



ZOOP SOUP (AND POOP!)

THE ROLE OF PLANKTON AND THEIR FECAL PELLETS IN THE CARBON CYCLE

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Grade Level

7th Grade through High School

Subject Area

Life Science, Biology, Environmental,
Oceanography, Physical Science, Mathematics

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Activity Title: Zoop Soup (and Poop!): The Role of Plankton and their Fecal Pellets in the Carbon Cycle

Focus: Zooplankton Communities, Fecal Pellets, and Carbon Cycling Around the World

Grade Levels/ Subject: 7th grade Life Science (focus), 7th grade Mathematics, 8th grade Physical Science; High School Biology, Environmental Science, Oceanography

VA Science Standard(s) addressed:

7th Grade Life Science

LS.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which

- b. a classification system is developed based on multiple attributes;
- c. triple beam and electronic balances are used to gather data;
- d. models and simulations are constructed and used to illustrate and explain phenomena;
- h. data are organized, communicated through graphical representation, interpreted, and used to make predictions;
- i. patterns are identified in data and are interpreted and evaluated

LS.5 The student will investigate and understand the basic physical and chemical processes of photosynthesis and its importance to plant and animal life. Key concepts include

- c. photosynthesis as the foundation of virtually all food webs.

LS.6 The student will investigate and understand that organisms within an ecosystem are dependent on one another and on nonliving components of the environment. Key concepts include

- a. the carbon cycle;
- b. interactions resulting in a flow of energy and matter throughout the system;
- c. complex relationships within marine and estuarine ecosystems; and
- d. energy flow in food webs.

LS.10 The student will investigate and understand that ecosystems, communities, populations, and organisms are dynamic, change over time, and respond to daily, seasonal, and long-term changes in their environment. Key concepts include

- b. factors that increase or decrease population size; and
- c. eutrophication, climate changes, and catastrophic disturbances.

LS.11 The student will investigate and understand the relationships between ecosystem dynamics and human activity. Key concepts include

- b. change in habitat size, quality, or structure;
- d. population disturbances and factors that threaten or enhance species survival; and
- e. environmental issues.

LS.13 The student will investigate and understand that populations of organisms change over time. Key concepts include

- c. how environmental influences, as well as genetic variation, can lead to diversity of organisms.

7th Grade Mathematics

7.4 The student will

- a. describe and determine the volume and surface area of rectangular prisms and cylinders; and
- b. solve problems, including practical problems, involving the volume and surface area of rectangular prisms and cylinders.

7.5 The student will

- a. compare and contrast quadrilaterals based on their properties; and
- b. determine unknown side lengths or angle measures of quadrilaterals.

7.9 The student, given data in a practical situation, will

- a. represent data in a histogram; and
- b. make observations and inferences about data represented in a histogram

8th Grade Physical Science

PS.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which

- b. length, mass, volume, density, temperature, weight, and force are accurately measured;
- c. conversions are made among metric units, applying appropriate prefixes;
- d. triple beam and electronic balances, thermometers, metric rulers, graduated cylinders, probeware, and spring scales are used to gather data;
- g. data tables showing the independent and dependent variables, derived quantities, and the number of trials are constructed and interpreted;
- i. scatterplots and histograms are constructed and interpreted;
- j. valid conclusions are made after analyzing data;
- k. research methods are used to investigate practical problems and questions;

High School Science

BIO.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which

- b. hypotheses are formulated based on direct observations and information from scientific literature;
- d. graphing and arithmetic calculations are used as tools in data analysis;
- e. conclusions are formed based on recorded quantitative and qualitative data;
- f. sources of error inherent in experimental design are identified and discussed;
- m. current applications of biological concepts are used.

BIO.2 The student will investigate and understand the chemical and biochemical principles essential for life. Key concepts include the capture, storage, transformation, and flow of energy through the processes of photosynthesis and respiration.

BIO.8 The student will investigate and understand dynamic equilibria within populations, communities, and ecosystems. Key concepts include

- b. nutrient cycling with energy flow through ecosystems;
- c. succession patterns in ecosystems;

- d. the effects of natural events and human activities on ecosystems; and
- e. analysis of the flora, fauna, and microorganisms of Virginia ecosystems.

Learning objectives/outcomes

- a. Students will classify and categorize simulated zooplankton “fecal pellets” by their shape and size
- b. Students will identify the zooplankton source species of “fecal pellets” using a dichotomous key
- c. Students will sort and weigh “fecal pellets” using a triple beam balance
- d. Students will hypothesize where their “sample” came from using a map of locations and data
- e. Students will calculate carbon flux using the data they collect
- f. Students will compare and contrast carbon cycling in different regions of the ocean
- g. Students will construct graphs showing weight of fecal pellets in each location
- h. Students will measure real zooplankton fecal pellets using a photograph and metric ruler
- i. Students will discuss the importance of carbon cycling in the marine environment

Total length of time required for the lesson

One 90-minute class block

Key words, vocabulary * For a glossary of listed vocabulary terms, see Appendix 6*:

Zooplankton; phytoplankton; meroplankton; holoplankton; diel vertical migration; photosynthesis; food web; fecal pellet; export; community; nutrients; carbon sequestration; passive sinking; active transport; remineralization; respiration; fossil fuels; carbon dioxide; gelatinous; marine snow; biological pump

Background information

Kristen Sharpe is a Masters graduate student at the Virginia Institute of Marine Science. She is studying zooplankton communities in the Chesapeake Bay and Sargasso Sea, with an emphasis on the role of surface zooplankton community composition on the production of fecal pellets.

The root of the word plankton is the Greek “*planktos*,” meaning drifter or wanderer. Plankton are broadly described as all organisms that cannot actively swim against a current. Plankton are universally found in all water bodies, including fresh and marine, and can range in both taxonomy and size.

There are two main types of plankton. Phytoplankton are microscopic protists which convert light energy from the sun into organic material, in a process known as photosynthesis. Through photosynthesis, carbon dioxide is sequestered from the air and oxygen is produced as a by-product. In fact, over 50% of the oxygen in the earth’s atmosphere is created by phytoplankton.

The general equation for the photosynthetic process is included below:



Zooplankton are animal plankton, which can range in size from microscopic animals to macroscopic organisms such as jellyfishes and giant pyrosomes. Animals which spend their entire life as plankton are called holoplankton, while those animals that spend only part of their life as plankton are referred

to as meroplankton. Meroplankton include the larval forms of almost every animal that lives in the ocean.

Zooplankton are important for a variety of reasons. Perhaps most importantly, they form a critical intermediate link in the global marine food web. By grazing on phytoplankton and then, in turn, being consumed by a variety of larger animals, zooplankton link primary producers to upper trophic levels. Every organism in the ocean depends either directly or indirectly on plankton for their food source.

Another important role that zooplankton play is in the global carbon cycle. By grazing on phytoplankton, the zooplankton take in most of the carbon that phytoplankton have fixed through photosynthesis. Then, just like every other animal that eats – zooplankton poop! Their fecal pellets, along with exoskeleton molts, remains of dead animals, and discarded gelatinous feeding houses, aggregate to form “marine snow.” The marine snow is denser than the water, and passively sinks down into deeper ocean zones where it can be remineralized by bacteria or used as a food source by other animals. Zooplankton can also actively transport this carbon-rich material to deeper waters through diel vertical migration.

Diel vertical migration is the daily movement of organisms from the surface waters to the deeper zones. Zooplankton hide from visual predators during the daytime by staying in the mid-depth waters where there is not much light to hunt with. When the sun goes down, the zooplankton migrate all the way up into the surface waters where they graze on the phytoplankton which have been growing all day. Before morning breaks, the zooplankton are on their way back down into the deep where they digest their food and create their fecal pellets. Scientists refer to this as active transport of fecal pellets, as the zooplankton themselves are releasing the pellets further down in the water column where they are more likely to be deposited onto the seafloor than if released near the surface. If this “marine snow” makes it to the seafloor, it can be buried and sequestered from the ocean. We call these biological activities that transport carbon from the surface to the deep the biological pump.

The biological pump is important because it helps to remove carbon dioxide from the atmosphere and bury it in deep ocean sediments where it can be trapped for at least 1,000 years. In the atmosphere, we have a variety of heat-trapping gases (including carbon dioxide, water vapor, methane, etc.). Regular amounts of these gases occur naturally due to the balance of photosynthesis and respiration. These gases form a “heat-trapping blanket,” keeping heat from the sun’s rays around the Earth so that it is a habitable temperature for all of the planet’s plants and animals (including us). It would be much, much colder here if it were not for this heat-trapping blanket. However, as we burn fossil fuels to power our lives, we release more carbon dioxide into the atmosphere. This rampant carbon dioxide adds more “layers” to the blanket, causing more heat to be trapped for longer periods of time before dissipating out into space. This leads to increases in air and water temperatures, loss of sea ice (icebergs) and land ice (glaciers), sea level rise, changes in precipitation patterns, and many other global impacts. Thus, any process that helps to sequester carbon dioxide from the atmosphere helps to counteract the effects of climate change.

However, not all zooplankton fecal pellets are the same and their behavior in the biological pump may differ. Different species and groups of zooplankton create very different fecal pellets in terms of their size, shape, carbon contents, and density. Therefore, different pellets have a different sinking rate and likelihood of being buried. For this reason, it is valuable to understand how different zooplankton community composition can influence carbon export to the deeper waters where it can be buried.

Student handouts and other materials needed (worksheet, data tables, diagrams, websites, etc. PLUS, answer keys for all questions, worksheets, graphing activities)

APPENDICES: Map of Sediment Trap Locations (Appendix 1), Dichotomous Keys (Appendix 2), Student Worksheets (Appendix 3), Answer Key (Appendix 4), Zooplankton Fecal Pellet Photographs (Appendix 5), Supplementary Powerpoint.

Video resources are included within the Powerpoint

Materials & Supplies, A/V/Tech Support

For the lesson, the instructor will need a computer loaded with the supplementary Powerpoint presentation and an overhead projector.

For the activity, the instructor will need:

- 10 paper bags or other small containers (tupperware, bowls, cups, Ziploc bags)
- Materials for “sediment trap” bags:

For a mostly non-edible, bean and craft material-based activity:

- Dried red kidney beans
- Dried corn kernels
- Dried brown/white rice
- Dried lentils or split peas
- Pipe cleaners
- Large marshmallows
- Small (mini) marshmallows

For an edible, candy based activity:

- Large marshmallows
- Small (mini) marshmallows
- Long thin candies (Twizzlers)
- Small candies (tic tacs, M&Ms, jelly beans, skittles)
- Coffee filters (at least 30, can be reused)
- Triple beam balances
- Ten copies of appropriate dichotomous key (Appendix 2)
- Ten copies of “sediment trap” location site maps (Appendix 1)
- Ten copies of student worksheet (Appendix 4 – <https://tinyurl.com/ZoopSoupWorksheet>)
- Copies of zooplankton fecal pellet photographs (Appendix 5), enough for each student to have one
- Rulers (preferably metric), enough for each student or for students to share in small groups

Classroom/Lab/Field Study Setup

Students will be working in small groups (2-3 students) on this project, so any table/desk setup that can facilitate that group work would be ideal. Triple beam balances should be set up at one end of the

classroom where students can weigh their “fecal pellets.” The “sediment trap” content bags should not be passed out until the teacher is ready to begin the activity (after the introductory PowerPoint and/or discussion). Each group will receive one of the “sediment trap” content bags (labelled A-J), a copy of the

student worksheet, 3 coffee filters, and a copy of the dichotomous key. After graphing their results and an intermediate discussion of preliminary findings, students will receive copies of the zooplankton fecal pellet photographs (probably best for each student to have their own, and instruct them not to write on them so that you may reuse them), and a ruler that they will use in order to “measure” the fecal pellet(s) in the photograph and calculate the carbon content.

Procedure:

Advance preparation of lab materials – 20 minutes

1. Use the proportions/guidelines below to create the ten “fecal pellet sediment trap” bags/sediments, and label A-J (with the letters included below):

“Sediment Trap” Location	Non-Candy Version	“Candy” Version
A. Antarctica - summer	18 kidney beans 112 4-inch pipe cleaners 3 marshmallows	6 Mike and Ikes 17 5-inch Twizzlers 3 marshmallows
B. Sargasso Sea - summer	375 grains of rice (~ 2 teaspoons) 3 mini marshmallows	16 Tic-Tacs 3 mini marshmallows
C. Subarctic North Pacific	45 kidney beans 100 2-inch pipe cleaners	15 Mike and Ikes 1 2-inch Twizzler
D. California coast	275 kidney beans 65 corn kernels 10 marshmallows	90 Mike and Ikes 12 jelly beans 10 marshmallows
E. Antarctica - winter	47 grains of rice 6 corn kernels 5 mini marshmallows	2 Tic-Tacs 1 jelly bean 5 mini marshmallows
F. Sargasso Sea - spring	28 kidney beans 230 grains of rice (~ 1 ½ teaspoons) 4 marshmallows	9 Mike and Ikes 10 Tic-Tacs 4 marshmallows
G. Chesapeake Bay - winter	250 grains of rice (~ 1 ½ teaspoons) 2 marshmallows	10 Tic-Tacs 2 marshmallows
H. Hawaii	27 split peas 500 grains of rice (~ 2 ½ teaspoons) 55 2-inch pipe cleaners	2 Skittles 20 Tic-Tacs 10 2-inch Twizzlers
I. Chesapeake Bay - summer	120 split peas 1,850 grains of rice (~ 9 teaspoons) 40 mini marshmallows	15 M&Ms 1 Skittle 80 Tic-Tacs 40 mini marshmallows
J. Amazon River plume	30 kidney beans 75 split peas 1400 grains of rice (~ 7 teaspoons) 80 2-inch pipe cleaners 50 mini marshmallows	10 Mike and Ikes 10 M&Ms 60 Tic-Tacs 15 2-inch Twizzlers 50 mini marshmallows

Introduction Powerpoint - 20 minutes

1. Instruct students not to touch the materials on their desks until you tell them to (it may be best to make piles of materials and leave on a side counter, and then students can quickly retrieve their materials just prior to doing the activity to prevent distractions during the introduction).
2. Use the accompanying Powerpoint slides and script (in the comments section of the slides, and in the Appendix) to introduce the activity and what students will be doing.

Fecal Pellet Sediment Trap Activity - 30 minutes

1. Tell students that Kristen has collected samples from sediment traps all over the world, but the labels got wet and fell off during shipment, and now she needs their help figuring out which one came from each location on the map.
2. Tell students that they will be working in small groups of 2-3 students each, and each group will receive a bag (or whatever container you choose to use) of “sediment trap” contents, and that they will be using dichotomous keys to sort and identify which species created each fecal pellet.
3. Students should use the information that they’ve been given so far, along with observations of their pellets, to make a hypothesis about where their trap bag came from based on what is inside.
4. Once students sort and identify the source species of the fecal pellets, they will keep track of how many pellets came from each type of animal - and will then use triple beam balances to weigh how much of each fecal pellet type was in their sample.
5. Tell students to keep track of the fecal pellet shapes, source species, counts, and weights on the student worksheets (you may choose to have one sheet for each group, or a separate sheet for each student).
6. Once students have completed weighing their “pellets” and filling out their datasheet, have them bring all their materials back together and place back in the bags/containers.
7. Students will be guided through data analysis questions on their worksheet.

Data Compilation and Graphing - 30 minutes

1. Bring students back together for a class discussion.
2. Have students take turns sharing out which site they thought their fecal pellet sample came from, and why.
3. Ask students to give feedback to each other – have them discuss which site they think each sample came from and come to a consensus. Then, tell students which site each sample came from using the answer key provided above.
4. Ask students to share the total weight of pellets that they measured in each site, and write these totals on the board.
5. Guide the students in a group development of a bar graph to compare the different fecal pellet production weights in each location.
6. Ask students if they can identify any “hot spots” of carbon export of the sites they investigated.

Conclusion, Breakdown and Clean-up - 10 minutes

1. Lead a discussion with students about why carbon export to the deep ocean is important:
 - a. What benefits does it create for other animals? *Food, and sometimes a temporary habitat.*

- b. What benefit does it provide for the planet? *Removing carbon dioxide from the atmosphere and trapping it in the deep ocean helps to reduce some of the impacts of climate change. It is estimated that if it were not for zooplankton fecal pellets, there would be 50% more CO₂ in our atmosphere which would cause even more warming!*
2. How may climate change affect fecal pellet production and export over time? *Changing temperatures can cause animals to move to new locations. For example, a long-term study in the North Atlantic Ocean has shown that copepods are increasing in numbers throughout the North Atlantic ocean and their habitat (range) is getting larger, which also leads to more of the smaller, slower-sinking fecal pellets. This increases the chance that the fecal pellets will be eaten or broken down in the water column before they make it down to the bottom where they can be trapped. This could lead to less carbon export over time. However, in other locations there may be MORE carbon export over time - for example, in Antarctica we are seeing decreases in krill but increases in the gelatinous zooplankton like salps, which leads to heavier fecal pellets sinking quickly to the bottom!*
3. Collect student worksheets and graphs for assessment.
4. Have students help you collect or re-set the materials for the next class (place all fecal pellets back in the bags/containers, set along with the coffee filters and ruler on the tables).

Optional - Analysis of Zooplankton Fecal Pellet Photos - 10 minutes

1. Pass out one of the provided photographs of fecal pellets from the ZooSCAN to each group (it is best to have students work with one partner on this).
2. Tell students that this is a real photograph of zooplankton fecal pellets.
3. Have students use the scale bar on the bottom right to estimate how large the fecal pellets are.
4. Tell students that this is how Kristen is estimating carbon content of the pellets that she studies. She takes photographs of pellets, measures their size and width, and uses these measurements to calculate the volume of the fecal pellet based on its shape. Calculating the volume of the pellet can help determine how much carbon is in it, and by adding up the content of all of the pellets she can get a better idea of how much carbon is being re-packaged into these fecal pellets which then have a potential to sink and be buried.

Optional Extension for Upper Level Students – Analysis of Zooplankton Community Composition

1. Explain to students that analyzing the community of zooplankton present can reveal a lot of information about fecal pellet production and export rates.
2. Ask students which types of graphs are useful in presenting parts of a whole. Pie charts are a useful tool for showcasing parts of a whole (relative proportions of each organism compared to each other and the whole).
3. Have students use the information contained in their data sheets to calculate the percent of each type of organism present in their samples (by adding up the numbers of all organisms, then dividing the numbers of each type of organism in their sample by the total number of organisms present and multiplying by 100). Have them produce a pie chart for the sediment trap site that they analyzed using these relative proportions of organisms.
4. Once the students are finished with their pie charts, allow them to do a “gallery walk” to examine the pie charts that the other students/groups produced.

Assessment:

Teachers can use the student worksheets and constructed graphs to assess student understanding of the topic, in addition to the class discussion and graphing activity.

References:

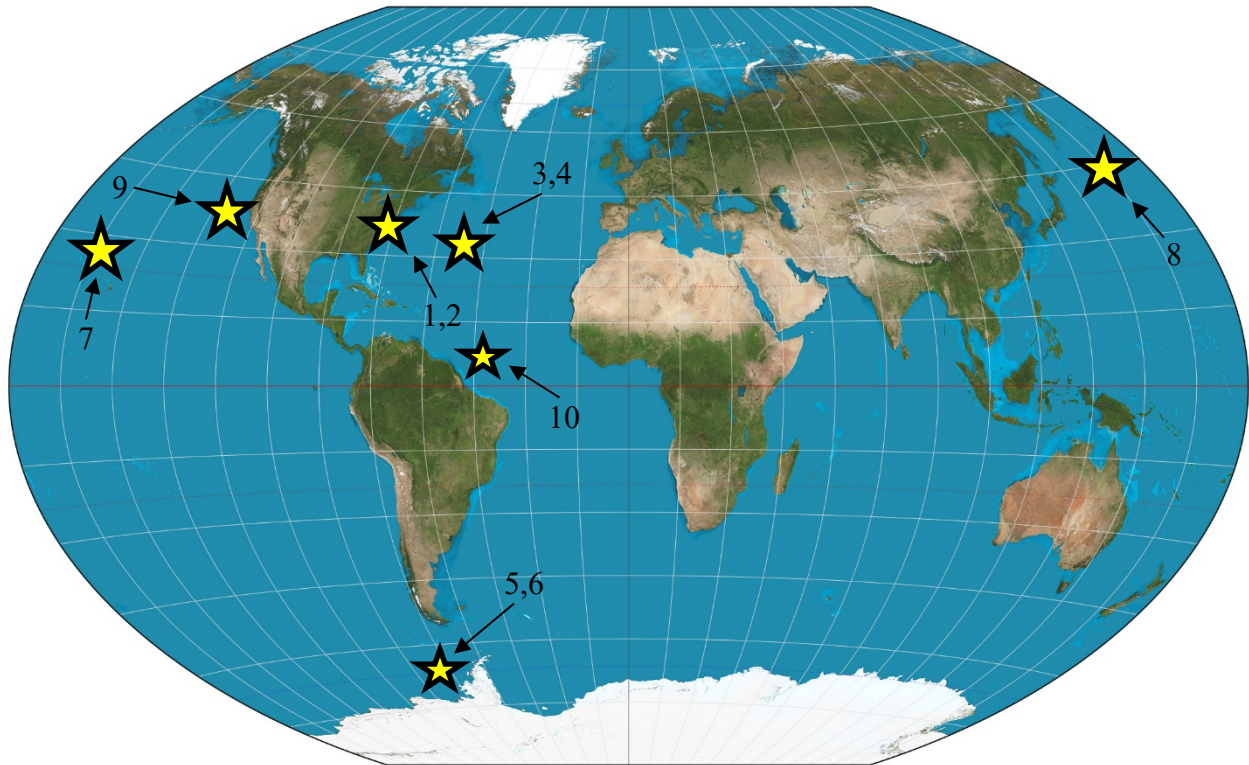
- Comprehensive review of zooplankton fecal pellet sediment trap content information from global studies up to 2015:

Turner, J. T. (2015). Zooplankton fecal pellets, marine snow, phytodetritus and the ocean's biological pump. *Progress in Oceanography*, 130, 205–248. doi: 10.1016/j.pocean.2014.08.005
- Literature used in creating the fecal pellet ratios for the activity:

Gleiber, M. R., Steinberg, D. K., & Ducklow, H. W. (2012). Time series of vertical flux of zooplankton fecal pellets on the continental shelf of the western Antarctic Peninsula. *Marine Ecology Progress Series*, 471, 23–36. doi: 10.3354/meps10021
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Appendix 1: Map of Sediment Trap Locations

Sediment Trap Locations



Site Location Information:

- | | |
|-----------------------------------|-----------------------------|
| 1. Chesapeake Bay – winter | 6. Antarctica – winter |
| 2. Chesapeake Bay – summer | 7. Hawaii |
| 3. Sargasso Sea (“BATS”) – spring | 8. Sub-arctic North Pacific |
| 4. Sargasso Sea (“BATS”) – summer | 9. California Coast |
| 5. Antarctica – summer | 10. Amazon River plume |

Appendix 2: Dichotomous Keys

Fecal Pellet Dichotomous Key

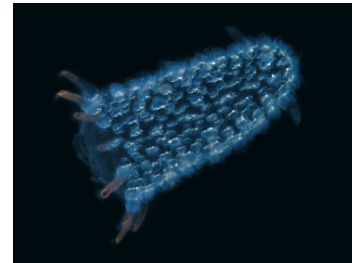
1. Pellet is *cylindrical* (long and skinny) Go to Step 2
 Pellet is not cylindrical Go to Step 3
2. Pellet is more than 3 inches long **Krill**
 Pellet is less than 3 inches long **Small shrimp**
3. Pellet is *tabular* (flat and square) Go to Step 4
 Pellet is not tabular Go to Step 5
4. Pellet is larger than 1 inch long **Large salp/jellyfish**
 Pellet is smaller than 1 inch long **Small salp/jellyfish**
5. Pellet is a flattened circle **Carnivore zooplankton**
 Pellet is not spherical Go to Step 6
6. Pellet is *ellipsoid* Go to Step 7
 Pellet is not ellipsoid Go to Step 8
7. Pellet is about 2 times longer than wide **Small copepod**
 Pellet is more than 2 times longer than wide **Large copepod**
8. Pellet is *ovoid* (egg-like) **Pteropod**



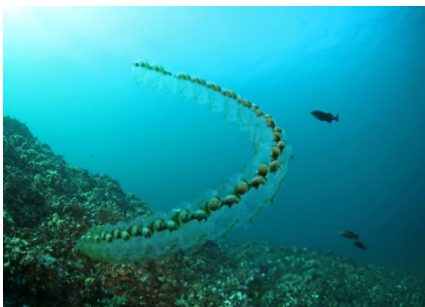
Antarctic krill, *Wikimedia commons*



Mysis shrimp, *Wikimedia commons*



Small salp, *Wikimedia commons*



Colony of large salps, *Flickr Oregon Dept. of Fish & Wildlife*



Pteropod, *Wikipedia*



Copepod, *Wikimedia commons*

Appendix 3: Student Worksheet

The following pages should be printed in advance and distributed to each student group in the class prior to them starting the activity. At the end of the class period, have students turn in their worksheets with all group members' names listed in order to cut down on need for copies and materials.

This file can also be downloaded as a Word document from the web so that it may be edited to fit your needs: <https://tinyurl.com/ZoopSoupWorksheet>

Names _____

Date _____

Zoop Soup (and Poop!): Student Worksheet

FIRST STEP: MAKE OBSERVATIONS

1. Empty your bag of zooplankton “fecal pellets” onto the desk.
2. Sort your fecal pellets by shape.
3. Think about the photo that you were shown of different fecal pellet shapes and the animals that create them. Think about which species may have made the shapes of “pellets” in your bag.

SECOND STEP: MAKE A HYPOTHESIS

4. Propose a **hypothesis** about which site on the **Fecal Pellet Sediment Trap Locations** map you think that your group’s fecal pellets came from.

Where do you think your fecal pellet trap bag came from? _____

Why? What evidence supports your hypothesis?

THIRD STEP: TEST HYPOTHESIS (COLLECT DATA)

5. Use the dichotomous key to find out which animal made each type of pellet and enter that information in the first column of the data table below.
6. Count how many of each type of pellet you have, enter this in the second column of the data table.
7. Place your piles of pellets into separate coffee filters and use the triple beam balance to weigh each type of pellet you had in your sample. Record these weights in the third column of your data table.

Bag Letter: _____

Which Animal Did it Come From?	How Many are There?	Weight
TOTALS:		

FOURTH STEP: ANALYZE YOUR DATA

8. What are some trends that you see in your data?

9. Which animals are the most common in your sample bag?

10. Does the data you collected provide evidence to support your hypothesis of where this sample was taken?

11. After all groups shared evidence from their sample, did discussion with the class change your evidence-based conclusion about where your sample was taken?

FIFTH STEP: SHARE YOUR FINDINGS

12. In science, it is important to share your findings with the rest of the scientific community, so that we can all learn together and build on each other's knowledge over time to discover new things!

13. We will be sharing our information as a group, creating a graph to compare weights of the fecal pellets from each site!

FINAL STEP: DRAW CONCLUSIONS

14. Which sites around the world are the "hot spots" for carbon export by fecal pellets?

15. Why is this information important to collect?

16. Why is fecal pellet carbon export important...
 - a. For animals?

 - b. For the planet?

Carbon Cycling Graph



Site Location

Total Weight of Pellets

Appendix 4: Answer Sheets

ANSWER KEY:

- BAG A

Contents (Candy Version):

- 6 large copepods (~11 grams)
- 17 krill (~28 grams)
- 3 large salps (~21 grams)
- TOTAL WEIGHT: ~60 grams

Contents (Non-Candy Version):

- 18 large copepods (~11 grams)
- 112 krill (~28 grams)
- 3 large salps (~21 grams)
- TOTAL WEIGHT: ~60 grams

Location: Antarctica in the summer – ice has melted, allowing for plenty of algae for krill to eat and open water for salps

- BAG B

Contents (Candy Version):

- 16 small copepods (~8 grams)
- 3 small salps (~2 grams)
- TOTAL WEIGHT: ~10 grams

Contents (Non-Candy Version):

- 375 small copepods (~8 grams)
- 3 small salps (~2 grams)
- TOTAL WEIGHT: ~10 grams

Location: Sargasso Sea in the summer – not many nutrients in this open ocean zone, phytoplankton bloom in the spring so they take many of the nutrients – the summer provides less food (phytoplankton) for Sargasso Sea plankton than in the spring

- BAG C

Contents (Candy Version):

- 15 large copepods (~28 grams)
- 1 small shrimp (~12 grams)
- TOTAL WEIGHT: ~40 grams

Contents (Non-Candy Version):

- 45 large copepods (~28 grams)
- 100 small shrimps (~12 grams)
- TOTAL WEIGHT: ~40 grams

Location: Subarctic North Pacific – the waters are cold with many nutrients – this allows diatoms (phytoplankton) to bloom, so large copepods have plenty of food

- BAG D

Contents (Candy Version):

- 90 large copepods (~165 grams)
- 12 pteropods (~13 grams)
- 10 large salps (~72 grams)
- TOTAL WEIGHT: ~250 grams

Contents (Non-Candy Version):

- 275 large copepods (~165 grams)
- 65 pteropods (~13 grams)
- 10 large salps (~72 grams)
- TOTAL WEIGHT: ~250 grams

Location: California coast – in this zone, there is an area of upwelling where nutrients are brought to the surface – this allows for lots of phytoplankton to grow, and makes lots of food for zooplankton

- BAG E

Contents (Candy Version):

- 2 small copepods (~1 gram)
- 1 pteropods (~1 gram)
- 5 small salps (~3 grams)
- TOTAL WEIGHT: ~5 grams

Contents (Non-Candy Version):

- 47 small copepods (~1 gram)
- 6 pteropods (~1 gram)
- 5 small salps (~3 grams)
- TOTAL WEIGHT: ~5 grams

Location: Antarctica in the winter – at this point, much of the water is frozen in ice – so salps don’t get as large because there is less water available for them to float in, and krill don’t have food yet

- BAG F

Contents (Candy Version):

- 9 large copepods (~16 grams)
- 10 small copepods (~5 grams)
- 4 salps (~29 grams)
- TOTAL WEIGHT: ~50 grams

Contents (Non-Candy Version):

- 28 large copepods (~16 grams)
- 230 small copepods (~5 grams)
- 4 salps (~29 grams)
- TOTAL WEIGHT: ~50 grams

Location: Sargasso Sea in the spring – this is the time when the phytoplankton bloom – whatever grows is quickly eaten by zooplankton because this region does not have lots of food available – salps are common in this area when phytoplankton bloom

- BAG G

Contents (Candy Version):

- 10 small copepods (~5 grams)
- 2 large jellyfish (~15 grams)
- TOTAL WEIGHT: ~20 grams

Contents (Non-Candy Version):

- 250 small copepods (~5 grams)
- 2 large jellyfish (~15 grams)
- TOTAL WEIGHT: ~20 grams

Location: Chesapeake Bay in the winter – at this time of year, there isn’t too much food – the zooplankton are mostly small copepods and some large cold-water jellies (lion’s mane jellyfish)

- Bag H

Contents (Candy Version):

- 2 carnivore zooplankton (~3 grams)
- 20 small copepods (~10 grams)
- 10 small shrimps (~7 grams)
- TOTAL WEIGHT: ~20 grams

Contents (Non-Candy Version):

- 27 carnivore zooplankton (~3 grams)
- 500 small copepods (~10 grams)
- 55 small shrimps (~7 grams)
- TOTAL WEIGHT: ~20 grams

Location: Hawaii – in this area, the water temperatures stay more constant than other areas which allows carnivores and shrimp to grow

- Bag I

Contents (Candy Version):

- 16 carnivore zooplankton (~15 grams)
 - 80 small copepods (~40 grams)
 - 40 small jellyfish (~25 grams)
- TOTAL WEIGHT: ~80 grams

Contents (Non-Candy Version):

- 120 carnivore zooplankton (~15 grams)
 - 1,850 small copepods (~40 grams)
 - 40 small jellyfish (~25 grams)
- TOTAL WEIGHT: ~80 grams

Location: Chesapeake Bay in summer – at this time of year, there is a bloom of phytoplankton which allows for lots of food for zooplankton – the warm waters allow copepods and small jellyfishes to bloom

- Bag J

Contents (Candy Version):

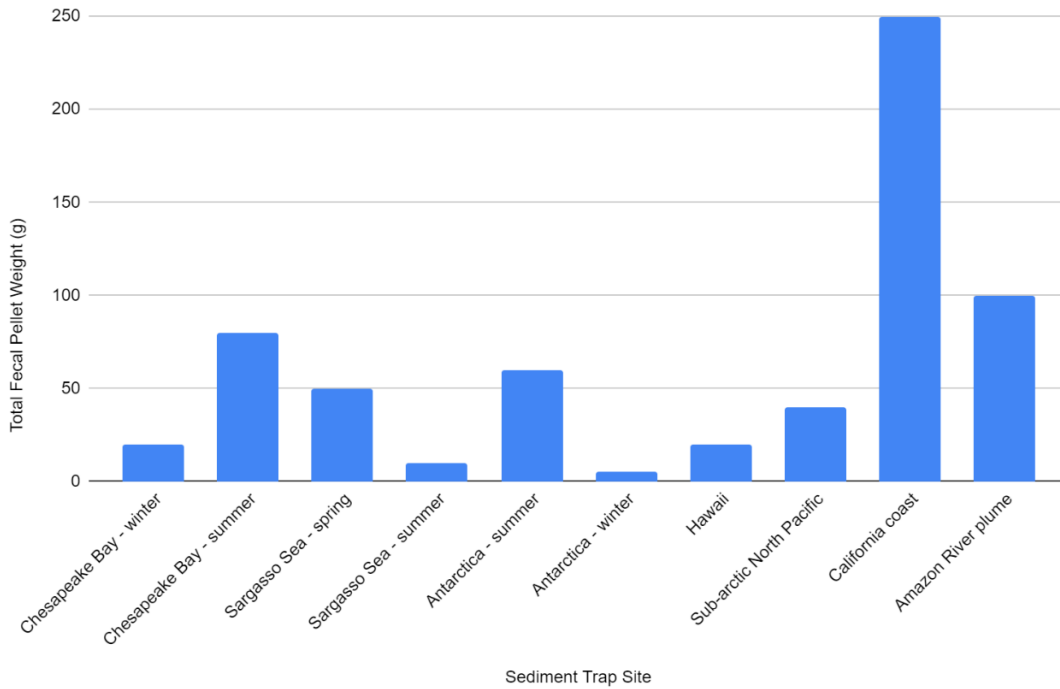
- 10 large copepods (~18 grams)
 - 10 carnivore zooplankton (~9 grams)
 - 60 small copepods (~30 grams)
 - 15 small shrimps (~10 grams)
 - 50 small salps (~31 grams)
- TOTAL WEIGHT: ~100 grams

Contents (Non-Candy Version):

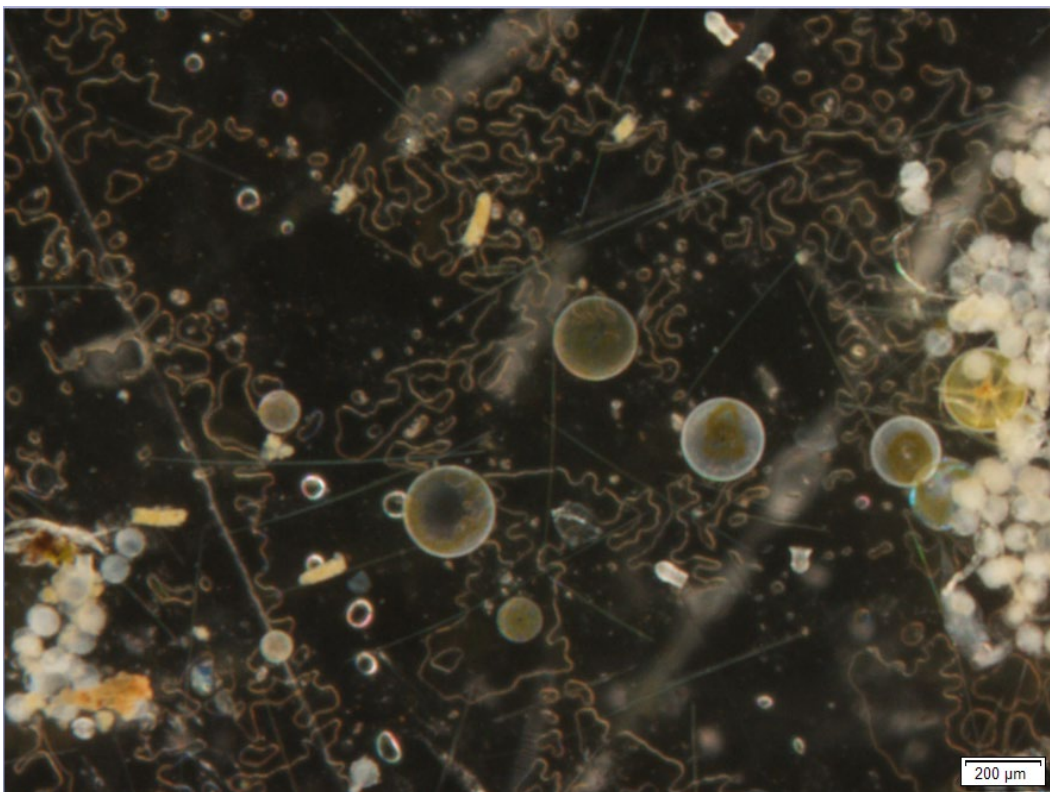
- 30 large copepods (~18 grams)
 - 75 carnivore zooplankton (~9 grams)
 - 1,400 small copepods (~30 grams)
 - 80 small shrimps (~10 grams)
 - 50 small salps (~31 grams)
- TOTAL WEIGHT: ~100 grams

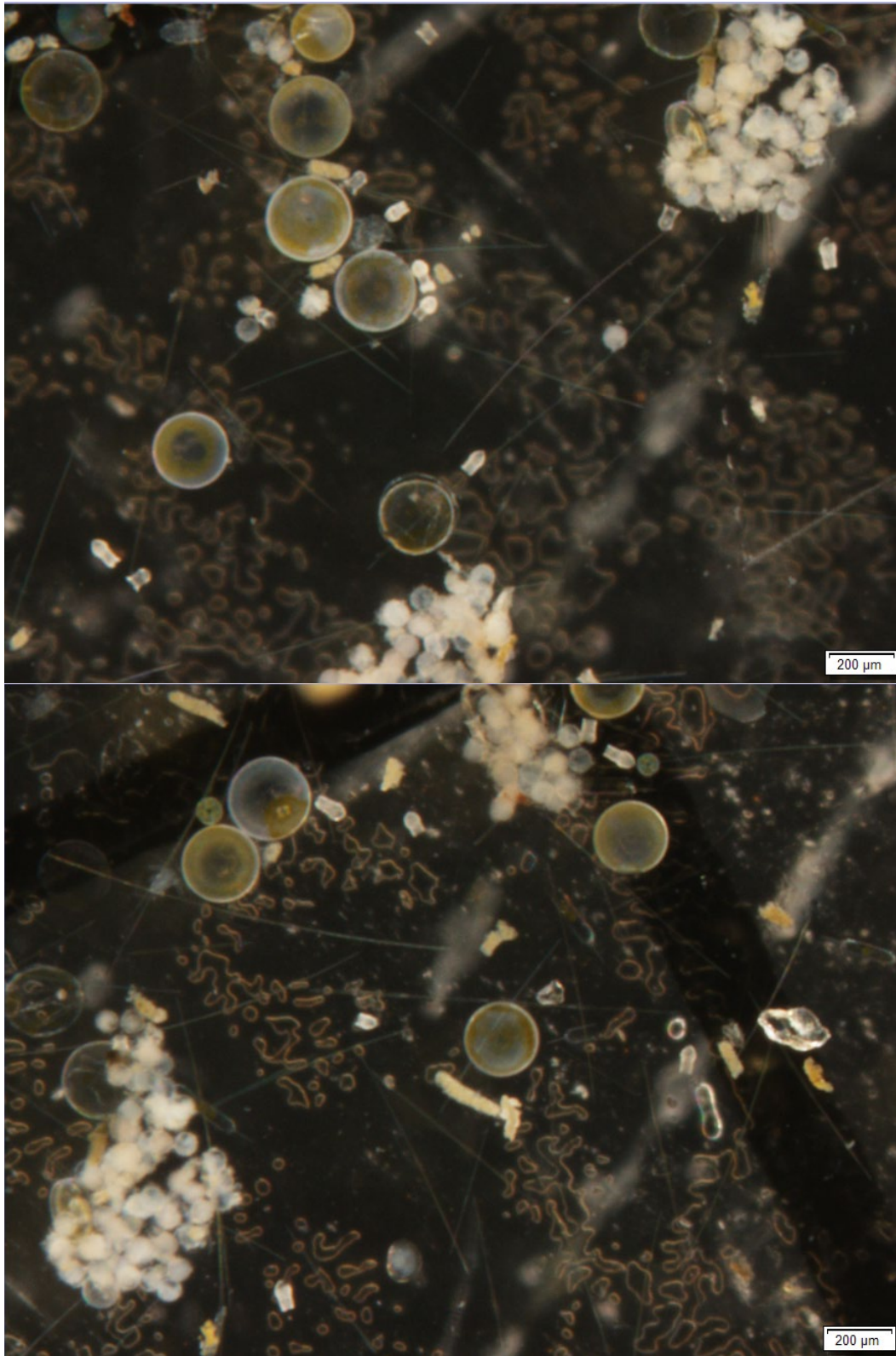
Location: Amazon River plume – LOTS of nutrients are washed into the ocean from the Amazon river, which allows for lots of photosynthesis and allows many animals to grow in numbers because there is plenty of food available

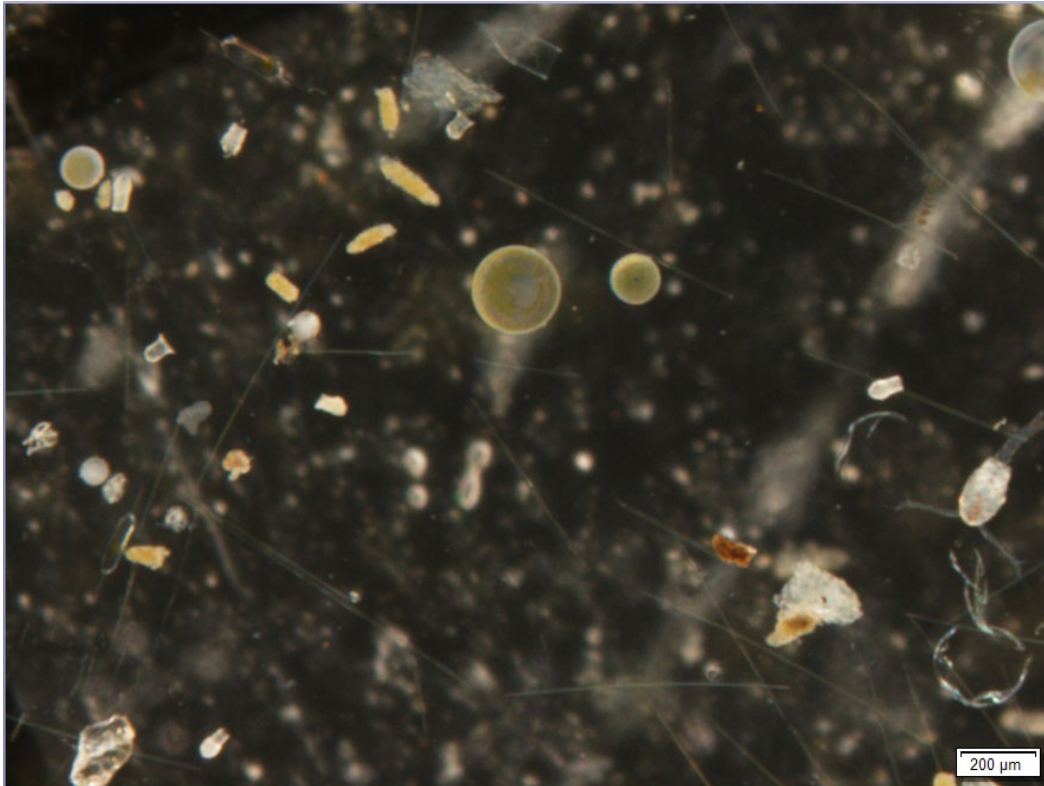
Comparison of Fecal Pellet Total Weight Around the World



Appendix 5: Zooplankton Fecal Pellet Photographs







Appendix 6: Glossary of Listed Vocabulary Terms

Zooplankton: aquatic animals that cannot actively swim against a current

Phytoplankton: aquatic protists that cannot actively swim against a current

Meroplankton: the group of aquatic animals that spend part of their life as zooplankton (typically the larval or juvenile stages of most aquatic invertebrates and fishes)

Holoplankton: the group of aquatic animals that spend their entire life as zooplankton

Diel vertical migration: the daily migration of zooplankton and other organisms from the surface waters (typically during the night) to deeper waters (typically during the day). This strategy is key for many zooplankton: they can avoid being consumed by visual predators; while benefitting from night-time grazing on phytoplankton that have been photosynthesizing during the day

Photosynthesis: the chemical conversion of light energy and carbon dioxide into energy-rich organic molecules (glucose) and oxygen

Food web: a system of interdependent food chains, mapping consumption throughout an ecosystem

Fecal pellet: a dense compaction of consumed organic material that is not digested but rather egested (pooped) by an organism (in this case, a zooplankter)

Export: the transport of an object from one place to another (in this case, of carbon from the surface waters to the deep ocean via fecal pellet sinking/transport)

Community: the group of organisms living in a common ecosystem/environment

Nutrients: mineral elements necessary for the growth and maintenance of living things

Carbon sequestration: the process(es) through which carbon dioxide gas is chemically or physically converted and removed from the atmosphere for temporary or permanent storage in another reservoir

Passive sinking: the sinking of fecal pellets to deeper waters based on gravity (pellet density differences affect the rate of sinking)

Active transport: zooplankton-mediated delivery and release of fecal pellets into deep waters

Remineralization: the breakdown or transformation of organic matter back into simple inorganic forms by various organisms (animals, fungi, bacteria, etc.)

Respiration: a process whereby organisms take in oxygen, produce energy through the chemical conversion of organic matter (energy-rich molecules like glucose) yielding chemical energy, and release carbon dioxide.

Fossil fuels: natural fuels (oil, gas, etc.) formed from pressurization of the remains of living organisms in the geological past

Carbon dioxide (CO₂): a colorless and odorless gas which is produced naturally through respiration processes and anthropogenically through burning carbon-rich fossil fuels. It is naturally present in the air (~ 0.03%) and is used by plants and protists in the conversion of sunlight into organic matter via photosynthesis

Gelatinous zooplankton: fragile zooplankton that passively drift in the open water column (i.e. jellyfishes, ctenophores, salps, and chaetognaths)

Marine snow: organic material that drifts throughout the oceanic water column (typically composed of fecal pellets, zooplankton carcasses, dead phytoplankton cells, discarded zooplankton feeding houses and mucus webs)

Biological pump: the suite of biological processes whereby carbon is transported from the surface of the ocean into deeper waters