The Education Program at the
NJ Sea Grant Consortium
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Microplastics Biomagnification Board Game

Overview

In this activity, students investigate how microplastics are biomagnified in the environment. Students will play a simple board-based game in which they take on the roles of various fish in different trophic levels in the ocean to model biomagnification of microplastic within each trophic level. Students analyze data collected from the game to observe biomagnification and discover how concentration increases in each higher trophic level. Students also evaluate the game as a model for biomagnification by discussing its strengths and limitations. The lesson concludes with student groups creating public service announcements that communicate the concept of biomagnification of microplastics and the dangers this imposes to our ocean, even becoming a human health concern.

Objectives

1. At the end of this lesson students should be able to communicate the reasons microplastics pose a real threat to our marine environment, and possible ways to mitigate them.
2. Students should understand the concepts of bioaccumulation and biomagnification, and how pollutants, such as microplastics, can increase as they move higher in food chains or along trophic levels.
3. Students will understand food energy pyramids and how energy and pollutants, such as microplastics, move along them.

Grade Levels

5^{th}- 12^{th}

Standards

Performance Expectations- 5-ESS3-1, MS-LS2-3, MS-LS2-5.
DCI's- LS2.A, LS2.B, LS2.C, LS4.D, PS1.B, ESS3.C
Cross Cutting Concepts- System and System Models, Energy and Matter, Scale, Proportion and Quantity, Cause and Effect, Stabilty and Change, Interdepence of Science, Engineering and Technology.
Science and Engineering Practices: Developing and Using Models, Anaylzing and Interpreting Data, Using Mathematics and Computational thinking, Constructing Explanations and Designing Solutions, Obtaining, Evaluating and Communicating Information.

Materials

Checkerboard
36 Tokens (see attached worksheet to cut out your own) 18 represent microplastic particles, 17 represent zooplankton
4 chess pieces or other objects to represent silversides (if chess pieces are unavailable, other materials such as 4 of the same colored Lego or small toys may also be used)
2 chess pieces to represent striped bass (if chess pieces are unavailable, other materials such Legos or small toys may be used)
1 different chess piece to represent a shark (if a chess piece is unavailable, other materials such a Lego or small toy may be used)
7 paper cups or envelopes (1 for each player)
1 dice (six-sided)
Copies of Data Collection sheets (attached)
Copies of Data Analysis sheets (attached)

Background

Plastics are everywhere. Look around and notice how much plastic is used in our everyday lives. Plastic does have some benefits – it's durable, lightweight, efficient, hygienic for medical use, and a great sealant. Over the past 70 years plastic has invaded our lives to make things easier and more convenient, with an overall belief that it was safe.

However, over long periods of time plastic starts to degrade. Sunlight, heat, water, wind, and abrasion over hard surfaces all eventually break plastics down, but it does not just go away. Plastic ultimately breaks into smaller and smaller pieces, eventually becoming a *microplastic*, defined as a plastic particle less than 5mm in size. Just like plastic, microplastics are turning up everywhere – in air, dust, dirt, beaches, waterways, even snow in the artic. As microplastics invade Earth's environments (including the ocean), they pose a threat to the health of organisms including humans. Some types of plastics contain toxic chemicals (such as BPA or phthalates) that have been shown to increase health issues, such as disrupting hormones or causing lung and liver issues. Current scientific research shows that plastics can also absorb other toxic chemicals already in the ocean from careless dumping and stormwater runoff, such as PCBs (polychlorinated biphenyls), PAHs (polycyclic aromatic hydrocarbons), and pesticides like DDT (dichloro-diphenyl-trichloroethane) that also leads to a host of other health issues including developmental delays and neurological problems. At high levels they are also carcinogenic.

These toxic chemicals that are absorbed or stick to plastics are called POPs, which means:

- **P**ersistent -- These chemicals are not water-soluble (hydrophobic) and thus break down very slowly in an aqueous environment. They can remain in an organism's tissues for long periods of time;
- **O**rganic – These chemicals contain carbon which tends to form very strong bonds, thus making them difficult to break down naturally; and

- **P**ollutants – These chemicals are toxic to nearly all organisms at some dose.

Plastics have been found to accumulate POPs at concentrations of up to 1 million times greater than what is found in the surrounding (ambient) seawater. In addition to adhering to plastics, the high lipid solubility (attraction to fats and oils) of POPs allows them to both pass through cell membranes and to bioaccumulate (build up) in the fatty tissues of living organisms. The ability to bioaccumulate some substances (vitamins, trace minerals, essential fats) is crucial to the survival of many organisms, including humans. However, organisms can accumulate unnecessary or even toxic substances like POPs. Once ingested, hydrophobic and fat-soluble compounds like POPs can be stored in fat tissue and passed along to the developing offspring of humans and other mammals.

The severity of the effects of toxic substances from plastics and POPs varies depending on the species, concentration, and time of exposure. There is much evidence that POPs have the potential to cause significant adverse effects on the health of a wide variety of organisms, although there are still a lot of unknowns. Plenty of scientific research is happening now to discover the hazards of microplastics and POPs and what that might mean to human health. Often, animals near the top of the food chain are most affected because of a secondary process called *biomagnification*. The biomagnification of microplastics occurs as they move up the food chain when predators consume prey, ingesting the microplastics with POPs adhered to them, which have already bioaccumulated in each prey item. Scientists, policymakers, and business leaders continue working on solutions that will better protect us and the ocean, but we can all do our part by using less plastic, helping to clean up along waterways, and telling others about the dangers and solutions of using too much plastic.

Procedure

Introduce students to microplastics. Discuss what they are, what their sources are, and how they enter the ocean environment. Then discuss how microplastics enter the ocean food web. If needed, discuss food chains, food webs, the energy food pyramid, and trophic levels. Lesson plans to help support these discussions can be found here at http://njseagrant.org/wp-content/uploads/2014/03/web_of_life.pdf and http://njseagrant.org/wp-content/uploads/2018/01/EstuaryJenga-2.pdf. Ask students to identify primary producers in the ocean (phytoplankton, marine algae, plants), primary consumers (zooplankton, mollusks), secondary consumers (small fish, shrimp, other small crustaceans), tertiary consumers (medium to large sized fish or larger crustaceans, turtles, octopus), and apex predators (sharks, dolphins, large seabirds such as osprey). Discuss what trophic levels allow microplastics to enter the marine food web or pyramid (primary producers or primary consumers). Tell students they will play a game to demonstrate biomagnification of microplastics in the ocean. Explain the definition of biomagnification and let students play the game to see how it works.

There are 36 tokens on the board, with 17 representing zooplankton and 18 representing zooplankton with ingested microplastic particles (microplastics mistaken for phytoplankton). These are labeled "zooplankton mp." One "space" is a safety zone where no prey may be collected. Each token equals 10,000 zooplankton and should be placed upside down so they cannot be distinguished from each other.

Directions for set up:

1. Place tokens upside down on the board in all spaces *except* the edges. Do not reveal which pieces are microplastics or zooplankton.
2. Place pieces representing silversides on the 4 corners.
3. Place 2 pieces representing a striped bass on middle edge opposite of each other.
4. Place 1 piece representing a shark on a middle edge not held by a striped bass.

EXAMPLE:

silver -side			shark				silver -side
			Safety Zone				
striped bass							striped bass
silver -side							silver -side

Each silverside player (4 players) on the board represents 2000 silversides. Each silverside player wants to capture as many zooplankton pieces as possible.

Each striped bass player (2 players) on the board represents 3 bass. Each bass player wants to capture the silversides.

The shark player represents only 1 shark. The shark wants to capture both striped bass players.

Game Play:

1. Place all 36 tokens on the board, in every space except along the edges. Each token should be upside down so they cannot be identified as having microplastic or not. Pick one square in the middle to be labeled a "Safety Zone" where players may go to hide from predators and not be caught.

2. Silverside players go first. Pick the youngest silverside player to go first and move in a clockwise direction. Each silverside rolls the dice and may move the corresponding number of spaces up, down, left or right (not diagonally). The silverside places each token it lands on in its cup. The goal for the silverside is to collect as many tokens (zooplankton) as possible. After each turn, the silverside will flip over the tokens and talley how many zooplankton verses how many

zooplankton with microplastics (labeled “zooplankton mp”) they collected in their corresponding boxes in the data collection sheet.

3. The next players to roll the dice are the striped bass. **The striped bass may only move if they roll a 1, 2, 3 or 6**.They then move to the corresponding number of spaces around the board, trying to capture the silversides. If they land on a silverside, they take it off the board along with any microplastic tokens (zooplankton mp) the silverside has collected, and place those in their cup. The bass may move over but may not occupy the same space as a token. The striped bass will tally the total number of silversides consumed and the amount of microplastics collected in their corresponding boxes on the data collection sheet.

4. Next the shark will roll the dice. **The shark many only move if they roll a 4 or 5**. Then they move the corresponding number of spaces around the board, trying to get to a striped bass. Sharks may not collect or land on a space with a silverside. If a shark lands on a space with a striped bass they are to remove it from the board, along with all the microplastic tokens the striped bass may have already collected from silversides. The shark is to record the total number of striped bass and the number of microplastics collected from striped bass in their corresponding boxes in the data collection sheet.

5. Game play will continue in this order until all striped bass have been captured by the shark.

6. Conduct a data analysis (using the worksheets attached) to calculate how microplastics bioaccumulate and biomagnify as they go up a food chain and through trophic levels.

Data Collection

Data is vital to the understanding of biomagnification in this game. Depending on mathematical skills and ability to work with data, the amount and difficulty of data analysis can be adjusted to fit the different needs and levels of the students. Urge students to get into the details of the calculations and data analysis. Have them create graphs and observe patterns in the data that demonstrate biomagnification. Data may also be entered into Microsoft Excel or Google Sheets for easy and automatic data analysis and graph generation. Two separate data analysis sheets have been created based on student levels and knowledge. Data analysis sheet #2 is a bit more in-depth, illustrating how energy passes through trophic levels and the biomagnification of microplastics based on **biomass** at each trophic level.

Students may play one or more rounds of the game in order to obtain enough data. After the shark has caught the 2 striped bass, just reset the game, pretend the silversides and striped bass have all respawned, and keep tallying numbers, however because the shark is our apex predator, he will not die and you will only tally 1 shark no matter how many games played. Two to three rounds should offer more than enough data. A separate data sheet is not needed. If time is limited, the number of rounds may be reduced, and students may add data from other groups. After the game(s) are played, have students count up the number of players collected (tokens, silversides, and striped bass) and the total number of zooplankton mp tallied on their data collection sheet. Have students share their data by reporting verbally or via class projector for the entire class to see. Have students calculate totals in each of their own data sheets.

To better help understand and explain the data collection and analysis, here is a sample of data collected from just *one* game played. Blank data collection and data analysis worksheets are attached.

Data Collection Sheet (Sample data)

	# of zooplankton or players collected	**Totals** x 10000 per token x 2000 per silverside x 3 per Striped Bass	# of zooplankton mp tokens captured	**Total # zooplankton mp** x 10000
Silverside 1	IIIII (5)	50,000	IIII (4)	40000
Silverside 2	IIII (4)	40,000	II (2)	20000
Silverside 3	IIII (4)	40,000	III (3)	30000
Silverside 4	IIII (4)	40,000	III (3)	30000
Striped Bass 1	II (2)	4000	~~IIII~~ I (6)	60000
Striped Bass 2	I	2000	III (3)	30000
Shark	2	6	~~IIII~~ IIII (9)	90000

Data Analysis #1: (answer sheet with sample data)

Use the data collection sheet to fill out the data analysis sheet. Be sure students share data for each organism. The first column includes the primary producers (zooplankton) played in the game. Each species (zooplankton,silversides, striped bass, and shark) represents a different trophic level. For the first row add up all the organisms played per trophic level in the game(s). For Primary Consumers (Zooplankton) multiply the total number of zooplankton tokens by 10,000. For Secondary Consumers (silversides) multiply each by 2000. For the Tertiary Consumers (Striped Bass) multiply each by 3. There is only one shark. The second row is total amount of microplastic consumed per trophic level. This number is found by adding up all the zooplankton mp tokens collected for each organism in their trophic level and multiply by 10,000. For the Primary consumers (zooplankton mp) take the number of the zooplankton mp tokens started on the board (18), multiply by 10,000. The last row is the average number of microplastics that could be found in each organism. This number is found by dividing the total number of microplastics per trophic level and dividing that into the total number of organisms in the trophic level.

Sample Data Analysis #1 - Average Microplastics per organism

	Trophic Level Primary Consumers (Zooplankton)	**Trophic level Secondary Consumers (Silversides)**	**Trophic Level Tertiary Consumers (Striped Bass)**	**Trophic Level Apex Predators (Shark)**
Total # of organisms per trophic level	350,000	8000	6	1
# of mp consumed per trophic level	180,000	120,000	90,000	90,000
Average # of mp per organism	.51	15	15,000	90,000

Discussion Questions:

1. What organism has the most microplastics?
   Answer – Shark
2. What do you notice about the amount of microplastics in each trophic level?
   Answer - Microplastics only slightly decrease or stay the same.
3. What trophic level had the most microplastics?
   Answer – Zooplankton
4. Why did the amount of microplastics per organisms go up when there are less organisms per trophic level?
   Answer - Because microplastics accumulate and are persistent (they do not go away), they are passed along to each consumer. The higher-level consumer does not just eat one prey
   . but many,
   making the amount of microplastics add up. The higher the trophic level the more microplastics are passed along.

Biomagnification of Microplastic Food Pyramid

Using numbers from the data analysis sheet, create a basic food pyramid and a microplastic pyramid.

Basic Food Pyramid - Record the organisms' names next to their consumer type and write the total number of each organism in the box (with or without microplastics). Primary producers from the ocean are given.

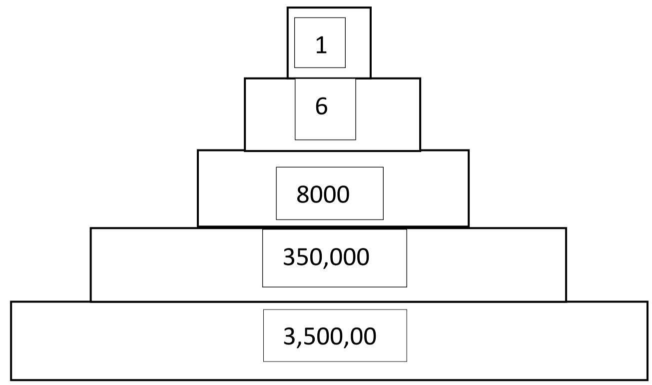
Apex Predators: shark

Tertiary Consumers: striped bass

Secondary Consumers: silversides

Primary Consumers: zooplankton

Primary Consumers: phytoplankton



Biomagnification occurs when individual organisms with bioaccumulated chemicals in their tissues are consumed by predators higher up the food web. This leads to higher concentrations of chemicals in organisms higher up in the food web.

Create a **Microplastic pyramid**. List the organism's name and average number of microplastics in order from highest to lowest. Phytoplankton has an average of .05 microplastics per organism. Create a rectangle box that is an appropriate size to represent your number, much like the energy pyramid above. Big rectangles represent big numbers, while smaller rectangles represent smaller numbers. Phytoplankton is given.
Optional: place a dot in each rectangle to represent each microplastic. You may want to have one dot represent multiple POPs. If so, include a key next to the diagram. This pyramid may also be created in Microsoft Excel using a Funnel Chart.

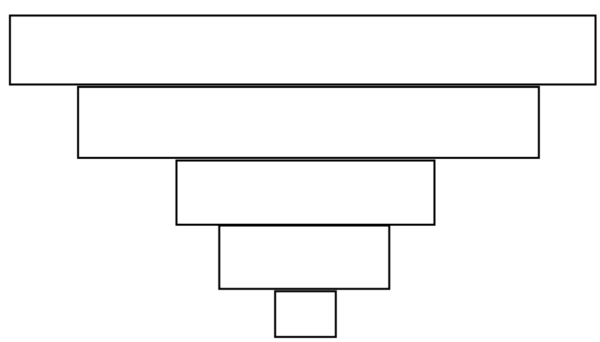
Shark – 90,000

Striped Bass – 15,000

Silversides – 15

Zooplankton - .5

Phytoplankton -.005



1. Compare the number of microplastics the producers consumed to that consumed by the apex predator. What do you notice?
   Answer - The producers only consume a small amount of microplastics, while the apex predator consumes much more microplastics.

2. In an energy or food pyramid, there are more producers than consumers (which is why the block representing the base of the food web is the largest). Compare the two pyramids. What do you notice?
   Answer - They are opposite of each other. Less consumers appear as you go up a food chain. As you go up in a microplastic food chain, the more microplastics there are.
3. From what you know, what do you think the biomagnification of microplastics means for the health of humans and the ocean ecosystem?
   Answer - Microplastics could present serious health concerns to humans and the ocean ecosystem because they keep increasing, and thus the potential for more toxins to be consumed.

Data Analysis #2 (Answer Sheet with Sample Data)

This data analysis sheet allows for greater analysis of the data comparing biomass in trophic levels and energy transfer. Use information from the data collection sheet to complete each box. The average weight of the organism is given so students can better understand how biomass decreases with higher trophic levels. However, because microplastics are persistent and bioaccumulate, the concentration of microplastics increase with higher trophic levels. For more information on energy transfer, visit this website: https://sciencing.com/biomass-vs-energy-pyramids-5028.html.

To calculate total biomass at each trophic level, multiply the number of organisms by average weight.

To calculate the microplastic concentration, divide the number of microplastics per trophic level by biomass at each trophic level.

Sample Data Analysis Sheet #2 - Biomass of Microplastics per Trophic Level

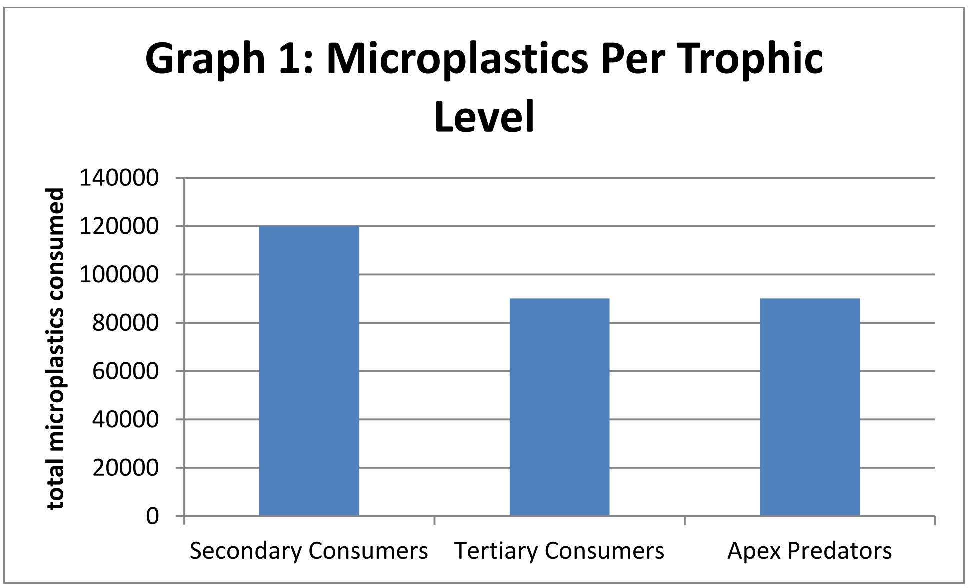
	Silversides **Secondary consumers**	Striped bass **Tertiary consumers**	Shark **Apex Predator**
Total organism caught per trophic level	290,000	6000	6
Total microplastics/ trophic level	120,000	90000	90000
# organisms played per trophic level	8000	6	1
Average weight of organism	.1lbs or .454kg	50lbs or 22.68kg	200 lbs or 90.72kg
Total biomass at each trophic level (# org x weight)	800lbs or 362.87kg	300lbs or 136.08kg	200lbs or 90.72kg
Mp concentration # mp/biomass	15 mp/lbs or 330.7 mp/kg	300 mp/lbs or 661.38 mp/kg	450 mp/lbs or 992.06 mp/kg

Using the total amount of zooplankton collected compared to zooplankton with microplastics; calculate the percentage of the zooplankton with microplastics eaten by silversides. *Answer- 120,000/290,000 x 100 = 41%.*

Compared to the total organisms caught per tropic level. Why did the concentration of microplastics go up with each trophic level? *Answer- The concentration went up because each organism in the trophic level passed the microplastics up to the next trophic level when they were consumed.*

Using Excel have students create three graphs to illustrate:

1- Total microplastics at each trophic level.
2- Total biomass at each trophic level.
3- Microplastic Concentration per trophic level.

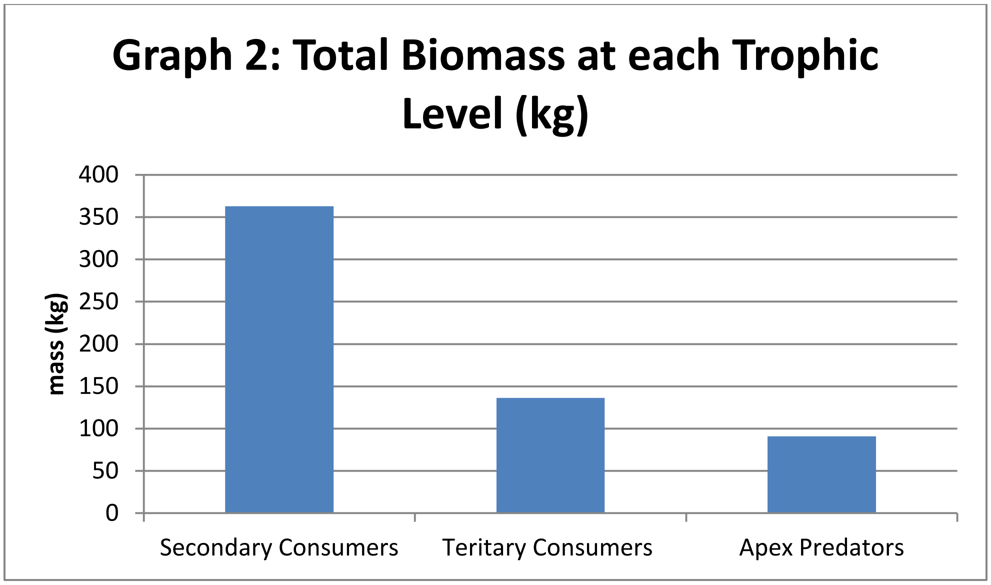


Discussion Questions Graph 1:

1. Why are the quantities of microplastics relatively close or the same at each trophic level? *Answer - The microplastics are retained in the tissues of the organisms even when consumed at trophic levels. Microplastics are persistent and do not go away.*

2. If the microplastics biodegraded, what trend would you expect to see across trophic levels? *Answer - You would expect the microplastics to decrease in higher trophic levels, and the amount of microplastics would decrease over time.*

3. Do you think this graph shows bioaccumulation? Explain. *Answer – Yes; this graph does not show microplastics degrading, so the microplastics are being retained by each organism. This graph shows that the more an organism consumes, the more microplastics accumulate.*



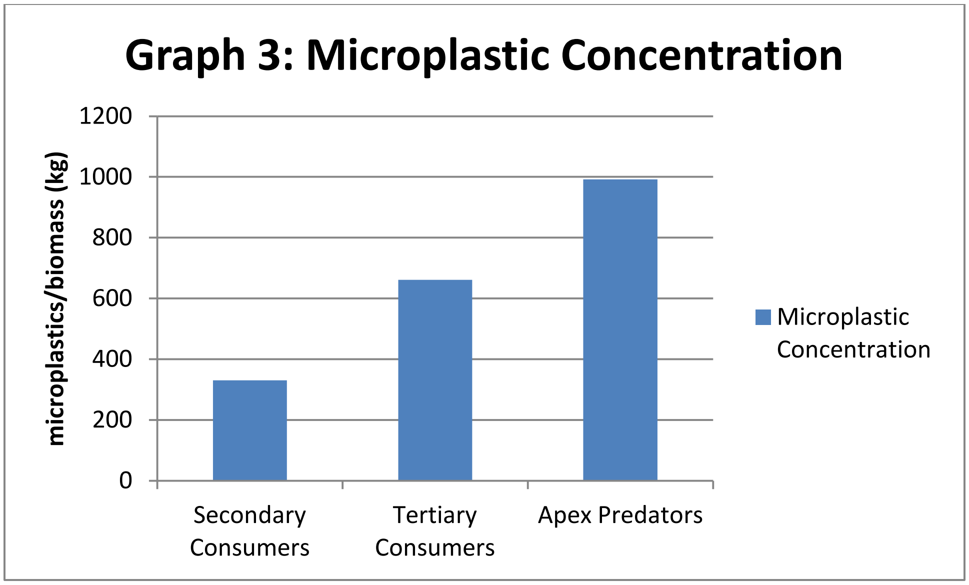
Discussion Questions Graph 2:

1. What pattern do you observe about biomass across trophic levels?
   Answer - Biomass decreases with higher trophic levels.

2. What do you think causes this pattern?
   Answer - This a question for students who understand energy transfer across trophic levels; have them look at weight and number of organisms in each trophic level played in the game.

3. Why do you think biomass decreases with higher trophic levels?
   Answer - Because there are fewer organisms as you go up in trophic levels. Although they might be larger (sharks are larger than striped bass) the total biomass of all the animals at each trophic level is less at higher trophic levels.

4. Why is there less energy available at higher trophic levels?
   Answer - Energy is lost as you go up through each trophic level. Energy is lost through heat as organisms use the energy to live, such as swimming, eating, growth, and other bodily functions. For example, when a striped bass eats a silverside, it may consume all the energy that is available from the silverside, but it typically spends 90% of that energy for bodily functions. The rest of that energy (about 10%) is stored in the body of the striped bass and is passed on to the shark or humans when they eat the striped bass.



Discussion Questions Graph 3:

1. How did you generate this graph?
   Answer -The total microplastics are divided by the total biomass at each trophic level. Therefore, the microplastic concentration is the level of toxicants per unit of mass.

2. Why should we consider toxicant concentration, instead of just examining toxicant per individual?
   Answer - Examining the concentration per unit of biomass accounts for differences in body mass. Individuals at each trophic level are different masses (sizes). An individual silverside is a lot smaller than a shark, so it wouldn't be surprising if the former had a lot less microplastic. Making this calculation helps us see that per unit of biomass, sharks (or apex predators) can carry a lot more microplastics.

3. What does this graph show in terms of microplastics concentration as you go higher in trophic levels?
   Answer - The graph shows an increase in microplastics concentration as trophic levels go higher.

4. How does this graph show biomagnification?
   Answer - The definition of biomagnification is the "magnification of toxicants with increasing trophic levels," which is exactly what the graph shows.

Discuss the game as a model. Help students put what they have learned into context by asking the following questions:

1. Evaluate the game as a model of bioaccumulation. How is this game useful as a model?
   Answer - It is useful because it illustrates how toxicants cycle through a food chain and magnify at higher levels. It is also useful for generating data and making predictions.

2. What are the limitations of this model?
   Answer - Biomagnification happens over a long period of time (years), and it is not clear in the game how long this takes. Ecosystems typically have food webs, so there would be multiple species at each trophic level. If these other food sources do not have (or have less) microplastics in them, the effect of biomagnification will be mitigated.

3. This game modeled an aquatic ecosystem. Does bioaccumulation and biomagnification apply to other systems, like terrestrial ecosystems?
   Answer – Definitely. A famous example of biomagnification in a terrestrial ecosystem would be that of DDT, which weakens egg shells of predatory birds at high trophic levels.

4. Seafood has many health benefits. How can you (a human) lower your ingestion of microplastics but still eat seafood?
   Answer - Eat animals at lower trophic levels like anchovies or shrimp instead of fish at higher trophic levels like sharks. Do not each too much of an animal higher on the food chain. Try to buy seafood that is not in or has less plastic packaging.

Microplastic Biomagnification Board Game

Game Data Collection:

Students representing silversides will tally each zooplankton token and each zooplankton mp token collected after each turn. Students representing striped bass will tally how many silversides they capture and how many zooplankton mp they received from each silverside. Students representing sharks will tally how many striped bass captured and how many zooplankton mp they receive from each striped bass.

	# of zooplankton or players collected	**Total** x 10,000 per zooplankton x 2000 per silverside x 3 per Striped Bass	Total # of zooplankton mp captured	# zooplankton mp x 10,000
Silverside 1				
Silverside 2				
Silverside 3				
Silverside 4				
Striped Bass 1				
Striped Bass 2				
Shark				

Microplastics Biomagnifications Board Game

Data Analysis Sheet # 1

(mp= microplastics)

	Trophic Level Primary Consumers (Zooplankton)	**Trophic level Secondary Consumers (Silversides)**	**Trophic Level Tertiary Consumers (Striped Bass)**	**Trophic Level Apex Predators (Shark)**
Total # of organisms per trophic level				
# of mp consumed per trophic level				
Average # of mp per organism				

Discussion Questions:

1. What organism has the most microplastics?

2. What do you notice about the amount of microplastics in each trophic level?

3. What trophic level had the most microplastics?

4. There are less organisms per tropic level. Why did the amount of microplastics per organisms go up when there are less organisms per trophic level?

Create a Biomagnification of Microplastic Food Pyramid

Using the numbers in the data analysis sheet, create a basic food and a microplastic pyramid.

Basic Food Pyramid - Record the organisms' names next to their consumer type and write the total number of each organism in the box (with or without microplastics). Primary producers from the ocean are given.

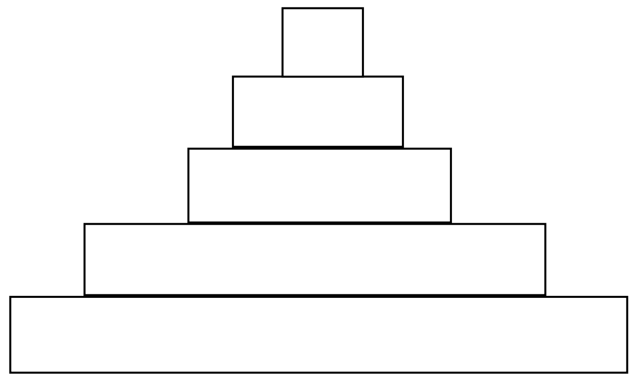
Apex Predators: shark

Tertiary Consumers: striped bass

Secondary Consumers: silversides

Primary Consumers: zooplankton

Primary Consumers: phytoplankton



Biomagnification occurs when individual organisms with bioaccumulated chemicals in their tissues are consumed by predators higher up the food web. This leads to higher concentrations of chemicals in organisms higher up in the food web.

Create a **Microplastic pyramid**. List the organism's name and average number of microplastics in order from highest to lowest. Phytoplankton has an average of .05 microplastics per organism. Create a rectangle box that is an appropriate size to represent your number, much like the energy pyramid above. Big rectangles represent big numbers, while smaller rectangles represent smaller numbers. Phytoplankton is given.
Optional: Place a dot in each rectangle to represent each microplastic. You may want to have one dot represent multiple POPs. If so, include a key next to the diagram. This pyramid may also be created in Microsoft Excel using a Funnel Chart.

1. Compare the number of microplastics the producers consumed to that consumed by the apex predator. What do you notice?

2. In an energy pyramid, there are more producers than consumers (which is why the block representing the base of the food web is the largest). Compare the two pyramids. What do you notice?

3. From what you know, what do you think the biomagnification of microplastics means for the health of humans and the ocean ecosystem?

Microplastics Biomagnification Board Game

Data Analysis Sheet #2 - Biomass and Concentration of Microplastics

	Silversides **Secondary consumers**	Striped Bass **Tertiary consumers**	Shark **Apex Predator**
Total organisms caught per trophic level			
Total microplastics per trophic level			
# organisms per trophic level			
Average weight of organism	.1lbs or .454kg	50lbs or 22.68kg	200 lbs or 90.72kg
Total biomass at each trophic level (# org x weight)			
Microplastic concentration (# total mp/total biomass			

Using the total amount of zooplankton collected compared to zooplankton with microplastics, calculate the percentage of the zooplankton with microplastic eaten by silversides.

Compared to the total organisms caught per tropic level, why did the concentration of microplastics go up with each trophic level?

Using Excel, have students create three bar graphs to illustrate:

1. Total microplastics at each trophic level (total microplastics on y axis, trophic level on x axis).
2. Total biomass at each trophic level (total biomass on y axis, trophic level on x axis).
3. Microplastic Concentration per trophic level (explain how you created this graph).
   ATTACH GRAPHS TO DATA SHEETS

Discussion Questions Graph 1:

1. Why are the quantities of microplastics relatively close or the same at each trophic level?
2. If the microplastics biodegraded, what trend would you expect to see across trophic levels?
3. Do you think this graph shows bioaccumulation? Explain.

Discussion Questions Graph 2:

1. What pattern do you observe about biomass across trophic levels?
2. What do you think causes this pattern?
3. Why do you think biomass decreases with higher trophic levels?
4. Why is there less energy available at higher trophic levels?

Discussion Questions Graph 3:

1. How did you generate this graph?
2. Why should we consider toxicant concentration, instead of just examining toxicant per individual?
3. What does this graph show in terms of microplastic concentration as you go higher in trophic levels?
4. How does this graph show biomagnification?

Discuss the game as a model. Help students put what they have learned into context by asking the following questions:

1. Evaluate the game as a model of bioaccumulation. How is this game useful as a model?
2. What are the limitations of this model?
3. This game modeled an ocean ecosystem. Does bioaccumulation and biomagnification apply to other systems, like terrestrial ecosystems?
4. From what you know about microplastics, do you think they propose a threat to our ecosystems and human health?
5. Use the worksheet attached to think about and research solutions to the plastic problem our world currently has. Create a one-page Public Service Announcement about your solution and how this is the best possible way to stop microplastics from entering our ocean.

Solutions to Microplastics organizer

Use the internet or books to research some possible solutions to the plastic problem. Some ideas to research are: **Engineering solutions** such as biological, chemical, or physical ways to either make plastic non-toxic, or to clean up the plastics in our environment. **Social solutions** such as educating others about recycling, and other ways we can stop or slow our use of plastic. **Legislative Solutions** such as laws to create a plastic ban, or to make people recycle.

Using the information from your research, you will decide on what you feel is the best possible plan to stop microplastics from entering our ocean. Think about the plan's costs and benefits as well as its feasibility (if it's possible). Answer the questions in the graphic.

Adapted from Oregon Sea Grant's Mitigating Microplastics (see references)

<table>
<tr><td colspan="6">The Problem</td></tr>
<tr><td colspan="2">What are microplastics?</td><td colspan="2">How do microplastics get in the ocean?</td><td colspan="2">What is the problem with microplastics?</td></tr>
<tr><td colspan="6">The Best Solution</td></tr>
<tr><td colspan="3">What solution did you decide is best?</td><td colspan="3">Why do you feel this is the best solution?</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="6">Evidence to Support Your Solution</td></tr>
<tr><td colspan="3">What evidence supports your solution?</td><td colspan="3">What evidence does not support your solution?</td></tr>
<tr><td colspan="3">Costs and Benefits</td><td colspan="3"></td></tr>
<tr><td colspan="3">Costs of your solution:</td><td colspan="3">Benefits of your solution:</td></tr>
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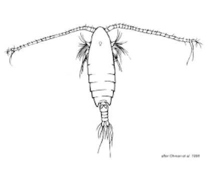
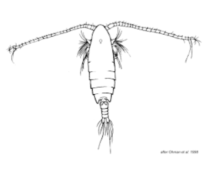
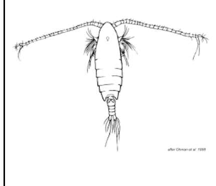
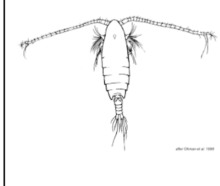
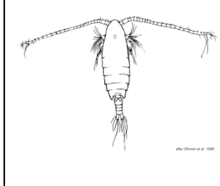
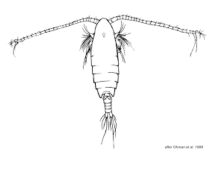
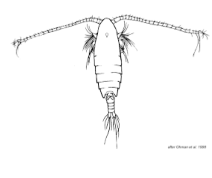
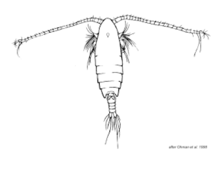
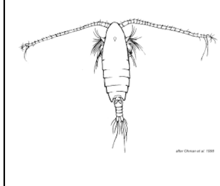
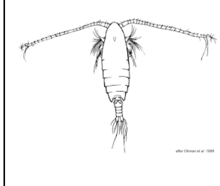
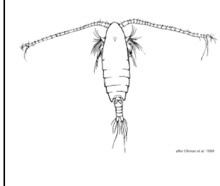
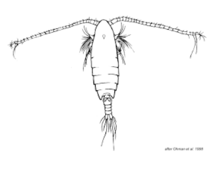
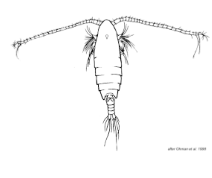
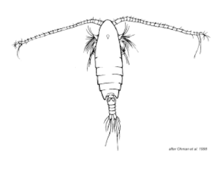
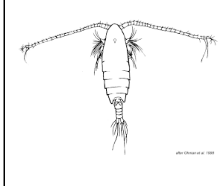
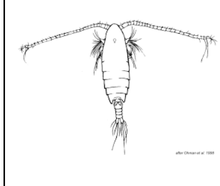
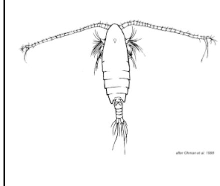
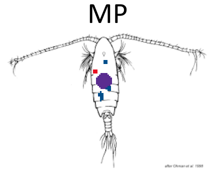
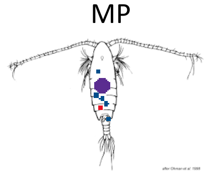
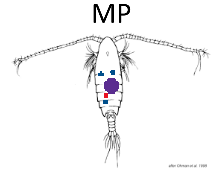
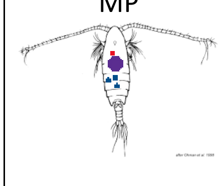
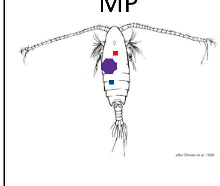
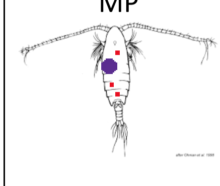
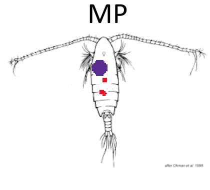
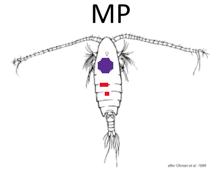
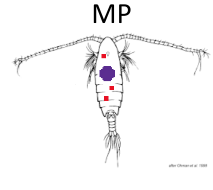
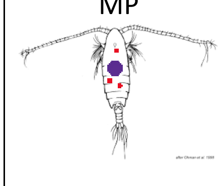
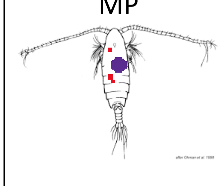
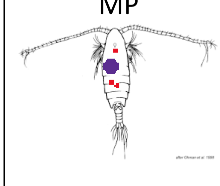
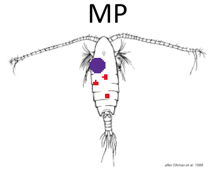
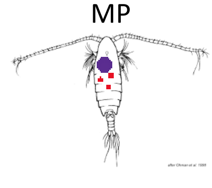
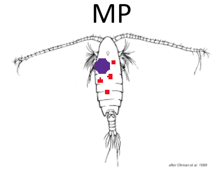
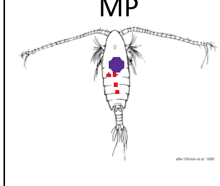
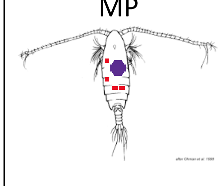
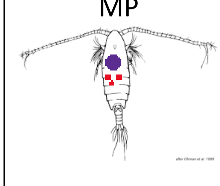
ZOOPLANKTON TOKENS (MP= Microplastics)

HIDEOUT SAFETY ZONE	Zooplankton 	Zooplankton 	Zooplankton 	Zooplankton 	Zooplankton 
Zooplankton 	Zooplankton 	Zooplankton 	Zooplankton 	Zooplankton 	Zooplankton 
Zooplankton 	Zooplankton 	Zooplankton 	Zooplankton 	Zooplankton 	Zooplankton 
Zooplankton MP 	Zooplankton MP 	Zooplankton MP 	Zooplankton MP 	Zooplankton MP 	Zooplankton MP 
Zooplankton MP 	Zooplankton MP 	Zooplankton MP 	Zooplankton MP 	Zooplankton MP 	Zooplankton MP 
Zooplankton MP 	Zooplankton MP 	Zooplankton MP 	Zooplankton MP 	Zooplankton MP 	Zooplankton MP 

Vocabulary

Apex Predator - A top predator; at the top of the food chain with no natural predators. The highest trophic level in a food/energy pyramid.

Bioaccumulation - A gradual accumulation or buildup of a substance or other compounds, often a toxin, in various tissues of an organism. Bioaccumulation often occurs when an organism absorbs a substance at a rate faster than the organism can expel or break down a substance.

Biomagnifcation - The increase in concentration of toxins in an organism as a result of ingesting other plants or animals (prey) lower on the food chain that already have the toxins. Toxins will accumulate with higher trophic levels along a food chain.

Biomass - The total mass of organisms in a given area or volume.

Food or Energy Pyramid - A model that shows the flow of energy from one trophic level to the next along a food chain in an ecosystem. The pyramid levels show the energy available at each level. The base starts with the energy available from primary producers, then flows up to primary consumers and continues up to the top of the food chain. Energy is gradually reduced as you move to the top like the shape of a pyramid.

Microplastic - A piece of plastic debris less than 5mm in size that pollutes the environment. They often result from the improper disposal and breakdown of consumer products and industrial waste.

POPs (Persistent Organic Pollutants) - Hazardous organic compounds that are resistant to biodegradation and thus remain in the environment for a long time.

Primary Consumers - Usually herbivores that prey on primary producers for energy. An example in the ocean would be a snail that eats algae.

Primary Producers - The foundation of an ecosystem and first step in the food chain, web, or food/energy pyramid. They are organisms such as a plants that can convert energy from the sun, or organisms in the deep sea that use chemical energy from deep sea vents to convert energy into food and allow organic matter to grow.

Secondary Consumers - Organisms that prey mostly on primary consumers for energy. They may be omnivores or carnivores.

Tertiary Consumers - Organisms that prey mostly on secondary consumers for energy, close to but not at the top of a food chain. They may be omnivores or carnivores.

Trophic Level - The level organisms occupy in a food chain or food/energy pyramid. There are five main trophic levels within a food chain. Energy from the sun starts the first trophic level known as primary producers, such as plants. The rest of the trophic levels are made up of consumers. The top level consists of the apex predator.

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HOW TO PLAY (instructional guide)

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