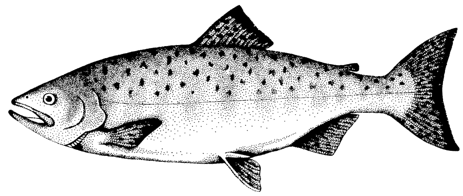
Biomagnification in Ocean Food Webs: Plastic Pollution



Topics
Plastics, Food Web

Grades
9-12

Site
Indoors, Outdoors

Duration
2 hours, over 2 days
Day 1 Steps 1-5
Day 2 Steps 6-9

Materials
see page 2

Vocabulary
absorb, adsorb, bioaccumulate, biomagnify, microplastics, persistent organic pollutants (POPs), sorb

Next Generation Science Standards

Practices
Analyzing and interpreting data Developing and using models
Core Ideas
LS2.C Ecosystem dynamics, functioning and resilience LS4.D Biodiversity and humans
Crosscutting Concepts
Cause and effect
Performance Expectations
See page 4

Focus Question

How does plastic in the ocean affect the food web?

Overview

Plastics are very effective in many ways: from keeping food fresh to providing lightweight protection (helmets, car bumpers, etc.). Certain plastics are also very good at sorbing toxic chemicals called persistent organic pollutants (POPs). In this activity, students take on roles in a simulated ocean food web that includes ingesting POP-contaminated prey. They develop and revise a model to show the relationships among variables in the ocean food web. By recording data from the ocean food web simulation, students see how POPs bioaccumulate in individual organisms at each trophic level and biomagnify in succeeding trophic levels. Students then participate in a guided discussion on the implications of POPs for ocean and human health and brainstorm ideas to reduce the presence of POPs and plastics in the ocean.

Objectives

Students will be able to:

- Describe how plastics in the environment can sorb POPs which may then enter a food web and be passed from prey to predator.
- Differentiate between bioaccumulation and biomagnification.
- Describe the biological effects of POPs on wildlife and humans.

Background

The increasing presence of plastics in our environment and particularly the ocean is a growing concern. Photodegradation and wave action on plastic marine debris create **microplastics** which marine organisms often mistake for food. Current research shows that plastics in the environment are also quite good at accumulating a class of chemicals called **persistent organic pollutants**, or POPs. POPs got their name by virtue of their chemical properties:

- Persistent: They are not water-soluble (hydrophobic) and thus break down very slowly. Once ingested, they have the ability to remain in an organisms' tissues for long periods of time.
- Organic: They contain carbon which tends to form very strong bonds.
- Pollutants: They (or their metabolic byproducts) are toxic to nearly all organisms at some dose.

Examples of POPs include polychlorinated biphenyls (PCBs), pesticides like DDT, and other hydrophobic compounds. 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, these POPs sorb to the sea surface microlayer, ocean sediment, the gills and skin of animals and to phyto- and zooplankton, which comprise the base of the ocean food web. 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. This ability to bioaccumulate some substances (like vitamins A, D, and K, trace minerals, essential fats and amino acids) is essential to the survival of many organisms, including humans. However, organisms can also accumulate unnecessary or even toxic substances like POPs. Once ingested, hydrophobic and lipid-soluble compounds like POPs can be stored in fat tissue and transferred through the placenta and breast milk to the developing offspring of humans and other mammals. POPs can interfere with body processes and healthy development of body systems, particularly the reproductive system, during critical stages of development. The severity of these effects varies depending on the species and timing of exposure, but there is much evidence that POPs have the potential to cause significant adverse effects on the health of a wide variety of organisms, including humans. Often, animals near the top of the food chain are most affected because of a secondary process called **biomagnification**.

Biomagnification of POPs occurs as they move up the food chain when predators consume prey, ingesting the POPs that have bioaccumulated in each prey item. Microplastics compound this problem by adding another, more concentrated layer of exposure to the biomagnification process. Scientists, policymakers and business leaders continue to work on solutions that will work for us and the ocean, but we can all do our part by reducing our use of single-use plastics.

This activity helps students differentiate between bioaccumulation in individuals and biomagnification at the trophic level and provides a real world context for understanding concepts of hydrophobic and hydrophilic interactions.

Materials

For the class:
- Computer, internet and projector
- Set of **Ocean Molecules and Compounds**
- Set of **POPs sorbed to Plastic Fragments** and **POPs**

Per student:
- One **Ocean Food Web Role Card**
- Student sheet: **Biomagnification Data** and **Toxin Pyramid**
- Envelope and scratch paper (to collect and record molecules, compounds and POPs)

Teacher Preparation

1. Copy and cut out enough of the **Ocean Food Web Role Cards** to provide one for each student. Copy and cut out **Ocean Molecules and Compounds (OMCs)** and **POPs** sheets. Decide whether you want students to have copies of the **Biomagnification Data** and **Toxin Pyramid** student sheet or record in their science notebooks.
2. Create and project an Excel or Google Sheets class data table or draw on a whiteboard.

VOCABULARY

Absorb: soak up a substance by chemical or physical action

Adsorb: to gather on the surface of an object in a condensed layer

Bioaccumulate: increase in the concentration of a chemical in an organism over time, compared to the chemical's concentration in the environment

Biomagnify: a process resulting from bioaccumulation in individual organisms which causes the tissue concentrations of a contaminant to increase in organisms higher up the energy pyramid

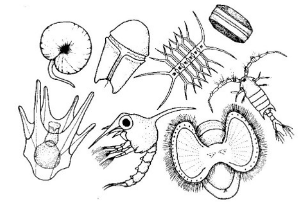
Microplastics: very small plastic fragments

Persistent Organic Pollutants (POPs): chemicals that are not water soluble (hydrophobic) and are toxic to most organisms

Sorb: to take up and hold by either absorption or adsorption

Procedure

1. **Introduce the focus question to the class.**
Share the question: *How does plastic in the ocean affect the food web?* Give students time to make some notes and then to draw and annotate a diagram illustrating their initial thoughts about what might be happening. (See page 7 for an example of a completed diagram.) They will return to this conceptual model throughout the investigation.



2. **Provide the context for an ocean food web simulation.**
   - Give students an **Ocean Food Web Role Card**. (There is an organism representing each trophic level. There are 40 provided role cards so adjust numbers for class size, ensuring each trophic level is represented.)
   - Ask them which organisms represent which trophic levels (e.g., phytoplankton are producers, salmon are tertiary consumers). Lead a discussion with students about the essential molecules, ions and compounds (Ocean molecules and compounds or "**OMCs**") in the ocean that organisms need to survive. Sometimes there are other substances and molecules in the ocean that aren't naturally-occurring and may even be toxic to ocean organisms. (Pages 16-26)

3. **Set up the simulation.**
   - Choose a large area for your ocean and distribute the **OMCs** and **POPs** face down in the ocean space. Note: There are two kinds of POPs, individual molecules and multiple POP molecules that have sorbed to plastic fragments.
   - Tell students this is the ocean and their organism will sorb (adsorb or absorb) nutrients required for survival and other substances and may consume other organisms depending on their trophic level.

4. **Explain the parameters of the simulation to students.**
   - Each producer or consumer type will get 15 seconds to swim in the ocean. The goal is for each organism to gather as many OMCs , POPs and prey (organisms carrying OMCs / POPs) as possible without being selective. As a result, they will also bioaccumulate POPs.
   - After each timed swimming session, the producer or consumer type records the number of POPs they accumulate on scratch paper and in the class data table. When students are "consumed" by the next organism they will hand off the scratch paper data to the next consumer and copy the POP data from the class data table to their own **Biomagnification Data** sheet.
   - After recording their accumulated POPs on their scratch paper, the organism type should remain in the ocean as potential food for the next consumer type that swims and feeds. Consumers tag the prey organisms and collect from them the scratch paper POP totals. Once tagged in a swimming session, the eaten/tagged organism turns over their scratch paper total to the consumer and returns to their seat. (Decide if you are going to allow the students or organisms to move or run to avoid predation in the ocean.) Students with the phytoplankton role card (the first round) will have only the OMCs and POPs as food.
   - Swimming sessions will model the energy transfer in an actual ocean food web: first the phytoplankton takes in OMCs and POPs; then the zooplankton, the sardines, the salmon and finally, the humans, feed. All organisms except the phytoplankton not only take OMCs and POPs from the ocean but also tag other students in their prey roles, ingesting all the POPs on their scratch paper.

5. **Students meet with like organisms, fill out Biomagnification Data Sheet and revise their conceptual model.**
After all of the feeding rounds, have students meet with the rest of their ocean organism type (e.g., all phytoplankton meet, etc.) and complete the appropriate Biomagnification Data

TEACHER TIP

If appropriate for your students, tell them that this is a simplified simulation and that in reality each organism excretes approximately 3/4 or 75% of the water-soluble compounds [H_2O, O_2, CO_2] and approximately 1/8 or 12.5% of the lipid-soluble POPs they ingest back into the ocean. You could use a discard bowl to model this.

column. They should record the total number of POPs they accumulated as a group, record the total number of like organisms (e.g., 20 phytoplankton) and average the number of POPs accumulated per organism. Then have one representative add their data to the class chart.

Have students refine their original model they sketched at the beginning of the activity, adding or modifying their initial ideas. Students shouldn't erase but instead use a different color pen or pencil to do this. Have them share with a partner and then add to or revise this conceptual model again.

The world's finest wilderness lies beneath the waves.

-Wyland
Marine Life Artist

6. **As a whole group, examine class data and discuss POPs.**

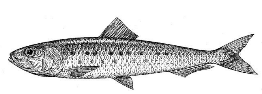
   After all organism groups have added their data to the class chart, have students think-pair-share what they notice on the data sheet. (*The average number of POPs increased or magnified at each trophic level.*) They should notice that the top predator (human) accumulated the most POPs. You may use the presentation in **Resources** to review POPs and how the bioaccumulation of POPs in individual organisms leads to biomagnification in top predators in the ocean food web, including humans. They will also see how the presence of plastics in the ocean can further magnify this process. Students should return to their model and again use a different color pen or pencil to add to or modify their original model.

7. **In small groups, students complete Biomagnification Data sheet.**

   Have students turn over the Biomagnification Data sheet and begin to complete the **Toxin Pyramid** sheet. They will compare an energy pyramid with a toxins pyramid and notice that while producers form the base of a trophic pyramid, top predators like humans bioaccumulate the highest number of POPs due to biomagnification in the food web. Have students revise and share their model with a partner. Ask students, *How are the models the same? How are they different?* Students may want to revise their models one more time.

8. **As a class, discuss the simulation and ways students can help reduce the problem of POPs in our ocean food web.**

   Be sure to remind students that this activity was a simulation; the concentrations of POPs and other compounds and ratios of primary producers and other components of the food web vary by ecosystem. Next ask students, "*What might be some ways to reduce POPs in the environment?*" and "*How else could we reduce the biomagnifying effect currently occurring in the ocean food web?*" As a class, discuss and record behaviors they might change or actions they or others could take to reduce POPs or plastic in the ocean.

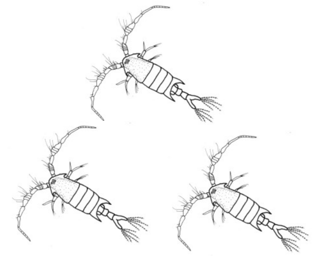


9. **Return to the focus question.**

   Now that students have simulated an ocean food web and observed how toxins like POPS may biomagnify, have them revisit the question: *How does plastic in the ocean affect the food web?* Ask them to review and revise their model one last time. Be sure to display the sample diagram on page 8 or use a student volunteer's to finalize as a class. During this consensus-building, be sure to ask students what the components of their models are, what interactions occur and what some of the limitations of the model might be (e.g., concentrations of POPs in the water vary and are not easily quantified, how could we test our model? What are some of the variables in this system?) Then in their science notebook, have students draw a line of learning and under it add to their original thoughts about the question.

Extension

Use math to consider the enormity of the POP issue. Sample problems may include:



- Suppose a salmon eats 300 g of sardines per day. Suppose sardines consumed by the salmon have an average POP concentration of 0.1 unit/g. What are the total units of POPs the salmon consumes in one day? *[(300g fish/day)(0.1 units of POPs/fish) = 30 units of POPs/day]*
  - If 80% of the POPs consumed by the salmon bioaccumulate in the salmon's tissue, calculate the following:
    - *i.* At the end of 1 day of feeding, how many units of POP has the salmon accumulated? *[(30 units POP/ 1 day)(80%) = 24 units POP]*
    - *ii.* after 2 days? *[(30 units POP/ 1 day)(80%) (2 days)= 48 units POP]*
    - iii. after 1 month? *[(30 units POP/ 1 day)(80%) (30 days)= 720 units POP]*
  - Many people enjoy eating salmon. The King Salmon, Alaska's state fish, can weigh 14 kg (more than 30 pounds). A typical salmon steak weighs 140 g. If a person eats a serving of salmon that fed on sardines for a month, what level of POPs has our human friend consumed? *[(140 g)(1 kg/1000g)(1 salmon/14 kg)(720 units POP/1 salmon) = 7.2 units POP]*

Resources

Websites

International Pellet Watch http://www.pelletwatch.org/

This citizen science project monitors POPs in the ocean. If your school is near a beach, organize a pellet collection event and send in your samples for analysis to add to the database!

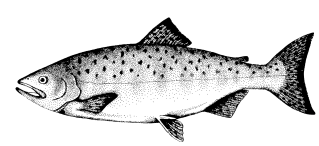
5 Gyres Project http://5gyres.org

This organization has pioneered much of the research done on the amount and distribution of plastic pollution in the oceans, specifically each of the five gyres. Many resources are available on this site.

Videos

How do we know ocean organisms are ingesting POP-laden bits of plastic? Watch "Chelsea Rochman Studies Salps." https://www.youtube.com/watch?v=eyn6dqX5uOM

Are microplastics a problem in ocean food webs? Watch https://www.youtube.com/watch?v=HN9j0y9bivo



Stephen Palumbi's TED talk discusses the potential for biomagnification of toxins to affect human health "Following the Mercury Trail." http://tinyurl.com/palumbitalk

Other

Review of hydrophilic and hydrophobic interactions: http://prezi.com/xjpwyfypeiiz/?utm_campaign=share&utm_medium=copy

The mission of the Monterey Bay Aquarium is to inspire conservation of the oceans.

Recommended Books

Plastic: A Toxic Love Story. Freinkel, Susan. Houghton Mifflin Harcourt, 2011.

Plastic-Free: How I Kicked the Plastic Habit and You Can Too. Terry, Beth. Skyhorse Publishing Inc., 2012.

Marine Anthropogenic Litter. Bergmann, Melanie; Gutow, Lars; Klages, Michael; Editors. Springer, 2015. http://www.springer.com/us/book9783319165097.

References

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Van, A.; Rochman, C.M.; Flores, E.M.; Hill, K.L.; Vargas, E.; Vargas, S.A.; Hoh, E. 2012 *Persistent organic pollutants in plastic marine debris found on beaches in San Diego, California.* Chemosphere 86 258-263.

Mizukawa, K.; Hideshige, T.; Ito, M.; Geok, Y.B.; Hosoda, J.; Yamashita, R.; Santos, I.; Micaelo, C.; Ferreira, A.M. 2013 *Monitoring of a wide range of organic micropollutants on the Portuguese coast sing plastic resin pellets.* Marine Pollution Bulletin, In Press.

Ogata, Y.; H. Takada, K. Mizukawa, H. Hirai, S. Iwasa, S. Endo,Y. Mato, M. Saha, K. Okuda, A. Nakashima, M. Murakami, N. Zurcher, R Booyatumanondo, M.P. Zakaria, L.Q. Dung, M. Gordon, Carlos Miguez, S. Suzuki, C. Moore, H.K. Karapanagioti, S. Weerts, T. McClurg, Erick Burres, W. Smith, M. Van Velkenburg, J. S. Lang, R.C. Lang, D. Laursen, B. Danner, N. Stewardson, R.C. Thompson. *International Pellet Watch: Global monitoring of persistent organic pollutants (POPs) in coastal waters. Initial phase data on PCBs, DDTs, and HCHs.* Marine Pollution Bulletin 58 (2009) 1437–1446.

Standards

Next Generation Science Standards www.nextgenscience.org

Performance Expectation

Relates to HS-LS2-7 Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

Common Core State Standards www.corestandards.org

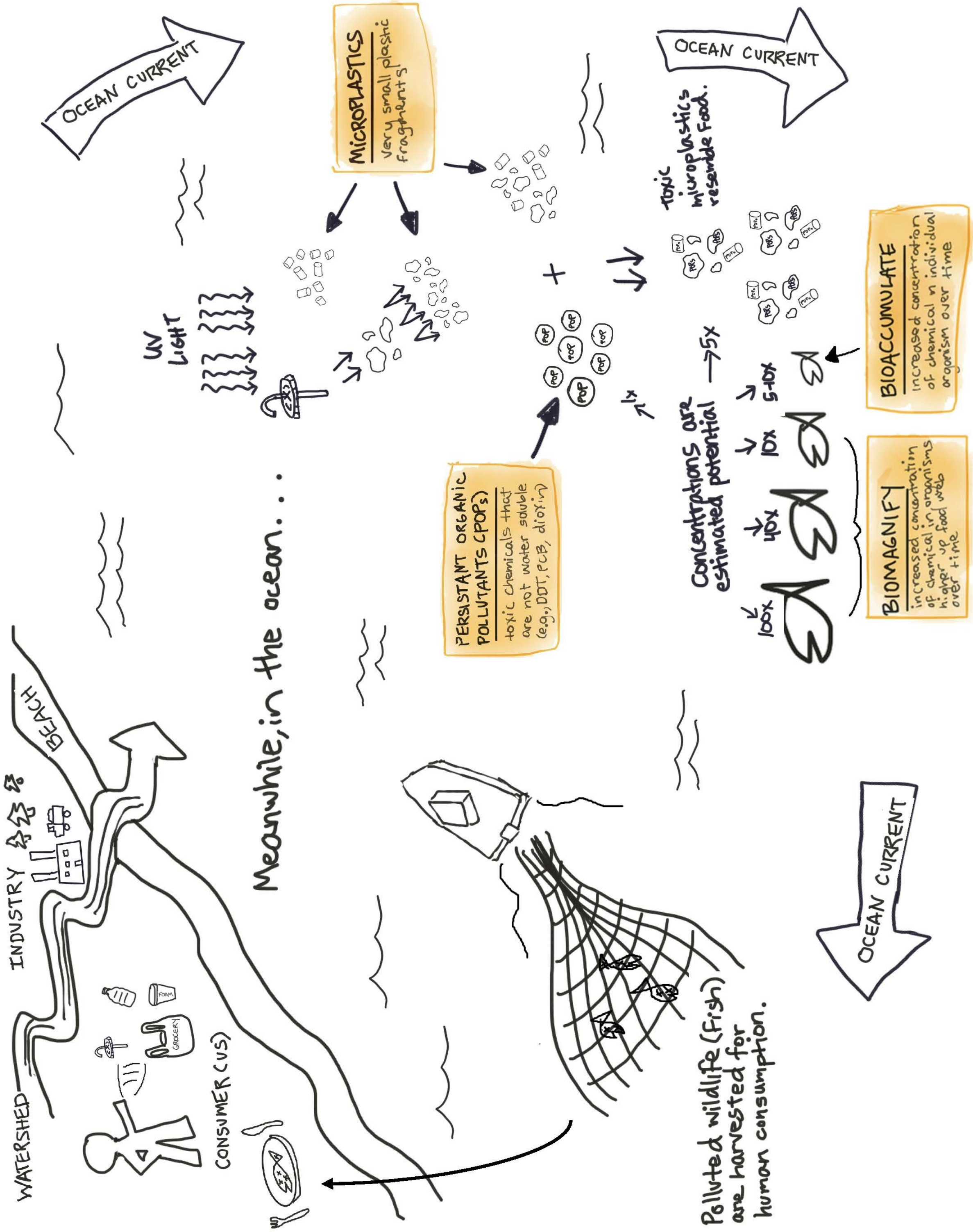
Language Arts, SL.9-12.1

Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 9-12 topics, texts, and issues, building on others' ideas and expressing their own clearly

Math, SN.Q.A.1

Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

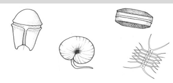
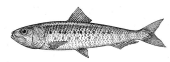
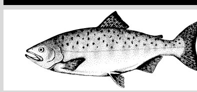
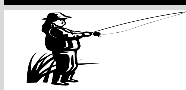
Sample Student Diagram



Biomagnification Data

Name:

1. Record your individual data in the first row of the chart below after you are done feeding.

	Producer *Phytoplankton*	Primary Consumer *Zooplankton*	Secondary Consumer *Sardine*	Tertiary Consumer *Salmon*	Top Predator *Human*
					
# of POPs in your organism					
Total # of POPs for all organisms at that trophic level					
Total # of organisms					
Average # of POPs per organism					

2. After the simulation is over, meet up with like organisms and finish filling out your column in the table above.
    - Record the total number of persistent, organic pollutants (POPs) all of you ingested, record the total number of organisms like you and then calculate the average number of POPs per individual organism. (To calculate the average, count up the total number of POPs that all of you collected and divide by the number of your organism.)

3. Use the class data table on the board to complete the table above (filling out all columns). Discuss:

    - What do you notice?

    - Which consumer type ingested the greatest number of POPs? Why do you think that is?

    - What are POPs?

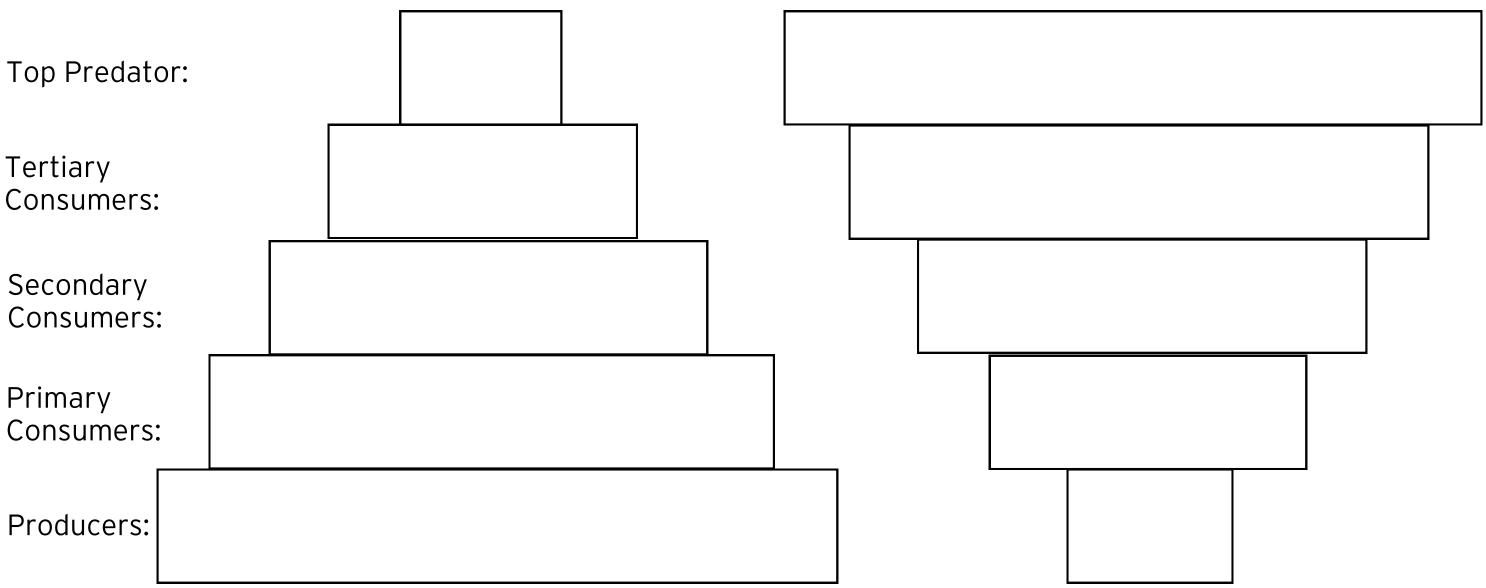
    - How might POPs affect the health of each consumer type (or producer)?

Biomagnification: Toxin Pyramid

Name:

Bioaccumulation is an increase in the concentration of a substance in an individual organism over time. **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.

1. Look at the diagrams below.
   - In the energy pyramid, add the organisms' names next to their consumer type and indicate how many there were of each organism.
   - In the toxin pyramid, add the organism name and average number of POPs to the appropriate level. Then use dots to represent POPs and using your data table, add the appropriate number to each level. (You may want to have one dot represent multiple POPs. If so, include a key next to the diagram.)



Energy Pyramid **Toxins (POP) Pyramid**

2. Compare the number of POPs the producers consumed to that consumed by the top predator. What do you notice?

3. 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?

4. What do you think the biomagnification of toxic chemicals, like POPs, means for the health of humans and the ocean ecosystem?

POPs and Humans: Unintended Consequences

Studies have linked ingestion or other exposures of POPs to declines, diseases, or abnormalities in wildlife species, including fish, birds, and mammals. Evidence of negative effects in wildlife can be a warning for humans.

Behavioral abnormalities and birth defects in fish, birds, and mammals in and around the Great Lakes, for example, led scientists to investigate POPs exposures in human populations. What they found was that in people, adverse effects in reproductive, developmental, behavioral, neurologic, endocrine, and immunologic functions have also been linked to POPs. These effects include low birth weights, birth defects and increased risks of developing Type 2 diabetes, certain types of cancers and a variety of brain and nervous system disorders.

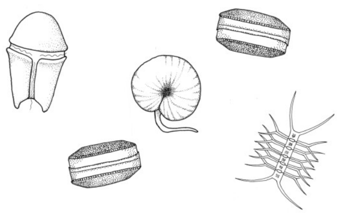
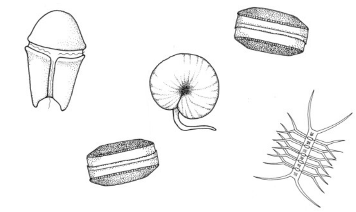
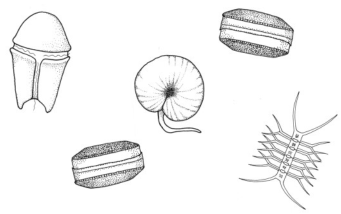
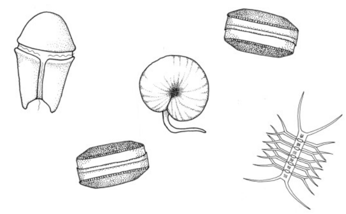
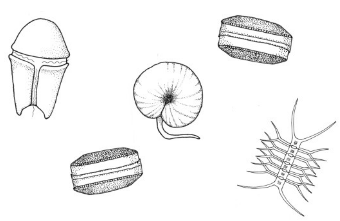
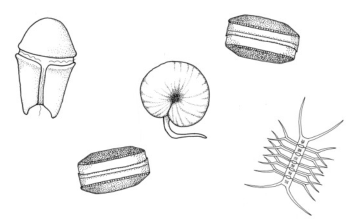
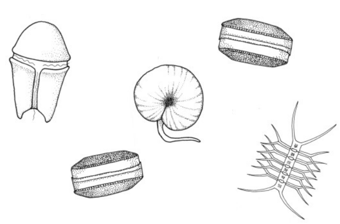
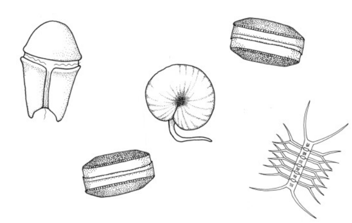
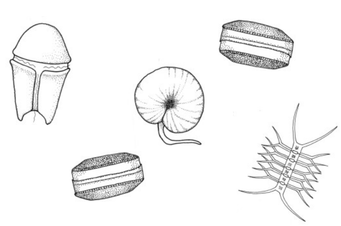
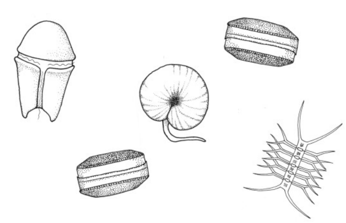
In addition to exposure through contaminated foods or water, in people and other mammals, POPs can be transferred through the placenta and breast milk of pregnant or breast-feeding mothers to developing offspring. For humans, it is important to note that the U.S. Environmental Agency says that in most human populations, the benefits of breast-feeding far outweigh the suspected risks of this potential exposure route for POPs. Some populations, however, have a greater risk of POPs being passed to the fetus or in early infancy when a baby is most vulnerable to the effects of disruption to its growth, immune and nervous systems development.

A number of populations are at particular risk of POPs exposure, including people whose diets include large amounts of fish, shellfish, or wild foods that are high in fat and locally obtained. For example, indigenous peoples may be particularly at risk because they observe cultural and spiritual traditions related to their diet. To them, fishing and hunting are part of a traditional, subsistence way of life, in which no useful part of the catch is wasted. In remote areas of Alaska and elsewhere, locally-obtained, subsistence food may be the only readily available food option, leaving these populations no choice but to ingest foods containing more concentrated amounts of POPs

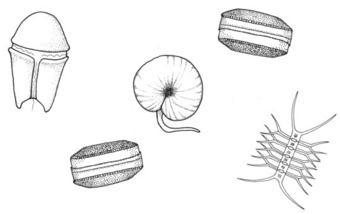
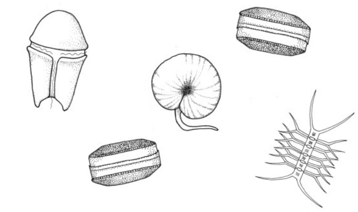
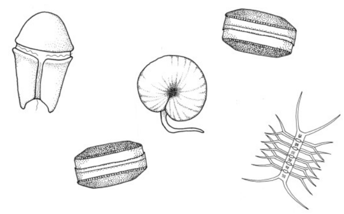
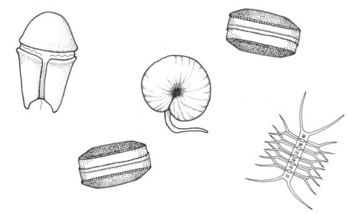
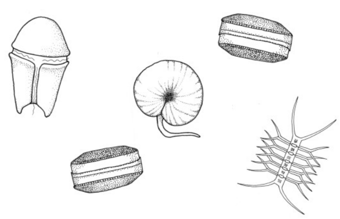
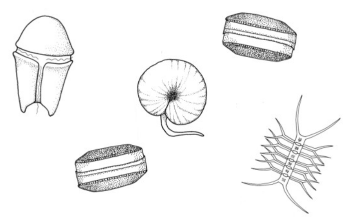
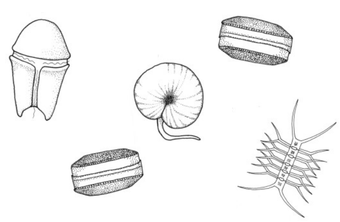
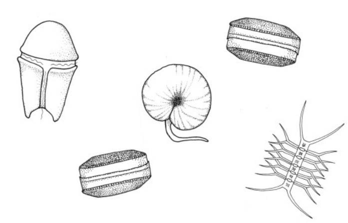
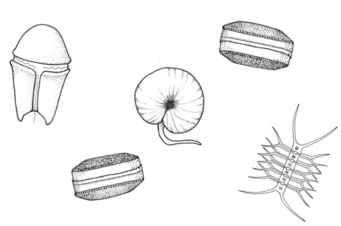
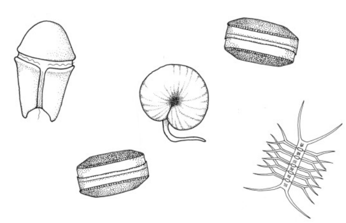
Researchers are continuing to investigate the effects of POPs on wildlife and human health and to better understand how POPs, once released into the environment, become distributed throughout earth systems.

Adapted from https://www.epa.gov and the National Institutes of Health

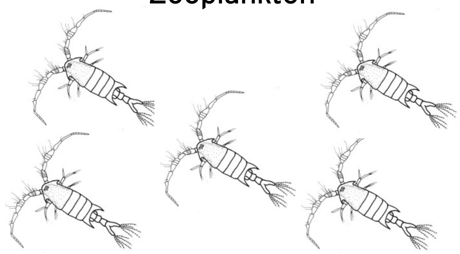
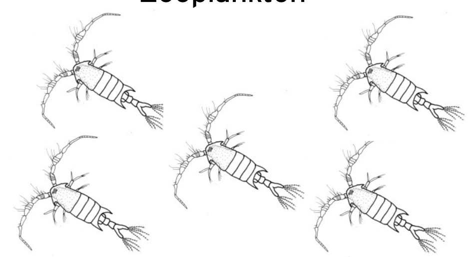
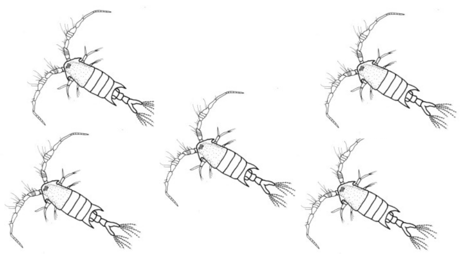
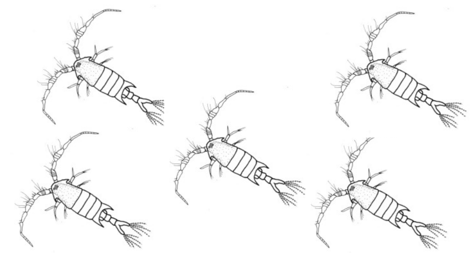
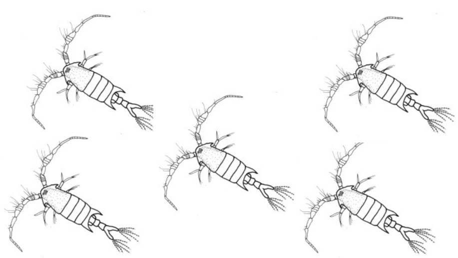
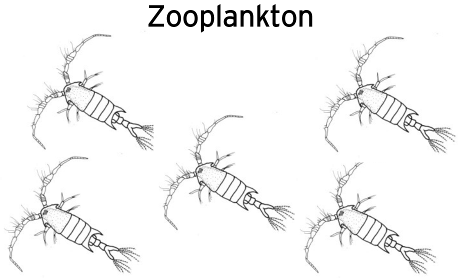
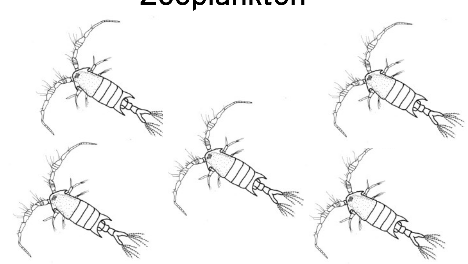
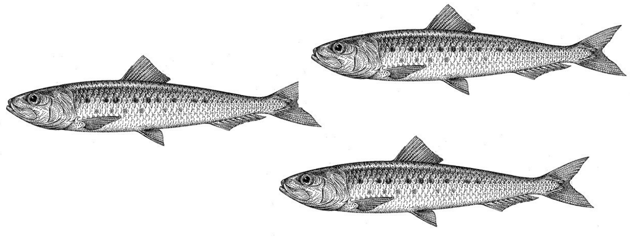
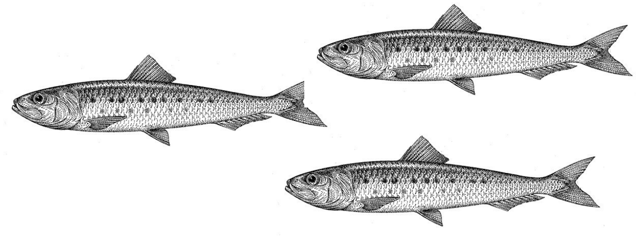
Ocean Food Web Role Cards

Phytoplankton 	Phytoplankton 
Phytoplankton 	Phytoplankton 
Phytoplankton 	Phytoplankton 
Phytoplankton 	Phytoplankton 
Phytoplankton 	Phytoplankton 

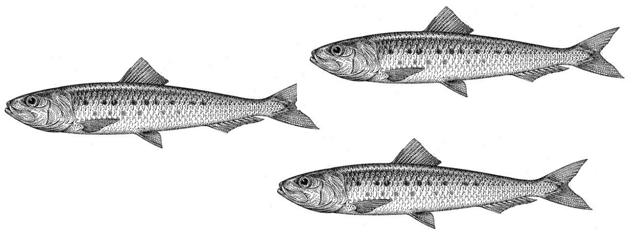
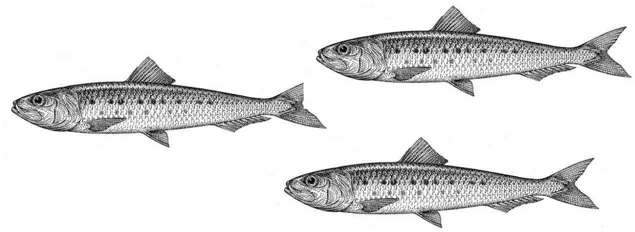
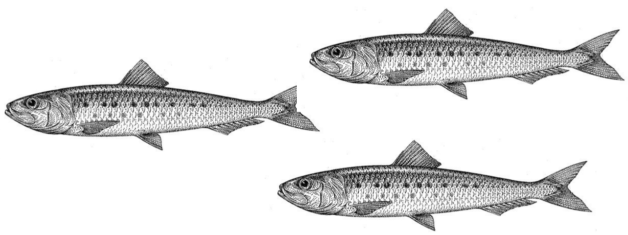
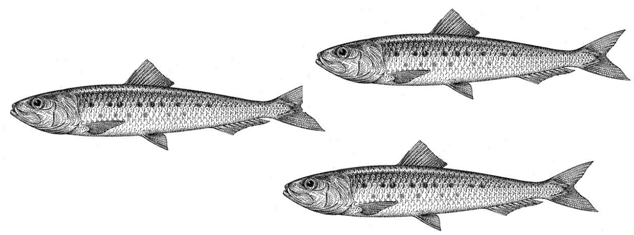
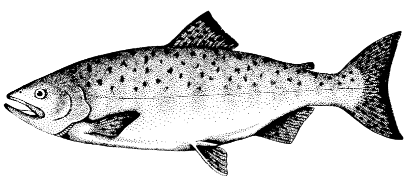
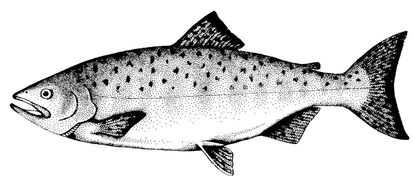
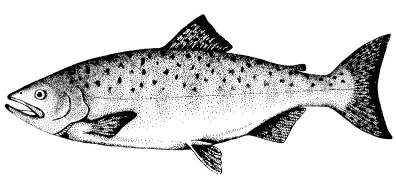
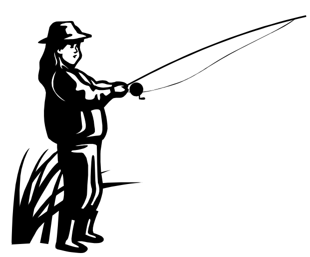
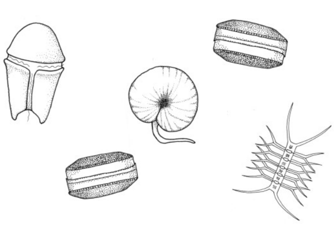
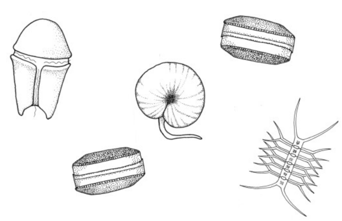
Ocean Food Web Role Cards

Phytoplankton 	Phytoplankton 
Phytoplankton 	Phytoplankton 
Phytoplankton 	Phytoplankton 
Phytoplankton 	Phytoplankton 
Phytoplankton 	Phytoplankton 

Ocean Food Web Role Cards

Zooplankton 	Zooplankton 
Zooplankton 	Zooplankton 
Zooplankton 	Zooplankton 
Zooplankton 	Zooplankton 
Sardines 	Sardines 

Ocean Food Web Role Cards

Sardines 	Sardines 
Sardines 	Sardines 
Salmon 	Salmon 
Salmon 	Human 
Phytoplankton 	Phytoplankton 

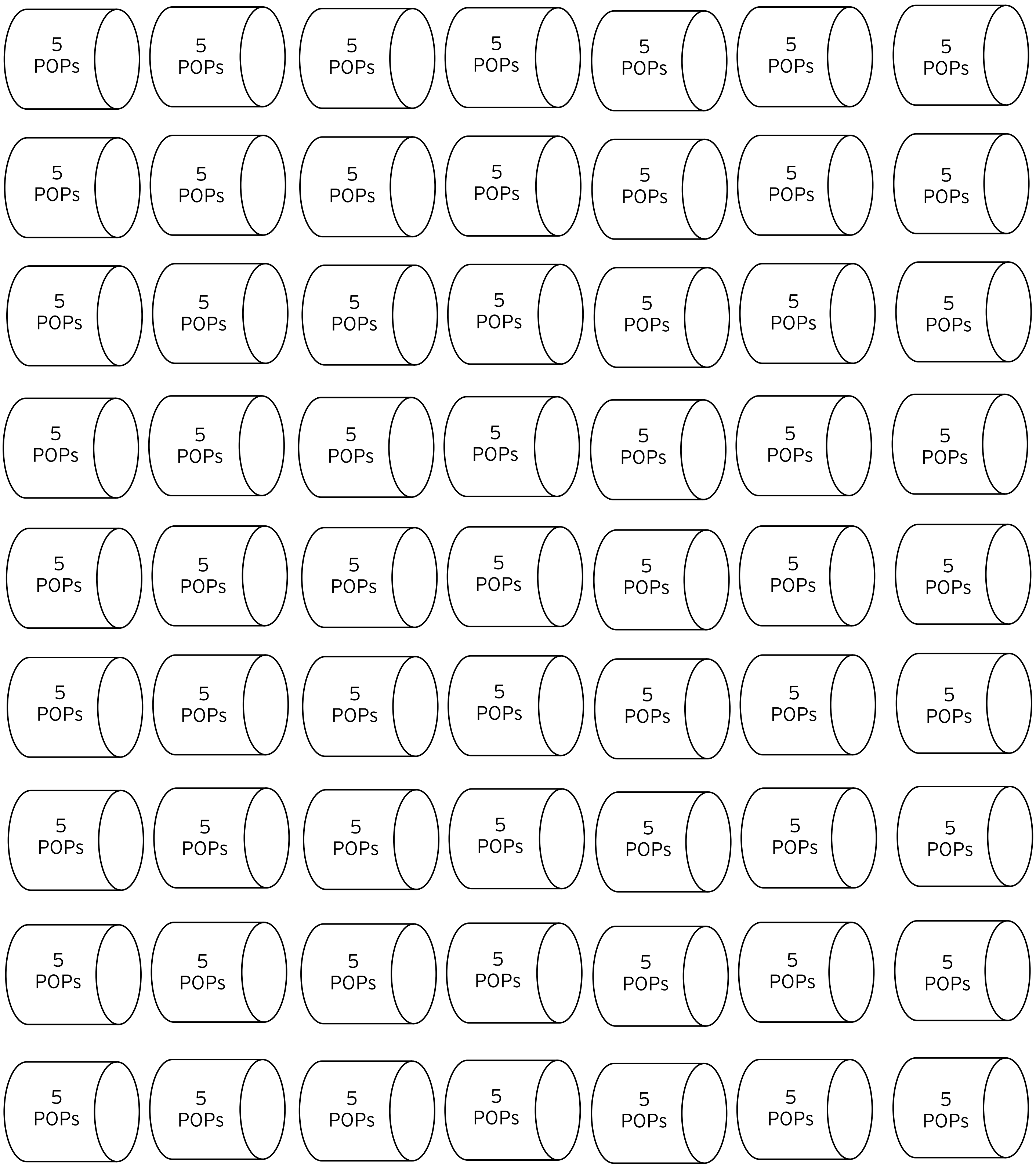
POPs*

*each circle counts as one unit of POP

POP	POP	POP	POP	POP	POP
POP	POP	POP	POP	POP	POP
POP	POP	POP	POP	POP	POP
POP	POP	POP	POP	POP	POP
POP	POP	POP	POP	POP	POP
POP	POP	POP	POP	POP	POP
POP	POP	POP	POP	POP	POP

POPs Sorbed to Plastic Fragments*

*each pellet counts as 5 units of POP



Ocean Molecules and Compounds

H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O

Ocean Molecules and Compounds

H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O

Ocean Molecules and Compounds

H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	O_2	O_2
O_2	O_2	O_2	O_2	O_2	O_2
O_2	O_2	O_2	O_2	O_2	O_2
O_2	O_2	O_2	O_2	O_2	O_2
O_2	O_2	O_2	O_2	O_2	O_2

H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	O_2	O_2
O_2	O_2	O_2	O_2	O_2	O_2
O_2	O_2	O_2	O_2	O_2	O_2
O_2	O_2	O_2	O_2	O_2	O_2
O_2	O_2	O_2	O_2	O_2	O_2

Ocean Molecules and Compounds

O_2	O_2	O_2	O_2	O_2	O_2
O_2	O_2	O_2	O_2	O_2	O_2
Na^+	Na^+	Na^+	Na^+	Na^+	Na^+
Na^+	Na^+	Na^+	Na^+	Na^+	Na^+
Na^+	Na^+	Na^+	Na^+	Na^+	Na^+
Na^+	Na^+	Na^+	Na^+	Na^+	Na^+
Na^+	Na^+	Na^+	Na^+	Na^+	Na^+
Na^+	Na^+	Na^+	Na^+	Na^+	Na^+

Ocean Molecules and Compounds

Cl^-	Cl^-	Cl^-	Cl^-	Cl^-	Cl^-
Cl^-	Cl^-	Cl^-	Cl^-	Cl^-	Cl^-
Cl^-	Cl^-	Cl^-	Cl^-	Cl^-	Cl^-
Cl^-	Cl^-	Cl^-	Cl^-	Cl^-	Cl^-
Cl^-	Cl^-	Cl^-	Cl^-	Cl^-	Cl^-
Cl^-	Cl^-	Cl^-	Cl^-	Cl^-	Cl^-
Cl^-	Cl^-	Cl^-	Cl^-	Cl^-	Cl^-
Cl^-	Cl^-	Cl^-	Cl^-	Cl^-	Cl^-

Ocean Molecules and Compounds

Cl^-	Cl^-	Cl^-	Cl^-	Cl^-	Cl^-
Cl^-	Cl^-	Cl^-	Cl^-	Cl^-	Cl^-
Cl^-	Cl^-	Cl^-	Cl^-	Cl^-	Cl^-
SO_4^{2-}	SO_4^{2-}	SO_4^{2-}	SO_4^{2-}	SO_4^{2-}	SO_4^{2-}
Mg^{2+}	Mg^{2+}	Mg^{2+}	Mg^{2+}	Ca^{2+}	Ca^{2+}
K^+	K^+	Sr^{2+}	O_2	O_2	O_2
O_2	O_2	O_2	O_2	O_2	O_2

Ocean Molecules and Compounds

CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O
H_2O	H_2O	H_2O	H_2O	H_2O	H_2O

Ocean Molecules and Compounds

CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
H_2CO_3	H_2CO_3	H_2CO_3	H_2CO_3	H_2CO_3	H_2CO_3
H_2CO_3	H_2CO_3	H_2CO_3	H_2CO_3	H_2CO_3	H_2CO_3
H_3BO_3	Br^-	Br^-	Br^-	Br^-	Br^-
Br^-	Br^-	Br^-	Br^-	Br^-	Br^-
Br^-	Br^-	Br^-	Br^-	Br^-	Br^-
Br^-	Br^-	Br^-	Br^-	Br^-	Br^-

Ocean Molecules and Compounds

CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
H^+	H^+	H^+	H^+	H^+	H^+
H^+	H^+	H^+	H^+	H^+	H^+
OH^-	OH^-	OH^-	OH^-	OH^-	OH^-
OH^-	OH^-	OH^-	OH^-	OH^-	OH^-