteen, Askarel, Pydraul. This MSDS can be found at: [http://www.gepower.com/prod_serv/products/capacitors/en/downloads/pcb_msd_s_pcb.pdf](http://www.gepower.com/prod_serv/products/capacitors/en/downloads/pcb_msd_s_pcb.pdf)*

Q7. What are common uses of PCBs?

*Pyranol and Inerteen were used as fluids in electrical transformers; Askarel is a generic name for a category of fire-resistant synthetic compounds; Pydraul is trade name for hydraulic fluids*

Q8. What are the sources, routes, and types of exposure to PCBs?

*Student answers will vary. For these compounds, routes of exposure include skin contact and inhalation of heated vapors*

Q9. What are the effects of exposure to PCBs? (note if these are different from what the EPA states)

*Effects may include: eye irritation; red, dry, itchy skin; respiratory tract irritation (at high temperatures)*

Q10. What are the safety guidelines for exposure to PCBs?

*If contact occurs, flush area with lots of water; handling instructions recommend safety equipment such as goggles, gloves, protective clothing, and when necessary respiratory protection equipment as well*
Investigation III: Bioaccumulation

Part 5: Pre-Modeling Activity – Bioaccumulation and Biomagnification

<table>
<thead>
<tr>
<th>Day</th>
<th>PCBs (number of beads)</th>
<th>Caloric Units (number of marshmallows)</th>
<th>Ratio of PCB to biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1:2</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2:3</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3:4</td>
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<tr>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4:5</td>
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<tr>
<td>6</td>
<td>5</td>
<td>6</td>
<td>5:6</td>
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<td>7</td>
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<td>6:7</td>
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<td>7:8</td>
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<td>9</td>
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<td>9</td>
<td>8:9</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
<td>10</td>
<td>9:10</td>
</tr>
</tbody>
</table>

Q1. Did the periphyton get “bigger” over the 10 day period?

*After respiring on the 10th day, the periphyton should have a biomass of 10 units. Since after respiring on the 1st day it only had 1 unit, it has gotten “bigger.”*

Q2. What happened to the concentration of PCBs in the periphyton? Remember to use appropriate science vocabulary.

*The ratio of PCB units (plastic beads) to biomass units (marshmallows) increased over time, from 1:2 to 9:10. Thus, the concentration of PCBs in the periphyton has increased and the organism has more toxins. Important note: Students should understand that these units are different, however: that the ratio of PCBs to biomass on Day 10 is 9:10 does not mean that 90% of the periphyton is made up of PCBs.*
<table>
<thead>
<tr>
<th>Day</th>
<th>PCBs (plastic beads)</th>
<th>Caloric units (number of marshmallows)</th>
<th>Ratio of PCB to mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90</td>
<td>110</td>
<td>0.08</td>
</tr>
<tr>
<td>2</td>
<td>180</td>
<td>120</td>
<td>0.15</td>
</tr>
<tr>
<td>3</td>
<td>270</td>
<td>130</td>
<td>0.21</td>
</tr>
<tr>
<td>4</td>
<td>360</td>
<td>140</td>
<td>0.25</td>
</tr>
<tr>
<td>5</td>
<td>450</td>
<td>150</td>
<td>0.3</td>
</tr>
<tr>
<td>6</td>
<td>540</td>
<td>160</td>
<td>0.34</td>
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<tr>
<td>7</td>
<td>630</td>
<td>170</td>
<td>0.37</td>
</tr>
<tr>
<td>8</td>
<td>720</td>
<td>180</td>
<td>0.4</td>
</tr>
<tr>
<td>9</td>
<td>810</td>
<td>190</td>
<td>0.43</td>
</tr>
<tr>
<td>10</td>
<td>900</td>
<td>200</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Q3. Based on the results of your previous two examples, what do you predict will happen to the PCB concentration in the smallmouth bass after ten days of eating this way?

*The ratio of PCB to smallmouth bass biomass will increase with each day of feeding.*
Investigation III: Bioaccumulation
Teacher Answer Guide

Part 6: Modeling bioaccumulation and biomagnification using NetLogo

The Crayfish

Below are three example data sets and graphs for these examples.

<table>
<thead>
<tr>
<th></th>
<th>Example 1</th>
<th></th>
<th>Example 2</th>
<th></th>
<th>Example 3</th>
<th></th>
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<tbody>
<tr>
<td>Step</td>
<td>Energy</td>
<td>Toxicity</td>
<td>Energy</td>
<td>Toxicity</td>
<td>Energy</td>
<td>Toxicity</td>
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<tr>
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<td>2</td>
<td>2</td>
<td>0</td>
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<td>7.5</td>
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<td>15.5</td>
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<td>14.5</td>
<td>12</td>
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<td>14</td>
<td>18.5</td>
<td>14</td>
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<td>20</td>
<td>18.5</td>
<td>16</td>
<td>17.5</td>
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<td>20</td>
<td>22</td>
<td>22.5</td>
<td>18</td>
<td>16.5</td>
<td>14</td>
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<tr>
<td>15</td>
<td>24</td>
<td>24</td>
<td>26.5</td>
<td>20</td>
<td>15.5</td>
<td>14</td>
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<tr>
<td>16</td>
<td>23</td>
<td>24</td>
<td>25.5</td>
<td>20</td>
<td>7.25</td>
<td>14</td>
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<tr>
<td>17</td>
<td>27</td>
<td>26</td>
<td>29.5</td>
<td>22</td>
<td>6.25</td>
<td>14</td>
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<tr>
<td>18</td>
<td>26</td>
<td>26</td>
<td>14.25</td>
<td>22</td>
<td>10.25</td>
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<td>25</td>
<td>26</td>
<td>13.25</td>
<td>22</td>
<td>14.25</td>
<td>18</td>
</tr>
<tr>
<td>20</td>
<td>24</td>
<td>26</td>
<td>17.25</td>
<td>24</td>
<td>18.25</td>
<td>20</td>
</tr>
</tbody>
</table>
Example Data 1

![Graph showing Energy and Toxicity units over steps](image1)

Example Data 2

![Graph showing Energy and Toxicity units over steps](image2)

Example Data 3

![Graph showing Energy and Toxicity units over steps](image3)
Questions:
Before answering the following questions, form groups of four. Record your name and the names of your three group members in the name column in the table below.

<table>
<thead>
<tr>
<th>Names</th>
<th>Step in which crayfish had the most energy</th>
<th>Step in which crayfish had the most toxicity.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example 1</td>
<td>13</td>
<td>17-20</td>
</tr>
<tr>
<td>Example 2</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td>Example 3</td>
<td>12</td>
<td>20</td>
</tr>
</tbody>
</table>

1. Look at your step versus energy plot and those of your all of your group members. Is there a relationship between step and energy? Explain your reasoning citing specific steps from your plot.

*In the initial steps the crayfish steadily gained energy until it reached an “adult” size; adult size energy level will fluctuate. The students should cite quantitative data to support their answer.*

*i.e., “In example 1, the crayfish began at 3 units of energy in step 1 and grew to an adult with a maximum of 36 units in step 13 and then fluctuated around 25 units of energy after step 13.”*

2. Look at your step versus toxicity plot and those of your group members. Is there a relationship between step and toxicity? Explain your reasoning citing specific steps from your plot.

*Toxicity either stayed constant or increased but never decreased. The students should cite quantitative data to support their answer.*

*i.e., “In step one the toxicity was 2 units and as the crayfish got older the toxicity steadily increased to step 17 with 26 toxicity units.”*

3. Use your data set to give specific case where bioaccumulation is occurring. Explain your reasoning citing specific steps from your plot.

*Student answers should include specific data points that show an increase in toxicity as the biomass increases, thereby showing the accumulation of contaminants from food.*
i.e., “In step 6 the energy units were 8 and the toxicity units were 6. In step 7 the energy units were 12 showing that the crayfish ate and the toxicity increased to 8. This illustrates the bioaccumulation of a toxin from food.”

The smallmouth bass

Below is an example of a data set and graph for the next section.

<table>
<thead>
<tr>
<th>Example 2-1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
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<td>4</td>
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<td>11</td>
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<td>16</td>
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<td>17</td>
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<tr>
<td>18</td>
</tr>
<tr>
<td>19</td>
</tr>
<tr>
<td>20</td>
</tr>
</tbody>
</table>

**Energy versus Toxicity for a smallmouth bass**

4. When the slope is vertical what is occurring? Explain and support your answer with specific data.
The slope is vertical when the fish is losing energy due to basic body functioning (metabolism). However, the toxin is persistent, therefore the toxicity level remains constant while the bass’s energy level decreases.

The Community

<table>
<thead>
<tr>
<th>Step</th>
<th>Periphyton</th>
<th>crayfish</th>
<th>Smallmouth bass</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.1</td>
<td>2.0</td>
<td>0.39</td>
</tr>
<tr>
<td>20</td>
<td>4.9</td>
<td>1.9</td>
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<tr>
<td>40</td>
<td>5.3</td>
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<td>0.36</td>
</tr>
<tr>
<td>60</td>
<td>4.6</td>
<td>3.0</td>
<td>0.65</td>
</tr>
</tbody>
</table>

5. Compare the three scatter plots from steps 11, 21 and 29. Which has the steepest slope and which has the shallowest? Use data from graph and tables to show.

The line for the smallmouth bass shows the steepest slope because POPs biomagnify as they move through the food chain. Smallmouth bass are at the 3rd trophic level in this ecosystem, and so they undergo significant biomagnification. Crayfish exist at the second trophic level and so the slope of this line is shallower than the smallmouth bass. Since the periphyton are on the first trophic level, the line is nearly flat. These patterns show an increasing accumulation of contaminant burden from food in this ecosystem.
Investigation III: Bioaccumulation

Part 1: What do I know about pollutants?

In the space below circle T for true or F for false

<table>
<thead>
<tr>
<th></th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>T or F</td>
<td>1. What we eat/drink we eventually digest and then excrete.</td>
</tr>
<tr>
<td>T or F</td>
<td>2. Contaminants stay close to where they are spilled.</td>
</tr>
<tr>
<td>T or F</td>
<td>3. Rachel Carson started the environmental movement when she observed a particularly “Silent Spring”.</td>
</tr>
<tr>
<td>T or F</td>
<td>4. The most common exposure route for a toxin in humans is contaminated drinking water.</td>
</tr>
<tr>
<td>T or F</td>
<td>5. The “Dirty Dozen&quot; was a movie in the early 1970’s starring Clint Eastwood.</td>
</tr>
<tr>
<td>T or F</td>
<td>6. We are exposed to chemicals in the womb before we are born.</td>
</tr>
<tr>
<td>T or F</td>
<td>7. If we do not wash our hands before we eat we are exposed to chemicals.</td>
</tr>
<tr>
<td>T or F</td>
<td>8. PCBs are a group of man-made chemicals.</td>
</tr>
<tr>
<td>T or F</td>
<td>9. PCBs are used in plastic water bottles and, when discarded, end up in the Great Lakes system.</td>
</tr>
<tr>
<td>T or F</td>
<td>10. Longer-lived animals have greater bioaccumulation.</td>
</tr>
<tr>
<td>T or F</td>
<td>11. PCBs can be absorbed through the skin into an organism</td>
</tr>
</tbody>
</table>
Investigation III: Bioaccumulation

Part 2: What is POP (don’t you mean soda)?

From the 1870s through much of the 20th century, Calumet Harbor, home to the ecosystem you are learning about, was one of the busiest ports in the Great Lakes. Steel mills, oil refineries and meat packing plants were a few of the big industries that established major facilities in what was to become Chicago's South Side. Chicago became a major international port in 1959 with the opening of the St. Lawrence Seaway, because ships could finally navigate all the way inland from the Atlantic Ocean.

Waste from these industries and Chicago’s sewers flowed freely into the Calumet River system, which polluted the local environment and contaminated Chicago’s drinking water. Though environmental regulations now prohibit the dumping of industrial waste, the pollutants from earlier in this century still persist in the sediments of Calumet Harbor and Lake Michigan.

Today you will read “Persistent Organic Pollutants: A Global Issue, A Global Response,” which was published by the U.S. Environmental Protection Agency (EPA publication EPA160-F-02-001). This reading will familiarize you with the environmental and human health impacts of persistent organic pollutants (POPs). You will also learn about the current legal and scientific actions taken by the United States and other countries to address these pollutants.

Use the following graphic organizer to identify important information as you read. Write what you learn in the bubbles in the glass of soda. In particular, read carefully the following sections:

- “What are POPs?”
- “What Domestic Actions Have Been Taken to Control POPs?”
- “How Do POPs Affect People and Wildlife?”
- “The Great Lakes: A Story of Trials and Triumphs”

You can read the document online at [http://www.epa.gov/international/toxics/pop.html](http://www.epa.gov/international/toxics/pop.html) or you can download it from: [http://www.epa.gov/oia/toxics/brochure.html](http://www.epa.gov/oia/toxics/brochure.html).
POP Graphic Organizer

As you read the EPA document, write down what you learn about POPs and their effects on the environment in the bubbles.
Investigation III: Bioaccumulation

Part 3: How are we exposed to chemicals?

Every day, we come into contact with chemicals such as water, oxygen, nitrogen, fructose etc. If we come into contact with these substances for a short time – less than 14 days – we call this exposure “acute.” If, however, our exposure lasts over a year it is called “chronic.” Anything in between is called “intermediate.”

Most of these substances have no adverse health effects, but some do. A toxin is a substance that has adverse acute (immediate) or chronic (long-term) health effects when it enters the body. Today, we will consider all the ways we expose ourselves to toxins.

For example, gasoline stations carry the following warning at the pump: “Avoid prolonged breathing of vapors as long term exposure to vapors has caused cancer in laboratory animals.” Merely spilling gasoline on your hand does not provide a pathway for its toxins to enter your body. Gasoline must volatilize (vaporize) and be inhaled into your lungs for the exposure pathway to be complete.

In this activity, you will work in groups of 4 to brainstorm routes of chemical exposure to humans using examples from everyday life.

Procedure

1. Write your name in the center oval of your map.
2. In each of the four squares on your map, write one way in which you think humans are exposed to chemicals in their environment.
3. Once everyone in your group has finished, pass your map to your neighbor on your left. Repeat this procedure until everyone in the group has read each other’s answers.
4. As a group, decide which activities could be grouped together. Use the highlighters provided to categorize the activities.
5. Once you think of three categories of activities, write them on the board at the front of the room under your group name.
6. Answer the questions on the following page.
Investigation III: Bioaccumulation

Part 3: How are we exposed to chemicals?

Exposure Pathways Concept Map
Once the class has shared their brainstorming, complete the following:

Q1. Write the three exposure pathways for humans by your class.

_____________________________  _____________________________  ___________________________

Q2. Now imagine you’re an organism living in a beautiful lake. Would your exposure pathways change?

Q3. Do exposure pathways change according to what type of aquatic organism you are: forage fish, a mussel, or a top predator? Think about where each one lives, what they eat, how they breathe, etc.

Q4. List the generalized exposure pathways for an aquatic organism.

_____________________________________________________________________________________________________

_____________________________________________________________________________________________________

_____________________________________________________________________________________________________
Investigation III: Bioaccumulation

Part 4: What is a PCB?

In every workplace and home there are chemicals. In an office, it is common to have toners for the copier or cleaners for equipment. In a hair salon, there are hair dyes and chemical straighteners. Auto shops have coolants, oils, degreasers and gasoline. In your home, there may be cleaning fluids, pesticides, or herbicides. Each of these chemicals has potential adverse health effects. Some of them are immediately (acutely) apparent, like a chemical burn or shortness of breath, or it might take years for these effects to appear, as is the case with cancer.

In order to protect workers’ safety, the federal government passed a law in 1983 that created the Occupational Health and Safety Administration (OHSA). As part of this law, a Material Safety Data Sheet (MSDS) is “required for all shipments of hazardous chemicals leaving the manufacturer’s workplace and from all importers of such on all shipments,” as well as all “distributors and employers.”

The OHSA-formatted MSDS requires identification of the substance, as listed on the product label, followed by:

I. Manufacturer’s Name and Pertinent Information
II. Hazardous Ingredients/Identity Information
III. Physical/Chemical Characteristics
IV. Fire and Explosion Hazard Date
V. Reactivity Data
VI. Health Hazard Data
VII. Precautions for Safe Handling and Use
VIII. Control Measures

It is very easy to recognize the immediate adverse health effects of many chemicals; however, long term health effects can be easily dismissed. Think about smoking! Many people choose to smoke knowing that cancer or emphysema may occur years later. Someday, you will choose a career and/or start a family. It is very important to know the consequences of exposure to various substances so you can protect yourself and your family.
Today you will read a citizen’s guide developed by the U.S. Environmental Protection Agency (EPA). The purpose of this guide is to inform the general public of what PCBs are, and where and when they are used. Calumet Harbor in Chicago, IL has been heavily polluted with PCBs. As you have learned in this unit, toxins like PCBs are easily absorbed by aquatic organisms through feeding and direct exposure in their environment. Some of these organisms, like the smallmouth bass, are important sport fish and are eaten by humans. The EPA guide will detail what we now know about how PCBs can affect human health.

You will also do an internet search for a MSDS. As you read, complete the following questions and graphic organizer.

Access the following website site and answer the questions below.

http://www.epa.gov/epawaste/hazard/tsd/pcbs/pubs/about.htm

Q1. What are polychlorinated biphenyls (PCBs)?

Q2. Why were they once a desirable substance?

Q3. Name some locations where PCBs may exist in your community:

Q4. What is a common trade name for PCBs?

Q5. How might PCBs be released?
Health Effects of PCB exposure

Go to: [http://www.epa.gov/epawaste/hazard/tsd/pcbs/pubs/effects.htm#Repro](http://www.epa.gov/epawaste/hazard/tsd/pcbs/pubs/effects.htm#Repro)
Use the internet to search for 2 Material Safety Data Sheets for polychlorinated biphenyls (PCBs). Read the materials and attach them to this sheet. Then answer the following questions:

Q6. What are other names for polychlorinated biphenyls?

Q7. What are common uses of PCBs?

Q8. What are the sources, routes, and types of exposure to PCBs?

Q9. What are the effects of exposure to PCBs? (note if these are different from what the EPA states)

Q10. What are the safety guidelines for exposure to PCBs?
Investigation III: Bioaccumulation

Part 5: Modeling Bioaccumulation and Biomagnification with

What did you eat for dinner last night? Most of the food we eat is used up by our bodies for energy and growth, and some of it is excreted as waste. But this doesn’t account for everything that enters our bodies. Sometimes there are chemicals present in our food, like pesticides from the farm on which it was grown, or compounds from the soil, that our bodies can’t use up or get rid of. These substances are stored in our bodies and their amount increases over time. The same happens to organisms in the wild that live in contaminated environments.

In today’s activity, you will model the bioaccumulation of PCBs in the freshwater organisms of the Calumet Harbor ecosystem. As you proceed through the activity, observe how PCBs biomagnify as the travel through the food web.

Materials

You will be provided with the following materials:

- Food chain diagrams
- 200 Skittles or M&Ms (each piece of candy represents 1 unit of caloric energy)
- 100 plastic beads (each bead represents 1 unit of PCB toxin)

Instructions

1. We will start by modeling bioaccumulation in a single periphyton.
2. Place ten candies (10 units of caloric energy) on one periphyton square.
3. When the periphyton respires, it will lose 9 units of caloric energy (remove 9 candies from the periphyton square). The single candy remaining represents energy converted into biomass. Fill out “Day 1” of the table.
4. Now, imagine the food source for the periphyton becomes contaminated with PCBs. As the periphyton consumes its daily 10 units of caloric energy (10 candies) it will also eat one bead (this plastic bead represents the PCBs in Lake Michigan). You cannot digest plastic, nor can you digest PCBs. But unlike the plastic bead, PCBs will get stored in your fat. So the more beads you eat, the more PCBs you will store.
5. Repeat Steps 3, 4, and 5, adding 10 candies and 1 bead. Then remove 9 of the candies, but leave the beads. Record the data on “Day 2” of the table.
6. Have the periphyton eat contaminated food for ten days. Remember that the periphyton will continue to respire each day.

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<thead>
<tr>
<th>Day</th>
<th>PCBs (number of beads)</th>
<th>Number of candies (caloric energy → biomass)</th>
<th>Ratio of PCB to biomass</th>
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Questions:
Q1. Did the periphyton get “bigger” over the 10-day period?

Q2. What happened to the concentration of PCBs in the periphyton? Remember to use appropriate science vocabulary.
We will now model biomagnification in this food chain.

7. Before you start, give 100 units of caloric energy to the crayfish.
8. Add plastic beads and candies to the rest of the periphyton so that they each match the one you just modeled.
9. Have the crayfish eat 10 contaminated periphyton per day for 10 days. Remember that each day, the crayfish will respire 90 units of caloric energy after eating (remove 90 candies). The crayfish will continue to store plastic beads in its biomass.
10. After each day, fill in the table below.

<table>
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<tr>
<th>Day</th>
<th>PCBs (plastic beads)</th>
<th>Number of candies (caloric energy → biomass)</th>
<th>Ratio of PCB to biomass</th>
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11. Now bring your crayfish up to the teacher, who will feed them to a smallmouth bass that has 250 units of caloric energy.

**Question:**
Q3. Using your previous two models, what do you predict will happen to the PCB concentration in the smallmouth bass after ten days of eating this way?
Crayfish

periphyton  periphyton  periphyton  periphyton  periphyton

periphyton  periphyton  periphyton  periphyton  periphyton
Smallmouth Bass
Investigation III: Bioaccumulation

Part 6: Modeling bioaccumulation and biomagnification using NetLogo

In Part 5, you physically modeled bioaccumulation and biomagnification. Now, you will use the NetLogo Bioaccumulation model to explore these concepts in a simulated ecosystem.

Materials

- Computers (1 computer for each student preferred) with NetLogo or Internet access and a Java-enabled web browser
- NetLogo Aquatic Bioaccumulation model
- Student Guide
- Graph paper

The Crayfish

First, we will take a look at bioaccumulation within one organism—in this case, a crayfish. Crayfish are in the second trophic level because they consume the primary producers of this ecosystem, the periphyton. In this model, the periphyton have been contaminated with a toxin. This toxin is a POP (persistent organic pollutant). We will examine how this affects energy and toxicity in a crayfish.

Procedure

1. Open the Aquatic Bioaccumulation model. You can do this in one of two ways:
   a. Open the NetLogo modeling software and click on File → Open. Select the Aquatic Bioaccumulation model from the list.
   b. Or, launch your internet browser and go to:
      http://ecocasting.northwestern.edu/NetLogo/Bioaccumulation.html

2. Notice the black box on the right side of the screen. In order to display the organisms that make up the food web in this region, you will need to click the button in the upper left corner of the screen.

*NOTE: This button will be helpful as you move through the rest of the investigation as it will always reset your model back to zero when clicked.*
When the data loads, your model should look like this:

3. Click .
4. Right-click (ctrl+click on a Mac) on a crayfish. A pull down menu will pop up. (hint: for this exercise, select a crayfish near a lot of periphyton but not near a smallmouth bass.)
5. Scroll down to the bottom of the pull down menu and select “a-crayfish ####”. A pop up menu will open.
6. Select **watch a-crayfish ####**. You will see values appear in the boxes labeled Energy/Toxicity of watched/followed creature.

7. Write down the number of your crayfish here: __________ (in this example, 1357)

8. Record the values for energy and toxicity next to Step 1 in the table provided below.

9. Click **Go One Step** again and record energy and toxicity for Step 2 in your table. Repeat this in a step-wise fashion until 20 steps are complete. If your crayfish dies, go back to Step 6 and begin again.

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<th>Step</th>
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Analysis

10. On a sheet of graph paper, create a plot of step (x-axis) versus energy (left y-axis) and on the same graph plot step (x-axis) versus toxicity (right y-axis).

Questions:

Before answering the following questions, form groups of four. Record your name and the names of your three group members in the name column in the table below.

<table>
<thead>
<tr>
<th>Names</th>
<th>Step in which crayfish had the most energy</th>
<th>Step in which crayfish had the most toxicity</th>
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</table>

Q1. Look at your step versus energy plot and those of your group members. Is there a connection between step and energy? Explain your reasoning citing specific steps from your graph.

Q2. Look at your step versus toxicity plot and those of your group members. Is there a connection between step and toxicity? Explain your reasoning citing specific steps from your graph.

Q3. Use your data set to give a specific example of where bioaccumulation is occurring. Explain your reasoning citing specific steps from your graph.
The smallmouth bass

Next, we will explore bioaccumulation at the third trophic level of this ecosystem by measuring toxin increase in the smallmouth bass.

Procedure, continued

11. Click to reset your model.

12. Click .

13. Right-click (or ctrl+click on a Mac) on a smallmouth bass (hint: make sure it is near a few crayfish). A pop-up menu will appear.

14. Scroll down to the bottom of the menu and select a-smallmouth_bass ####. A second pop-up menu will appear.

15. Select watch a-smallmouth_bass ####. Values will appear in the boxes labeled Energy/Toxicity of watched/followed creature.

16. Record the values for energy and toxicity next to Step 1 in the table provided on the next page.

17. Write the number of the smallmouth bass you selected here:

   a-small-mouth-bass ____________

18. Click again and record the new values for energy and toxicity next to Step 2 in your table. Repeat this in a step-wise fashion until 20 steps are complete in the table below. If your smallmouth bass dies go back to Step 11 and begin again.
19. On a sheet of graph paper, create a plot of energy (x-axis) versus toxicity (y-axis).

**Questions:**

Q4. When the slope is horizontal what is occurring? Explain and support your answer with specific data.
The Community

We will now shift our focus from individual organisms to the whole community. We will explore how a persistent organic pollutant (POP) behaves within a complex food web.

Procedure, continued

20. Click on Setup to reset your model.
21. Move your cursor over the top of the first bar on the left (green bar) in the Average Energy Level by Species graph. The left bar is the average energy level of the periphyton. A cross hair will show up. Align the horizontal axis of the cross hair with the top of the column. You will note two numbers show up. The only one we are interested in is the number to the left (y-value), which is the average energy level.
22. Record the average energy for the periphyton.
23. Repeat this procedure for the crayfish, which is represented by the red middle bar, and the smallmouth bass, which is represented by the black right bar.
24. Move the cursor to the Toxin Level by Species bar graph and record the average toxin levels for each of the species in the below graph using the procedure outlined above.
25. Click Go One Step 20 times.
26. Repeat steps 21-25 three times and fill in the table below as you go.

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Analysis

27. On one graph, create a plot for step (x-axis) versus average toxicity level per average energy level energy (y-axis) for all three species.
Questions:

Q5. Compare the three graphs you made in steps 10, 19, and 27. Which has the steepest slope and which has the shallowest? Use data from your graphs and tables to support your answer.
Investigation III: Bioaccumulation

Part 5: Candy Bioaccumulation Activity – Bioaccumulation and Biomagnification

<table>
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<tr>
<th>Day</th>
<th>PCBs (number of beads)</th>
<th>Number of marshmallows</th>
<th>Ratio of PCB to biomass</th>
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Q1. Did the periphyton get “bigger” over the 10 day period?

Q2. What happened to the concentration of PCBs in the periphyton? Remember to use appropriate science vocabulary.
<table>
<thead>
<tr>
<th>Day</th>
<th>PCBs (number of beads)</th>
<th>Number of candies (caloric energy → biomass)</th>
<th>Ratio of PCB to biomass</th>
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Q3. Using your previous two models, what do you predict will happen to the PCB concentration in the smallmouth bass after ten days of eating this way?
Investigation III: Bioaccumulation

Part 6: Modeling bioaccumulation and biomagnification using NetLogo

Record the energy level and toxicity of the crayfish you are watching in the table below.

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<tr>
<th>Step</th>
<th>Energy</th>
<th>Toxicity</th>
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Before answering the following questions, form groups of four. Record your name and the names of your three group members in the name column in the table below.

<table>
<thead>
<tr>
<th>Names</th>
<th>Step in which crayfish had the most energy</th>
<th>Step in which crayfish had the most toxicity</th>
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</table>
Q1. Look at your step versus energy plot and those of your group members. Is there a connection between step and energy? Explain your reasoning citing specific steps from your graph.

Q2. Look at your step versus toxicity plot and those of your group members. Is there a connection between step and toxicity? Explain your reasoning citing specific steps from your graph.

Q3. Use your data set to give a specific example of where bioaccumulation is occurring. Explain your reasoning citing specific steps from the graph you created in step 11.
Record the energy level and toxicity of the smallmouth bass you are following in the table below.

<table>
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<tr>
<th>Step</th>
<th>Toxicity</th>
<th>Energy</th>
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<td>20</td>
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</tbody>
</table>

Q4. Look at the graph you drew for step 19. When the slope is horizontal what is occurring? Explain and support your answer with specific data.
Record the average toxicity and energy levels for each species in your model below.

<table>
<thead>
<tr>
<th>Step</th>
<th>periphyton</th>
<th>crayfish</th>
<th>smallmouth bass</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<td></td>
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<td>40</td>
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<td></td>
<td></td>
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<tr>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q5. Compare the three graphs you made in steps 10, 19, and 27. Which has the steepest slope and which has the shallowest? Use data from your graphs and tables to support your answer.
4. Invasive Species

Teacher Overview
Answer Key
Student Guide
Student Response Sheet
Investigation IV: Invasive Species

Purpose
The purpose of this activity is to analyze the effects of introducing invasive species into an existing food web. Students begin to investigate how predator-prey relationships and population sizes change with the addition of a new species. They will also begin to look at how the introduction of invasive species changes the bioaccumulation of toxic compounds, such as polychlorinated biphenyls (PCBs), across trophic levels. Students will work with the NetLogo Aquatic Invasive Species model to look for cause-and-effect relationships within this new scenario.

Overview
This investigation begins by exploring how the introduction of a new species into a food web can change feeding relationships amongst the native organisms. Students will look at how invasions of round goby add a new trophic level to the environment, and how the presence of this new organism affects population sizes of the native periphyton (algae, detritus), crayfish, and smallmouth bass. The students will be asked to analyze population data displayed graphically in the NetLogo Aquatic Invasive Species model to detect any cause-and-effect relationships focused around the invasion of a new species into an already established environment. Students will then explore how invasions of the round goby alter the process of PCB bioaccumulation throughout that same food web. Students will again be asked to perform graphical analysis of toxicity data displayed in the NetLogo model to understand how the round goby are involved in the process of PCB bioaccumulation throughout the food web.

Student Outcomes Specific to this Investigation

Illinois State Science Standards for grades 9-12

• Using available technology, report, display and defend to an audience conclusions drawn from investigations.

College Readiness Standards

• Identify key issues or assumptions in models.
• Determine whether given information supports or contradicts a simple hypothesis or conclusion, and why
Time
Two to three 45-minute class periods

Level
Secondary (9-12)

Materials and Tools
• Student Guides– 1 per student (optional)
• Computers – ideally 1 per student
• NetLogo software with Aquatic Invasive Species model loaded or a Java-enabled web browser and Internet access to: http://ecocasting.northwestern.edu/NetLogo/Invasive%20Species.html.
• White board
• Dry erase markers

Preparation
• Download NetLogo software and the Aquatic Invasive Species model onto computers
  ▪ Download the NetLogo software from: http://ccl.northwestern.edu/netlogo/
  ▪ Then, go to: http://ecocasting.northwestern.edu/NetLogo/Invasive%20Species.html. Under the model, right-click on “view/download model file” and select “Save Link As…”
  ▪ Save file to a labeled folder that students can access from their computers.
• Or, provide Internet access to the NetLogo Aquatic Invasive Species model (see address under Materials and Tools).
• One Student Guide per student; download from: http://ecocasting.northwestern.edu/curriculum/invasive-species/
• If necessary, schedule class time in computer lab
Prerequisites

- Investigation I: Is Fish Safe To Eat, Or Is It A Toxic Risk?
- Investigation II: Aquatic Food Chains, Food Webs, & Modeling
- Investigation III: Bioaccumulation

Background

**What are “invasive species?”**

According to the USDA’s National Invasive Species Information Center ([http://www.invasivespeciesinfo.gov/whatis.shtml](http://www.invasivespeciesinfo.gov/whatis.shtml)), “an ‘invasive species’ is defined as a species that is non-native (or alien) to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health.” These alien species can come in the form of plant, animal, insect, etc. and they are mainly introduced to their new environment via human interaction.

If you want additional information specific to invasive species within the Great Lakes, the U.S. EPA has a website ([http://www.epa.gov/glnpo/invasive/](http://www.epa.gov/glnpo/invasive/)) detailing those organisms that have changed our freshwater ecosystems since about the 1800s. There are additional links on this website that provide great extensional information and research opportunities for students interested in this topic, such as the USGS Nonindigenous Aquatic Species Database.

In case you or your students have not seen any of the organisms that make up the food web in this investigation, some are shown on the student handouts. Please reference/share the following additional images that are not included on those documents:

Native crayfish profile

Native crayfish head-on
Teaching Notes
If this investigation is your first use of this unit, it would be beneficial to review the previous investigations in order to ensure an understanding of the location-specific food web (Investigation II) used here. In addition to reviewing the food web, Investigation III presents information about PCBs and their bioaccumulation/biomagnification throughout this food web. It is also suggested to take a look over the background material for that investigation before starting Investigation IV.

There may be many new vocabulary terms students may not recognize and/or understand in the introductory reading to this investigation. It may be wise to review some of these terms/organisms before and after the students read and, if possible, include visuals to help the students make better connections to the content.

There are two invasive species that will be presented in this model: the mussel and the round goby. The mussels shown in the model are a generic mussel species, not specific to either the zebra or quagga mussel species. In order to avoid overcomplicating the model, it will represent a filter feeder that is an additional food source for both the round goby and the crayfish.

Before students begin this activity, ask them to come up with their own definitions of what an invasive species is and how they think one would affect an ecosystem. Will it positively affect their new home space or negatively impact it? How? Have students work together in pairs during this brainstorming session and write their answers on white boards for a large group discussion. Make sure to provide the correct definition as to what invasive species are and how they can potentially impact their new environments before allowing them to continue with the investigation.

The model
As the model runs, time is constantly being plotted on the bottom Population Size graph. The timing of invasions will change observed results. If possible, have students take screen shots of the current state of the model being used to answer particular questions. Since not all students may know how to take screen shots and print them up, it may be helpful to review this technique before beginning the investigation. On a PC, use Ctrl+Alt+PrtSc, or
Fn+PrtSc, depending on the computer. On a Mac, use Command+Shift+4 to select a portion of the screen.

The model is designed to randomize the starting conditions, meaning every run of the model will show slightly different results. Because of this, some runs of the model will not display an inversion in the toxicity of the round goby and the smallmouth bass. To get a better understanding of general trends, rather than unique examples within the model, students should run the model at least 3 times for each part of the activity. This will ensure they observe general patterns and not isolated, random outcomes.

It is important to consider how the values in the **Toxicity History** graph are calculated. The total amount of toxicity of a species is averaged over the number of organisms of that species present in the model at a given time. Thus, if you observe a sharp peak in the toxicity of round gobies, for example, it likely represents a small number of old round gobies with a very high toxicity level.

In this activity, students will be able to change the food chains listed in the FoodWeb box (Figure 2) at the top of the model. During their initial runs of the model, do not have them change the food chains. As they move through the investigation questions, they will be allowed to make edits to this section of the model. If students do happen to make changes before the Student Guide instructs them to do so, have them to return to the default food chain settings before continuing by clicking **Setup** and removing any added commands in the **FoodWeb** box. They will again be able to make edits to this section of the model as they move through the investigation questions.

In order to answer some of the questions in the later parts of this activity, students will need to refer to earlier predictions. If you have divided the Student Guide into separate packets, make sure students have access to their previous work as they progress through the activity.

**Suggested Extension Activities**
A suggested extension activity would be individual investigations into a particular invasive species for your state or region and local/state/federal government responses to the presence of the organism. Students could then share their findings with classmates via a mix/pair/share activity or a large group mapping session of confirmed locations of various invasive species across your state or area.
Another suggested extension activity is to take your students fishing for invasive species. In the greater Chicago area, the best search would be for the round goby. This can possibly be accomplished through your local park and/or forest preserve districts, or through the Chicago Park District’s Fishing Chicago program (http://fishingchicago.org/). You may also be able to attempt to collect non-native mussels (Asiatic clams, zebra mussels, and/or quagga mussels), but please check to make sure that whatever body of water you do decide to investigate for these species is known to be an invaded ecosystem/body of water.

**Exercise caution when leaving a body of water known to contain invasive species to ensure you do not spread these invasive species to an unaffected body of water later on.**

If you would like to go more in depth than this investigation with how invasive species can affect the biodiversity of an ecosystem, the Friends of the Chicago River has an activity called “Biodiversity - Who Cares?” This activity uses manipulatives to visually demonstrate how the introduction of invasive species can change the dynamics of an aquatic ecosystem (the Chicago River).

(http://www.chicagoriver.org/upload/Biodiversity_Who_Cares.pdf)
Investigation IV: Invasive Species

Part 1: Getting Started – Brainstorming

Q1. When you hear the term “invasive species”, what do you think of? List as many thoughts as you can in the time provided to you. Compare lists with a partner to see if any commons ideas emerge. Using these common ideas, create your own definition of an invasive species with your partner.

*Student brainstorming ideas will vary. According to the USDA, an invasive species is a “species that is non-native (or alien) to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health.”*

Q2. How do you think invasive species affect the environment in which they exist? Are they positive or negative influences? Working together with your partner, come to a consensus as to how invasive species affect their new home spaces.

*Students will likely come up with a variety of influences that invasive species will have on their new environment: plant invasive species can become weeds that reduce the amount of space in which other plants can grow; insect species can become pests whose populations soar without predators in their new environment; alternatively, students may suggest that new species provide additional food sources to existing species.*

Part 2: Exploring the Effects of a New Trophic Level on the Food Web

Q3. Which of the organisms listed in the Food-Web box is missing from the model frame? Why is this?

*The round goby is missing because it has not yet invaded the ecosystem.*

Q4. Now that you know what an invasive species is and how it can impact an ecosystem, predict how you think an invasion of round goby will affect the population size of each of the organisms in this aquatic ecosystem model.

<table>
<thead>
<tr>
<th>Aquatic Species</th>
<th>Predicted round goby side effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periphyton</td>
<td><em>Periphyton population may increase if one of its predators, the crayfish, is being eaten by the round goby</em></td>
</tr>
<tr>
<td>Mussels</td>
<td><em>Mussel population may decrease with introduction of the round goby, a new predator</em></td>
</tr>
</tbody>
</table>
Crayfish | Crayfish population may decrease with introduction of the round goby, a new predator

Smallmouth bass | Round gobies will add a new food source for the smallmouth bass which would benefit their population size, but the round goby also provides increased competition. Both species feed on crayfish and mussels, which could potentially reduce the food available to the smallmouth bass. In addition, the round goby can feed in total darkness, which increases the species chances for survival in this ecosystem.

Q5. How do you think the round goby will fare in its new environment? Provide a prediction about how you think its population will react.

*Despite the presence of a predator, the smallmouth bass, the round goby population will probably grow because of its ability to adapt to its new environment. It has several options for food: crayfish, mussels, fish eggs and fry. In addition, the round goby has the ability to search for food at night.*

Q6. Were your predictions about the round goby’s impact on the food web supported by the model? Describe any differences between your predictions and what you saw happening AND provide some possible explanations for any differences you saw.

<table>
<thead>
<tr>
<th>Aquatic Species</th>
<th>Observed round goby side effects</th>
<th>Possible causes for change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periphyton</td>
<td>Population size stays large, dips at times but appears to be positively affected by round goby invasion</td>
<td>Both the round goby and the smallmouth bass are now preying on the crayfish, which is the periphyton’s only predator in this food web.</td>
</tr>
<tr>
<td>Mussels</td>
<td>Population size grew until gobies were introduced, then dropped slowly over time.</td>
<td>Mussels were not being preyed upon before the round goby invasion.</td>
</tr>
<tr>
<td>Crayfish</td>
<td>Population size dropped once round goby invaded and continues to stay low; however it does slightly recover for a short time</td>
<td>Crayfish are now being preyed upon by an additional predator (round goby)</td>
</tr>
<tr>
<td>Smallmouth bass</td>
<td>Population size rises and falls gently at first, but then crashes</td>
<td>Smallmouth bass now have a new source of food, but eventually its food sources (crayfish and round goby) become depleted</td>
</tr>
</tbody>
</table>
Q7. How did the round goby population fare? Was this what you predicted? Describe any differences between your predictions and what you saw happening AND provide a possible explanation for any differences you saw.

The round goby initial invasion was large, but the population quickly dropped off because it ran out of food. It was competing with the smallmouth bass for crayfish, while also being food itself for the smallmouth bass.

Q8. How would your ecosystem react to multiple invasions of the round goby? Predict how the populations of each of the organisms in this ecosystem might react to more than one invasion of the round goby.

<table>
<thead>
<tr>
<th>Aquatic Species</th>
<th>Predicted side effects of multiple invasions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periphyton</td>
<td>More round gobies in the ecosystem may drastically reduce the crayfish population, causing the periphyton population to increase dramatically</td>
</tr>
<tr>
<td>Mussels</td>
<td>Population will decrease more quickly</td>
</tr>
<tr>
<td>Crayfish</td>
<td>Population will decrease more quickly</td>
</tr>
<tr>
<td>Smallmouth bass</td>
<td>Population will crash sooner</td>
</tr>
</tbody>
</table>

Q9. How many times did you press the “Start Invasion” button? Were your invasions evenly distributed or not? Why did you choose to invade the ecosystem this way?

Student answers will vary, but should provide a logical reasoning for why they chose to invade the ecosystem a certain way.

Q10. How did the pre-existing species in the ecosystem react to more than one invasion of the round goby? Describe your observations.

Student answers will vary, but they should not have seen the round goby taking over the ecosystem. The timing of their invasions and the number of invasions will cause different things to occur so it is suggested that you have the students do a screen shot of their final screen used to answer this question.

Q11. Could multiple invasions of an invasive species into an ecosystem actually happen in nature? Explain your answer.

Yes. Situations such as multiple ballast water dumps from ships carrying invasive species can occur in a body of water. Even within an ecosystem, portions of the ecosystem can experience various population sizes of a species moving in to and out of the area over time.
Part 3: Different Species, Different Adaptations

Q12. As was stated in the reading at the start of this investigation, zebra and quagga mussels are additional invasive species found within the Calumet Harbor ecosystem and are represented by the mussel image in the model. Zebra mussels have been found to be more contaminated than their quagga counterparts. What do you think could be the reason for this?

_The zebra mussels are only able to attach themselves to hard substrate (rock), whereas the quagga mussels are able to live in softer substrate (sand, mud). The periphyton tend to accumulate on the harder substrate than on the softer, so the zebra mussels become more contaminated due to their direct contact with a contaminated food source (periphyton)._  

Q13. Scientists have found that between 1999 and 2005, quagga mussels became the dominant mussel species within the Calumet Harbor. How do you think this mussel succession could affect PCB biomagnification throughout the food web?

_If the quagga mussels end up replacing the zebra mussels over time, the round goby will have a larger, cleaner food source available to them (because the quagga mussels consume less of the PCB-contaminated periphyton). This could help to reduce total PCB biomagnification in the food web over time._

Part 4: Exploring the Effects of a New Trophic Level on Toxin Transfer

Q14. How do you think an invasion of round goby will affect the bioaccumulation of PCBs in each of the species in this ecosystem model?

<table>
<thead>
<tr>
<th>Aquatic Species</th>
<th>Predicted effects on toxicity</th>
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</thead>
<tbody>
<tr>
<td>Periphyton</td>
<td>No effect</td>
</tr>
<tr>
<td>Mussels</td>
<td>The round gobies will be predating the mussels, so they may not live as long, reducing the total bioaccumulation they can reach.</td>
</tr>
<tr>
<td>Crayfish</td>
<td>The round gobies will be predating the crayfish, so they may not live as long, reducing the total bioaccumulation they can reach.</td>
</tr>
<tr>
<td>Smallmouth bass</td>
<td>Round gobies will have a greater PCB concentration than other food sources for the bass, so as the amount of gobies in the bass’ diet increases, so will their exposure to PCBs.</td>
</tr>
</tbody>
</table>
Q15. Looking back to the answers you provided for Question 14, did the model’s results support your prediction about the round goby’s impact on bioaccumulation and biomagnification? Describe any differences between your predictions and what you saw happening AND provide some possible explanations for these differences.

<table>
<thead>
<tr>
<th>Aquatic Species</th>
<th>Observed effects on toxicity</th>
<th>Possible causes for change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periphyton</td>
<td>Starts high but then drops.</td>
<td>Being eaten by crayfish</td>
</tr>
<tr>
<td>Mussels</td>
<td>Stays relatively low during entire run.</td>
<td>No observed changes over time.</td>
</tr>
<tr>
<td>Crayfish</td>
<td>Rises high initially, but then begins to drop.</td>
<td>Is being eaten by both the smallmouth bass and round goby, have a very young population</td>
</tr>
<tr>
<td>Smallmouth bass</td>
<td>Gradually rose and stayed high, but dropped from time to time</td>
<td>Eating crayfish that were exposed to PCBs in periphyton; eating round goby that were exposed to PCBs from crayfish</td>
</tr>
</tbody>
</table>

Q16. You may have observed that the Toxicity History levels fluctuate over time, particularly for the round goby and smallmouth bass. What do you think is happening in the model when the average toxin level of a species decreases?

Students may have a variety of responses for this answer. Sharp peaks in the Toxicity History graph correspond to a small number of highly contaminated organisms in the species. When the peaks disappear, it means that these older organisms have died, or that the average toxicity level for the species has dropped as a result of an increased number of young organisms with less contamination. The subsequent lower level of species toxicity likely reflects a younger, less contaminated population.

Part 5: Reading Real Data from the Scientists

Q17. What is this graph saying about the trophic positions of the round goby and the smallmouth bass?

According to this figure, some round goby individuals have the same trophic position as some of the smallmouth bass individuals.
Q18. Develop a hypothesis as to how a smallmouth bass can be prey to the round goby. Remember... the smallmouth bass is a larger fish than the round goby and when we look at simple food chains, the bigger organism typically eats the smaller one. How is a smaller species able to be a predator to a larger one?

The round goby prey on the smallmouth bass fish eggs and fry (young smallmouth bass).

Q19. What did you learn about how the round goby can be a predator to the smallmouth bass?

Round gobies eat the eggs and fry of the smallmouth bass. They invade the nests of the smallmouth bass to steal the eggs.

Q20. How do you think the ability of the round goby to feed at two different trophic levels will change what you saw happen earlier to the populations of other species following your initial round goby invasion?

<table>
<thead>
<tr>
<th>Aquatic Species</th>
<th>Predicted side effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periphyton</td>
<td>No effect</td>
</tr>
<tr>
<td>Mussels</td>
<td>Population may not be as affected as before if round goby are also consuming another food source (smallmouth bass eggs)</td>
</tr>
<tr>
<td>Crayfish</td>
<td>Population may not be as affected as before if round goby are also consuming another food source (smallmouth bass eggs)</td>
</tr>
<tr>
<td>Smallmouth bass</td>
<td>Population will not grow as quickly because eggs and young fish are being eaten by round goby.</td>
</tr>
</tbody>
</table>

Q21. Did the model support your prediction from Question 21? Describe any differences between your predictions and what you saw happening in the model AND provide some possible explanations for these differences.

<table>
<thead>
<tr>
<th>Aquatic Species</th>
<th>Observed side effects</th>
<th>Possible causes for change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periphyton</td>
<td>Population size stays large, but rises and dips over time.</td>
<td>Depends on the crayfish population since that is its predator.</td>
</tr>
<tr>
<td>Mussels</td>
<td>Population grows until the round goby invasion, dips, levels out for a short while, and then slowly drops over time.</td>
<td>The mussels were not preyed upon by anything until the round goby invasion. Since the round goby now has 3 different food sources, the</td>
</tr>
</tbody>
</table>

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Investigation IV: Invasive Species – Answer Key – 10 pages
Crayfish

Population size grows for a while, but then drops gradually over time.

Round goby has more prey options, and a lower smallmouth bass population has less predation pressure on crayfish, but it still has 2 predators.

Smallmouth bass

Population size stays fairly low but does gently grow over time.

Now has a predator to keep population growth in check. As food sources decrease so does its population.

Q22. Were any of the organisms from this portion of the ecosystem eliminated after the round goby invasion? Is this realistic? Explain your answer below.

Yes, if the model is left to run long enough it is possible to eliminate an organism from the ecosystem. A prompt will pop up asking the student to either reintroduce one organism of that type into the ecosystem or to continue on without it. This is realistic because an organism can die out if an invasive species consumes or changes the necessary resources for that organism to survive.

Q23. What did you choose to do once this portion of the ecosystem was absent of a particular species? Explain your choice AND describe how the ecosystem reacted.

Student answers will vary. It is suggested that you have students do a screen shot following their decision. They have the option to stop the model run or add another organism from that species to the model.

Q24. What is the relationship between size of round goby and trophic level on this graph?

Trophic position is inversely related to size of round goby individual.

Q25. Do you think the ability for the round goby to feed at two trophic levels will change the toxicity levels throughout the food web that you observed earlier? Write your prediction below.

<table>
<thead>
<tr>
<th>Aquatic Species</th>
<th>Predicted effects on toxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periphyton</td>
<td>No effect, PCB contamination will stay low</td>
</tr>
<tr>
<td>Mussels</td>
<td>No effect</td>
</tr>
</tbody>
</table>

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Investigation IV: Invasive Species – Answer Key – 10 pages
Q26. Looking back to Question 25, was your prediction supported by the model? Describe any differences between your prediction and what you saw happening AND provide some possible explanations for these differences. How is this graph different from the Toxicity History graph in Part 4 (before you changed the Food-Chain rules)?

<table>
<thead>
<tr>
<th>Aquatic Species</th>
<th>Observed effects on toxicity</th>
<th>Possible causes for change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periphyton</td>
<td>Toxicity levels stayed low the entire run.</td>
<td>No major changes observed.</td>
</tr>
<tr>
<td>Mussels</td>
<td>Toxicity levels stayed low the entire run.</td>
<td>No major changes observed.</td>
</tr>
<tr>
<td>Crayfish</td>
<td>Toxicity level dropped very low to almost negligible levels.</td>
<td>The population size of the crayfish dropped very low.</td>
</tr>
<tr>
<td>Smallmouth bass</td>
<td>The toxicity levels continued to climb over time until the population crashed.</td>
<td>Because the round goby are consuming the PCB-rich eggs of the smallmouth bass they are providing an even more contaminated food source for the smallmouth bass. In addition, the round goby are now preying upon the smallmouth bass, limiting their population growth over time.</td>
</tr>
</tbody>
</table>

Q27. Are there other factors (besides feeding at two different trophic levels) that could play a role in how the round goby affect the biomagnification of PCBs throughout the Calumet Harbor ecosystem? Explain.

Yes. The time of year (seasons) can affect how PCBs move throughout a food web. Behaviors of organisms change throughout a year, such as spawning times. The predominant sex of a species within an ecosystem can impact PCB transfers depending on the feeding rates of males versus females, body fat content differences between males & females, and reproduction rates. Finally, the size of individuals within the
different species will also affect how PCBs may move throughout a food web. A big population of large-size round gobies will affect an ecosystem differently than a big population of small-size round gobies. This is because large-size round gobies tend to feed exclusively on mussels, whereas small-size round gobies will feed on fish eggs (round goby and smallmouth bass) and mussels as they grow in size.

Q28. Based on these new findings, how would you change the model to better represent the food web?

Students may suggest including seasonality in the model to account for different behaviors among fish during various times of the year. Or, they may suggest a way to differentiate between large and small round gobies or males and females.

Q29. Is this ecosystem unique? Why or why not?

That this ecosystem is experiencing observable change as a result of invasive species is not unique. Many ecosystems, particularly in the Great Lakes, are exposed to the effects of invasive species. The PCB contamination feedback loop created by the feeding habits of the round goby is unusual, however, though it may exist in other ecosystems where it has not yet been documented.

Q30. Make a policy statement regarding what we should do about invasive species in the Great Lakes.

Students may suggest restricting the spread of invasive species through outreach and education efforts that would teach anglers about the risks of invasive species. They may also suggest policies that would force anglers and others to clean their boats more regularly and thoroughly to prevent the spread between lakes. Or, they could suggest a policy that would somehow help to reduce or eliminate the initial introduction of invasive species via ballast water.

Q31. Cut out the images on the next page and use them to construct a diagram of the Calumet Harbor food web based on what you have learned in this investigation. Paste this new diagram onto the back of this sheet and draw arrows that better represent the feeding habits of the species in Calumet Harbor.

The image on the following page was taken from the same article as the graphs in the Student Guide. It describes in detail the complexities of the food web, including seasonality and life-stage of fish.
Fig. 3. Calumet Harbor (Chicago, IL, USA) food web model. (a) Simple trophic description showing predator–prey links. (b) Model integrating time-dependent effects (ontogeny and seasonality) and consumption of detritus. Trophic links for the round goby and small-mouth bass are functions of time, \( f(t) \), as size changes (ontogeny). Trophic links for crayfish and round gobies are a function of time, \( f(t) \), through seasonal availability. Consumption of detritus and fish eggs links predators to prey items at equal or higher trophic positions than their own, creating a positive feedback effect (dashed lines).

Investigation IV: Invasive Species

Introduction

“AHHHH!!! We’re being invaded! Save yourself!” When you hear statements like these, you may think of either a castle being stormed by an enemy army during the medieval time period, or instead you might imagine a sky filling up with disc-shaped UFOs. Either way, what you’re picturing probably isn’t all that positive of a situation for the person who would be making those initial comments. But is this how non-human organisms feel when a new species makes its way into an ecosystem? Would those little critters want to yell warnings to the other organisms they share resources with? Or would it be more like a new neighbor quietly moving into the house next door, not really bothering anyone as they settle into their new environment?

When we look at our Great Lakes freshwater ecosystems, we know we aren’t looking at pristine bodies of water that have remained untouched by the human hand. Investigation III should have taught you how polychlorinated biphenyls (PCBs) came to appear in the waters of the Calumet Harbor. We have also influenced the dynamics of native aquatic ecosystems within the Great Lakes through the introduction of invasive species, starting around the early 1800s. According to the United States Environmental Protection Agency’s (US EPA) Great Lakes invasive species website, this includes approximately 25 different types of fish, mollusks, plants, and crustaceans. The particular aquatic ecosystem you’ve been looking at throughout Investigations II & III has been invaded by two different types of mussels (the zebra and quagga mussels) and the round goby. In this model, we will be mainly focusing our attention on the impact of the round goby on a portion of the Calumet Harbor aquatic ecosystem.
Mussels

The first invasive species to have worked its way into Calumet Harbor was the zebra mussel. The zebra mussel is a small shellfish (mollusk) that is commonly found attached to hard objects in water such as water intake pipes, piers, and boat bottoms. This species is named for the striped pattern that runs across the surface of its shell. Zebra mussels are filter feeders that can remove large amounts of phytoplankton from an ecosystem, significantly changing properties including water clarity and algae content.

These mussels came from bodies of water in Eurasia such as the Black and Caspian Seas. According to the United States Geological Survey’s (USGS) Nonindigenous Aquatic Species Database, zebra mussels most likely were introduced to the Great Lakes as young, developing mussels held in the ballast water of a cargo ship from Europe or Asia. They were first found in the Great Lakes in 1988 in the waters connecting Lake Huron and Lake Erie, and by 1990 were detected in all of the Great Lakes.

However, the zebra mussel has been out-invaded (also known as succeeded) by another mussel in the Calumet Harbor: the quagga mussel. The quagga mussel is a close
cousin to the zebra mussel, getting its name from the “quagga”, an extinct ancestor of the zebra (USGS Nonindigenous Aquatic Species Database, 2010). As you can see in the picture on the next page, quagga mussels are mollusks just like the zebra mussels, but they are larger in size and rounder. Their impacts on aquatic ecosystems are very similar to that of zebra mussels; however, they can be found on both hard and soft underwater surfaces.

Quagga mussels are native to the Ponto-Caspian Sea and the Dneiper River watershed of the Ukraine. This species is thought to have entered the Great Lakes from the ballast waters of transoceanic ships. Quagga mussels were first found in Lake Erie in 1989 and by 2005 had spread to the remaining Great Lakes (USGS Nonindigenous Aquatic Species Database, 2010).

Round Goby

The final invasive species looked at in this investigation is the round goby. The round goby is a small brown fish that is native to the same bodies of water in Eurasia as the zebra mussels. They prefer shallower waters and perch themselves on rocks using their small, front fins; however, they can travel to deeper waters to feed. Round gobies are aggressive eaters who enjoy diets of smaller fish, fish eggs and fry (early life stage of fish), aquatic insects, and zebra mussels. They can out-compete for food with native species within an ecosystem because they have the ability to feed in total darkness (USGS Nonindigenous Aquatic Species Database, 2010).
Just like the zebra and quagga mussels, the round goby was introduced to the Great Lakes waterways via the ballast water found in freighter ships from Europe or Asia. They were first found within the Great Lakes near the Michigan-Ontario, Canada border in 1990. By 1994 the round goby had been detected in southern Lake Michigan, in places like Calumet Harbor and other ports around Chicago, IL. They can now be found in all five of the Great Lakes (USGS Nonindigenous Aquatic Species Database, 2010).

What is an invasive species and how can it affect a food web?

In this section, you will start off working with a partner to share ideas about what an invasive species is and how it could potentially affect an ecosystem. You will then put your ideas to the test by using the NetLogo modeling software to see how an invasive species can impact a food web.

Part 1: Getting started – Brainstorming

Questions:

Q1. When you hear the term “invasive species”, what do you think of? List as many thoughts as you can in the time provided to you. Compare lists with a partner to see if any common ideas emerge. Using these common ideas, create your own definition of an invasive species with your partner and write it in the space below.
Q2. How do you think invasive species affect the environment in which they exist? Are they positive or negative influences? Working together with your partner, come to a consensus as to how invasive species affect their new home environments.

Part 2: Exploring the Effects of a New Trophic Level on the Food Web

If you’ve been working through Investigations I, II, & III of this unit, you’ve already been introduced to one type of relationship that can exist within an ecosystem: predator-prey. You should also have seen how humans can impact the health of an ecosystem through the addition of toxins, specifically PCBs, into the environment. Now it’s time to expand upon both of those investigations by looking at how a new species introduced to an ecosystem can change both the initial predator-prey relationships AND change how a pollutant moves through a food web.

The scientists who are studying Calumet Harbor set out to answer those same questions: How do new species affect predator-prey relationships and toxin transfer in a food web? You might ask, “How did they do this?” They went fishing! They collected lots and lots of fish and examined samples of their tissues and stomach contents to see what kinds of organisms they had been eating. They used this information to create computer models that could help them predict the effects of invasive species and POPs on the ecosystem.

In this investigation, you will examine how an invasive species can affect the transfer of a pollutant through an ecosystem. Recall from Investigation III that bioaccumulation is the buildup of a toxin in the tissues of an individual organism during its lifespan, while biomagnification is the increasing concentration of a toxin in the tissues of organisms in successive (higher) trophic levels. As you complete this activity, you will want to focus on both the accumulation of PCBs within each species as well as how the toxin biomagnifies as it moves from one trophic level to the next.

Procedure
1. Open the NetLogo Aquatic Invasive Species model. This can be done in one of two ways:
   a. Open the NetLogo software on your computer. Click on File → Open and select the Aquatic Invasive Species model from the list.
   b. Or, open your internet browser and type in the following address:
      http://ecocasting.northwestern.edu/NetLogo/Invasive%20Species.html
2. Notice the black box on the right side of the screen. In order to display the organisms that make up the food web in this region, click the **setup** button in the upper left corner of the screen.

*NOTE:* The setup button will be helpful as you move through the rest of the investigation as it will always reset your model back to zero when clicked.*

When the data loads, your model should look like this:

Notice the **Food-Web** box on the left-hand side of the model. These rules govern how the model runs. They were written based on how the scientists predicted the food web would be structured, with larger organisms eating the smaller ones.

**Question:**

Q3. Which of the organisms listed in the **Food-Web** box is missing from the model frame? Why is this?
Q4. Now that you know what an invasive species is and how it can adapt to living in a new ecosystem, predict how you think a round goby invasion will affect the population size of each of the organisms that make up this aquatic ecosystem model.

Q5. How do you think the round goby will fare in its new environment? Provide a prediction about how you think its population will react.

3. Click on the button in the upper left corner of the screen to start the model running. This button will both start and stop the model run.

4. Let the model run to 100 on the time axis. Begin to invade your ecosystem model with round goby. In order to do this, click on the “Start Invasion” button on the upper left side of the screen.

Once your invasion begins, you should see a few round gobies appear in the ecosystem image as small brown fish:

Watch what happens to the population size for each of the organisms as you let the model run. Focus your attention on the line graph labeled “Population Size” on the left of the screen.
*NOTE: Let the model run to *at least* 300 on the time axis in the “Population Size” graph before stopping it or recording any observations.* Run the model 3 times to identify general trends.

If the model is changing too quickly for you as it runs, you can adjust the speed using the slider bar at the top of the model:

![Slider bar for adjusting the speed of the model]

Questions:

Q6. Were your predictions about the round goby’s impact on the food web supported by the model? Describe any differences between your predictions and what you saw happening AND provide some possible explanations for any differences you saw.

Q7. How did the round goby population fare? Was this what you predicted? Describe any differences between your predictions and what you saw happening AND provide some possible explanations for any differences you saw.

Q8. How would your ecosystem react to multiple invasions of the round goby? Write a hypothesis about how the populations of each of the organisms in this ecosystem might react to more than one invasion of the round goby.

5. Test your prediction! Reset your model using the button, get it running, and then re-invade the ecosystem as many times as you would like.
Questions:

Q9. How many times did you press the “Start Invasion” button? Were your invasions evenly distributed or not? Why did you choose to invade the ecosystem this way?

Q10. How did the pre-existing organisms in the ecosystem react to more than one invasion of the round goby? Describe your observations.

Q11. Could multiple invasions of an invasive species into an ecosystem actually happen in nature? Explain your answer.

Part 3: Different Species, Different Adaptations

Q12. As was stated in the reading at the start of this investigation, zebra and quagga mussels are additional invasive species found within the Calumet Harbor ecosystem and are represented by the mussel image in the model. In tissue samples, zebra mussels have been found to be more contaminated than their quagga counterparts. What do you think could be the reason for this?
Q13. Scientists have found that between 1999 and 2005, quagga mussels became the dominant mussel species within Calumet Harbor. How do you think this mussel succession could affect PCB biomagnification throughout the food web?

Part 4: Exploring the Effects of a New Trophic Level on Toxin Transfer

You will now run the model to examine how biomagnification in the Calumet Harbor ecosystem is affected by an invasion of round goby. Round gobies become contaminated with polychlorinated biphenyls (PCBs) due to their diet. They eat organisms in their new ecosystems, such as zebra and quagga mussels, that cause PCBs to be directly passed on to them.

**Question:**

Q14. How do you think an invasion of round goby will affect the bioaccumulation of PCBs in each of the species in this ecosystem model?

6. Reset your model and click go/stop. After 100 units of time has passed, click Start Invasion to invade your ecosystem. This time, follow what is happening in the toxicity graphs. Allow the model to run for at least another 200 units of time before recording any observations. **Run the model 3 times.**

Here are some sample toxicity graphs. Yours may look slightly different.
Questions:

Q15. Looking back to the answers you provided for Question 14, did the model’s results support your prediction about the round goby’s impact on bioaccumulation and biomagnification? Describe any differences between your predictions and what you saw happening AND provide some possible explanations for these differences.

Q16. You may have observed that the Toxicity History levels fluctuate over time, particularly for the round goby and smallmouth bass. What do you think is happening in the model when the average toxin level of a species decreases?
Part 5: Reading Real Data from the Scientists

To test their models against the real data, the scientists collected samples of each species in the ecosystem. They took tissue samples from each species and calculated their trophic level. This graph was created using the real data from Calumet Harbor. Each sample the scientists measured is represented by a point on the graph. The black vertical lines above and below the sample are error bars—they represent the amount of uncertainty in each data point. Look carefully at the trophic levels of the round goby and the smallmouth bass.

Figure 1. Trophic position of organisms in Calumet Harbor ecosystem. Reproduced from Ng, et al. 2008. Chemical amplification in an invaded food web: seasonality and ontogeny in a high-biomass, low-diversity ecosystem. Environ. Toxicol. Chem. 27L 2186-2195.

Q17. What is this graph saying about the trophic positions of the round goby and the smallmouth bass?

As you have observed, the introduction of invasive species to the Calumet Harbor ecosystem has added a new trophic level to the mix. The smallmouth bass have a new source of food, and the crayfish now have a new predator to avoid. However, what scientists have learned about the round goby is that they aren’t just prey to the smallmouth bass, but the smallmouth bass can be prey to them too! This means that the round goby can occupy two different trophic levels in the same food web.
Question:

Q18. Develop a hypothesis as to how a smallmouth bass can be prey to the round goby. Remember... the smallmouth bass is a larger fish than the round goby and when we look at simple food chains, the bigger organism typically eats the smaller one. How is a smaller species able to be a predator to a larger one?

In addition to collecting fish and analyzing samples in the lab, the scientists wanted to observe how the fish behaved in their own environment. To do this, they went diving in the harbor with a video camera. Open your internet browser and navigate to Dr. John Janssen’s website, http://www.glwi.uwm.edu/people/jjanssen/goby/index.html, where you can watch a short video clip of a round goby invasion in action!

Questions:

Q19. What did you learn about how the round goby can be a predator to the smallmouth bass?

Q20. How do you think the ability of the round goby to feed at two different trophic levels will change what you saw happen earlier to the populations of other species following your initial round goby invasion?
Let’s see what happens!

7. Stop your model if it is still running by clicking \textit{go/stop}.

8. Find the \textbf{Food-Web} box at the top of the model. In order to add a new food chain to the model, click on the \textit{Change} button on the \textbf{Food-Web} box.

Once you do that, a new \textbf{Food-Web pop up window} will appear. Here is where you will be able to enter a new food chain.

9. In the new \textbf{Food-Web} window, add in a new food chain demonstrating that smallmouth bass are now prey to the round goby.

10. When you are done typing in the new food chain click the \textbf{Apply} button. Notice that after you clicked the button, in the original \textbf{Food-Web} box at the top of the model a new food chain has been added.
11. Click \textcolor{blue}{OK} in the \textcolor{red}{Food-Web} window to close the pop up.

12. Click \textcolor{blue}{setup} in the upper left corner of the model to reset the ecosystem.

13. Click \textcolor{blue}{go/stop} to start the model running. Remember... if you want to stop the model from running at any time, click this button again.

14. After 100 units of time have passed, click \textcolor{blue}{Start Invasion} to introduce the round goby into the ecosystem. Allow the model to run for \textit{at least} another 200 units of time on the “Population Size” graph before recording any observations. \textbf{Run the model 3 times.}

Questions:

Q21. Did the model support your prediction from Question 20? Describe any differences between your predictions and what you saw happening in the model AND provide some possible explanations for these differences.

Q22. Were any of the organisms from this portion of the ecosystem eliminated after the round goby invasion? Is this realistic? Explain your answer.

Q23. What did you choose to do once this portion of the ecosystem was absent of a particular species? Explain your choice AND describe how the ecosystem reacted.
Here’s the same trophic level graph you saw earlier. This time, however, the round goby data points are grouped according to the size of the fish the sample came from.

![Trophic Level Graph](image)

**Figure 2.** Trophic position of organisms in Calumet Harbor ecosystem with small (S), medium (M) and large (L) size classifications. Reproduced from Ng, et al. 2008. Chemical amplification in an invaded food web: seasonality and ontogeny in a high-biomass, low-diversity ecosystem. *Environ. Toxicol. Chem.* 27L 2186-2195.

Q24. What is the relationship between size of round goby and trophic level on this graph?

The scientists discovered that small round gobies are better at invading smallmouth bass nests than larger round gobies. Therefore, small round gobies are at a higher trophic level than larger round gobies because they are the ones eating smallmouth bass eggs. Eggs are a rich source of lipids (fats), but they are also a rich source of PCBs because these toxins are stored in the fatty tissues of organisms. We will now investigate how the ability of the round goby to feed at two trophic levels impacts biomagnification of PCBs through the food web.
Q25. Do you think the ability of the round goby to feed at two trophic levels will change the toxicity levels throughout the food web that you observed earlier? Write your prediction below.

15. If your model is still running, click go/stop to stop it. Reset your model to clear the graphs—this should not change the new rule you have added to the Food-Web box.

16. Click go/stop in the upper left corner of the screen to start the model running.

After 100 units of time have elapsed, click Start Invasion.

Focus your attention this time on the “Average Toxin Level by Species” and the “Toxicity History” graphs.

*NOTE: Let the model run to at least 300 before stopping it or recording any observations. Run the model 3 times.*

Questions:

Q26. Looking back to Question 25, was your prediction supported by the model? Describe any differences between your prediction and what you saw happening AND provide some possible explanations for these differences. How is this graph different from the Toxicity History graph in Part 4 (before you changed the Food-Chain rules)?

Q27. Are there other factors (besides feeding at two different trophic levels) that could be playing a role in how the round goby affects the biomagnification of PCBs through the Calumet Harbor ecosystem? Explain.
Part 6: A Twist on Bioaccumulation

As you have probably realized, Calumet Harbor is a unique example of what happens to an ecosystem when it is invaded by new species. The scientists studying this ecosystem have learned a great deal about the potential impacts of invasive species on population sizes and toxin transfer within a food web.

In the beginning of their study, scientists expected that round gobies would have greater concentrations of PCBs in their tissues than mussels, but smaller concentrations than the smallmouth bass. They predicted this because, initially, they thought smallmouth bass were the predator of round gobies. When this team of scientists collected fish to study, however, they had two surprises. The first was that some round gobies had greater concentrations of PCBs than smallmouth bass. The second surprise was that most small round gobies had a higher concentration of PCBs than larger round gobies. Both of these findings contradict typical patterns within ecosystems. A big question remains: How will this impact the smallmouth bass population, which is a much more desirable sport fish to humans than the round goby?

The study had other interesting results, too. They learned that small round gobies have an equal trophic position or PCB concentration to the smallmouth bass only during certain times of the year. It actually varies by season. Round gobies can only eat fish eggs when fish are spawning, right? Therefore, they will only have an elevated trophic position and higher PCB levels during spawning season. For round gobies, that’s May to September and for smallmouth bass it’s only during the month of June. Round gobies will eat the eggs of smallmouth bass in addition to eggs of other round gobies.
Figure 3. Changes in round goby 15-N stable isotope signature over the course of a calendar year. On the x-axis, time is measured in days, where January 1 is day 0 and December 31 is day 365. Graph reproduced from Ng, et al. 2008. Chemical amplification in an invaded food web: seasonality and ontogeny in a high-biomass, low-diversity ecosystem. Environ. Toxicol. Chem. 27: 2186-2195.

$^{15}$N is an isotope of nitrogen (a variant of an atom that has a different number of protons than neutrons) that scientists use as a way to measure an organism’s place in a food web. The non-isotope form of nitrogen is $^{14}$N. The greater the ratio of $^{15}$N: $^{14}$N in an organism, the higher up on the food chain it is. This ratio is represented as $\delta^{15}$N. The graph you see above shows that the round goby’s trophic position rises during the summer months (days 120-213) when smallmouth bass and other round gobys are spawning. The different lines indicate that the amount of increase in $\delta^{15}$N depends on how many eggs are eaten by round gobies.

Scientists use this information to better guide consumers about when it is safe to eat fish. While round gobies are not a popular fish eaten in the Great Lakes region, smallmouth bass are a favorite. If their food source – the round gobies – have a higher toxicity level during certain times of the year because they are feeding on fish eggs, anglers need to know. The complicated nature of this food web shows that there may be more going on in an ecosystem than meets the eye. To have the best guidelines, we need to know a lot about how all the different fish interact. Science research is an ongoing process to better understand the complexities of our world and how we interact with it.
Questions:

Q28. Based on these new findings, how would you change the model to better represent the food web?

Q29. Is this ecosystem unique? Why or why not?

Q30. Make a policy statement regarding what we should do about invasive species in the Great Lakes.

Q31. Based on what you have learned in this investigation cut out the images on the next page and use them to construct a diagram of the Calumet Harbor food web. Paste this new diagram onto the back of this sheet and draw arrows that better represent the feeding habits of the species in Calumet Harbor.
Investigation IV: Invasive Species

Part 1: Getting started – Brainstorming

Q1. When you hear the term “invasive species”, what do you think of? List as many thoughts as you can in the time provided to you. Compare lists with a partner to see if any common ideas emerge. Using these common ideas, create your own definition of an invasive species with your partner and write it in the space below.

Q2. How do you think invasive species affect the environment in which they exist? Are they positive or negative influences? Working together with your partner, come to a consensus as to how invasive species affect their new home environments.

Part 2: Exploring the Effects of a New Trophic Level on the Food Web

Q3. Which of the organisms listed in the Food-Web box is missing from the model frame? Why is this?

Q4. Now that you know what an invasive species is and how it can adapt to living in a new ecosystem, predict how you think a round goby invasion will affect the population size of each of the organisms that make up this aquatic ecosystem model.
Q5. How do you think the round goby will fare in its new environment? Provide a prediction about how you think its population will react.

Q6. Were your predictions about the round goby’s impact on the food web supported by the model? Describe any differences between your predictions and what you saw happening AND provide some possible explanations for any differences you saw.

Q7. How did the round goby population fare? Was this what you predicted? Describe any differences between your predictions and what you saw happening AND provide some possible explanations for any differences you saw.

Q8. How would your ecosystem react to multiple invasions of the round goby? Write a hypothesis about how the populations of each of the organisms in this ecosystem might react to more than one invasion of the round goby.

Q9. How many times did you press the “Start Invasion” button? Were your invasions evenly distributed or not? Why did you choose to invade the ecosystem this way?
Q10. How did the pre-existing organisms in the ecosystem react to more than one invasion of the round goby? Describe your observations.

Q11. Could multiple invasions of an invasive species into an ecosystem actually happen in nature? Explain your answer.

Part 3: Different Species, Different Adaptations

Q12. As was stated in the reading at the start of this investigation, zebra and quagga mussels are additional invasive species found within the Calumet Harbor ecosystem and are represented by the mussel image in the model. In tissue samples, zebra mussels have been found to be more contaminated than their quagga counterparts. What do you think could be the reason for this?

Q13. Scientists have found that between 1999 and 2005, quagga mussels became the dominant mussel species within Calumet Harbor. How do you think this mussel succession could affect PCB biomagnification throughout the food web?

Part 4: Exploring the Effects of a New Trophic Level on Toxin Transfer

Q14. How do you think an invasion of round goby will affect the bioaccumulation of PCBs in each of the species in this ecosystem model?
Q15. Looking back to the answers you provided for Question 14, did the model’s results support your prediction about the round goby's impact on bioaccumulation and biomagnification? Describe any differences between your predictions and what you saw happening AND provide some possible explanations for these differences.

Q16. You may have observed that the **Toxicity History** levels fluctuate over time, particularly for the round goby and smallmouth bass. What do you think is happening in the model when the average toxin level of a species decreases?

**Part 5: Reading Real Data from the Scientists**

Q17. What is this graph saying about the trophic positions of the round goby and the smallmouth bass?

Q18. Develop a hypothesis as to how a smallmouth bass can be prey to the round goby. Remember... the smallmouth bass is a larger fish than the round goby and when we look at simple food chains, the bigger organism typically eats the smaller one. How is a smaller species able to be a predator to a larger one?

Q19. What did you learn about how the round goby can be a predator to the smallmouth bass?
Q20. How do you think the ability of the round goby to feed at two different trophic levels will change what you saw happen earlier to the populations of other species following your initial round goby invasion?

Q21. Did the model support your prediction from Question 20? Describe any differences between your predictions and what you saw happening in the model AND provide some possible explanations for these differences.

Q22. Were any of the organisms from this portion of the ecosystem eliminated after the round goby invasion? Is this realistic? Explain your answer.

Q23. What did you choose to do once this portion of the ecosystem was absent of a particular species? Explain your choice AND describe how the ecosystem reacted.

Q24. What is the relationship between size of round goby and trophic level on this graph?

Q25. Do you think the ability of the round goby to feed at two trophic levels will change the toxicity levels throughout the food web that you observed earlier? Write your prediction below.
Q26.  Looking back to Question 25, was your prediction supported by the model? Describe any differences between your prediction and what you saw happening AND provide some possible explanations for these differences. How is this graph different from the Toxicity History graph in Part 4 (before you changed the Food-Chain rules)?

Q27.  Are there other factors (besides feeding at two different trophic levels) that could be playing a role in how the round goby affects the biomagnification of PCBs through the Calumet Harbor ecosystem? Explain.

Q28.  Based on these new findings, how would you change the model to better represent the food web?

Q29.  Is this ecosystem unique? Why or why not?

Q30.  Make a policy statement regarding what we should do about invasive species in the Great Lakes.
Q31. Construct a diagram of the Calumet Harbor food web using the images provided at the end of your Student Guide. Paste this new diagram below and draw arrows that better represent the feeding habits of the species in Calumet Harbor.