SCIENCE 3D

BATTLE DEEP: SPERM WHALES

In this packet, sample student answers are provided in red and notes to teachers are in blue.

In the **Science Mission**, students will enhance their math skills as they build a simple model to investigate the predator-prey interaction of sperm whales and giant squid. This model will also explore how population sizes change. Next, students will use the data they saw collected in the **Mission Video** to map where sperm whale prey are found and calculate how many sperm whales can be supported by the prey base. Then, students will explore how sperm whales might respond to changes in their environment and use what they have learned to make predictions and design next steps in the investigation.

Materials needed for Forager Game: Small rewards/tokens

ACTIVITY I: SPERM WHALE VS SQUID – A POSSIBLE EVOLUTIONARY ARMS RACE

Predators and prey are locked in an "evolutionary arms race," in which predators develop behaviors or traits to better catch prey and then prey develop behaviors or traits to better avoid being eaten. Sperm whales have echolocation to help them find squid in the darkness of the deep sea. Besides weapons like their beaks and barbed hooks that swivel, how could a squid escape from a whale? Scientists think that having large eyes may be the answer. Most squids have small eyes relative to the size of their bodies but giant squid have huge eyes. And in the deep sea, those eyes are good for seeing big objects in the dim light from bioluminescence. Let's create a simple model to see if this might work.

Even though the populations in nature are much larger, for this model we'll start with a population of 30 giant squid. These squid could have eyes that are small, medium, large or extra-large.

The following rules will help you fill out the table on the next page.

• To start, let's say the population has ten squid with small eyes, ten with medium eyes, and ten with large eyes. None have extra-large eyes to start.

• In the first part of every generation, before reproduction, squid are hunted by sperm whales.

• Because larger eyes mean squid can escape more easily (by detecting sperm whales sooner), 70% of small-eyed squid are eaten, 50% of medium-eyed squid are eaten, 30% of large-eyed squid are eaten, and 10% of extra-large-eyed squid are eaten.

• When calculating how many squid get eaten, round to the nearest whole number of squid. Always round 0.5 up. Meaning if the chances of being eaten are 50% or greater, and there is one squid left, it is eaten.

• Once predation is completed, squid reproduce. Each squid leaves two offspring.

• In each generation, one squid in each eye category produces offspring that have the next size larger eyes.

• If there is only one individual left to reproduce, it produces one offspring with the same size eyes and one with the next size larger eyes.

• After reproduction, the cycle starts again.

GENERATION I	Small Eyes	Medium Eyes	Large Eyes	X-Large Eyes
Population at Start	10	10	10	0
Number Eaten	7	5	3	0
Number Left After Predation	3	5	7	0
Number After Reproduction	4	10	14	2

My Calculations:

Have students use this space to show their work.

Small eyes
Number eaten: 10 small eyes • 0.7 death rate = 7 dead small eyes
Number left after predation: 10 – 7 = 3 remaining small eyes
Number after reproduction: The 3 remaining small eyes, only produce 2 offspring with small eyes; 2 • 2 = 4 new small squid.

Medium Eyes
Number eaten: 10 medium eyes • 0.5 death rate = 5 dead medium eyes
Number left after predation: 10 – 5 = 5 remaining medium eyes
Number after reproduction: The 5 remaining medium eyes, only produce 4 offspring with medium eyes; 2 • 4 = 8 new medium-eyed squid; plus one small-eyed squid produces medium-eyed offspring = 2 new medium eyed squid for a total of 10.

Large Eyes
Number eaten:10 large eyes • 0.3 death rate = 3 dead large eyes
Number left after predation: 10 – 3 = 7 remaining large eyes
Number after reproduction: The 7 remaining large eyes, only produce 6 offspring with large eyes; 2 • 6 = 12 new large-eyed squid; plus one medium-eyed squid produces large-eyed offspring = 2 new large eyed squid for a total of 14.

There were no squid with extra-large eyes at the beginning of generation 1, but one large-eyed squid produced extra-large eyed offspring (2) so there are 2 extra-large eyed squid to begin in generation 2.

GENERATION 2	Small Eyes	Medium Eyes	Large Eyes	X-Large Eyes
Population at Start	4	10	14	2
Number Eaten	3	5	4	0
Number Left After Predation	1	5	10	2
Number After Reproduction	1	9	20	6

Have students use this space to show their work.

Small Eyes
Number eaten: 4 small eyes • 0.7 death rate = 2.8, round to 3 dead small eyes
Number left after predation: 4 – 3 = 1 remaining small eyes
Number after reproduction: The 1 remaining small eyes, produces 1 offspring with small eyes for a total of 1 new small-eyed squid.

Medium Eyes
Number eaten: 10 medium eyes • 0.5 death rate = 5 dead medium eyes
Number left after predation: 10 – 5 = 5 remaining medium eyes
Number after reproduction: The 5 remaining medium eyes, only 4 produce offspring with medium eyes; 2 • 4 = 8 new medium-eyed squid; plus one small-eyed squid produces 1 medium-eyed offspring for a total of 9.

Large Eyes
Number eaten: 14 large eyes • 0.3 death rate = 4 dead large eyes
Number left after predation: 14 – 4 = 10 remaining large eyes
Number after reproduction: The 10 remaining large eyes, only 9 produce offspring with large eyes; 2 • 9 = 18 new large-eyed squid; plus one medium-eyed squid produces 2 large-eyed offspring for a total of 20.

Extra-large Eyes
Number eaten: 2 extra-large eyes • 0.1 death rate = 0 dead
Number left after predation: 2 – 0 = 2 remaining extra-large eyes
Number after reproduction: These 2 extra-large eyes produce 2 offspring each for 4 extra-large eyed offspring; plus 2 extra-large offspring produced by 1 large-eyed squid. 4 + 2 = 6 extra-large eyed squid left at the end of generation 2.

GENERATION 3	Small Eyes	Medium Eyes	Large Eyes	X-Large Eyes
Population at Start	1	9	20	6
Number Eaten	1	5	6	1
Number Left After Predation	0	4	14	5
Number After Reproduction	0	6	28	12

Have students use this space to show their work.

Small Eyes
Number eaten:1 small eyes • 0.7 death rate = 0.7, round to 1 dead small eyes
Number left after predation:1–1= 0 remaining small eyes
Number after reproduction: 0

Medium Eyes
Number eaten: 9 medium eyes • 0.5 death rate = 4.5, round to 5 dead medium eyes
Number left after predation: 9 – 5 = 4 remaining medium eyes
Number after reproduction: Of the 4 remaining medium eyes, only 3 produce offspring with medium eyes; 2 • 3 = 6 new medium-eyed squid.

Large Eyes
Number eaten: 20 large eyes • 0.3 death rate = 6 dead large eyes
Number left after predation: 20 – 6 = 14 remaining large eyes
Number after reproduction: Of the 14 remaining large eyes, only 13 produce offspring with large eyes; 2 • 13 = 26 new large-eyed squid; plus 1 medium-eyed squid produces 2 large-eyed offspring for a total of 28.

Extra-large Eyes
Number eaten: 6 extra-large-eyed squid • 0.1 death rate = 1 dead
Number left after predation: 6 – 1= 5 remaining extra-large eyes
Number after reproduction: 5 remaining extra-large eyed squid produce 2 offspring each, for a total of 10 extra-large eyed offspring; plus 2 extra-large offspring produced by 1 of the large-eyed squid. There are 10 + 2 = 12 extra-large eyed squid left at the end of generation 3.

GENERATION 4	Small Eyes	Medium Eyes	Large Eyes	X-Large Eyes
Population at Start	0	6	28	12
Number Eaten	0	3	8	1
Number Left After Predation	0	3	20	11
Number After Reproduction	0	4	40	24

Have students use this space to show their work.

Small Eyes
0 remaining

Medium Eyes
Number eaten: 6 medium eyes • 0.5 death rate = 3 dead medium eyes
Number left after predation: 6 – 3 = 3 remaining medium eyes
Number after reproduction: Of the 3 remaining medium eyes, only 2 produce offspring with medium eyes; 2 • 2 = 4 new medium-eyed squid.

Large Eyes
Number eaten: 28 large eyes • 0.3 death rate = 8 dead large eyes
Number left after predation: 28 – 8 = 20 remaining large eyes
Number after reproduction: Of the 20 remaining large eyes, only 19 produce offspring with large eyes; 2 • 19 = 38 new large-eyed squid; plus 1 medium-eyed squid produces 2 large-eyed offspring for a total of 40.

Extra-large Eyes
Number eaten: 12 extra-large-eyed squid • 0.1 death rate = 1 dead
Number left after predation:12 – 1= 11 remaining
Number after reproduction: 11 extra-large eyed squid produce 2 offspring each for 22 extra-large eyed offspring; plus 2 extra-large offspring produced by 1 of the large-eyed squid. There are 22 + 2 = 24 extra-large eyed squid left at the end of generation 4.

GENERATION 5	Small Eyes	Medium Eyes	Large Eyes	X-Large Eyes
Population at Start	0	4	40	24
Number Eaten	0	2	12	2
Number Left After Predation	0	2	28	22
Number After Reproduction	0	2	56	46

Have students use this space to show their work.

Small Eyes
0 remaining

Medium Eyes
Number eaten: 4 medium eyes • 0.5 death rate = 2 dead medium eyes
Number left after predation: 4 – 2 = 2 remaining medium eyes
Number after reproduction: Of the 2 remaining medium eyes, only 1 produces offspring with medium eyes; 1 • 2 = 2 new medium-eyed squid.

Large Eyes
Number eaten: 40 large eyes • 0.3 death rate = 12 dead large eyes
Number left after predation: 40 – 12 = 28 remaining large eyes
Number after reproduction: Of the 28 remaining large eyes, only 27 produce offspring with large eyes; 2 • 27 = 54 new large-eyed squid; plus 1 medium-eyed squid produces 2 large-eyed offspring for a total of 56.

Extra-large Eyes
Number eaten: 24 extra-large-eyed squid • 0.1 death rate = 2 dead
Number left after predation: 24 – 2 = 22 remaining extra-large eyed squid
Number after reproduction: 22 extra-large eyed squid produce 2 offspring each, for a total of 44 extra-large eyed offspring; plus 2 extra-large offspring produced by 1 of the large-eyed squid. There are 44 + 2 = 46 extra-large eyed squid left at the end of generation 5.

Below are some articles on the subject of squid eye size as it relates to sperm whale predation:

https://www.bbc.com/news/science-environment-17365736
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3852725/
https://www.ncbi.nlm.nih.gov/pubmed/24010674

1. How might sperm whales eating giant squid influence the development of squid with larger eyes. Use the data from your model to support your claim.

   Over time, sperm whales eating more squid with smaller eyes led to the loss of squid with small eyes and growth of the population with large eyes.

2. What do you think would happen if you ran the model for more generations?

   Eventually the vast majority of squid would have extra-large eyes.

3. Describe the trend in the overall population size of squid based on the model predictions. What would happen to the squid population if you kept running the model for hundreds of generations?

   The population is increasing. It would increase very quickly.

   Extend the lesson: Ask students to discuss how the different parameters affect the model. You could have different groups of students do the exercise again, changing the proportion of squid eaten, the number of offspring squid have, or other parameters.

ACTIVITY 2: FINDING FOOD...WITH MATH

If you were a sperm whale, where would you look for food? For lots of animals, food is a very important part of their environment. Scientists use math to determine the expected number of animals that should be found in different habitats. Play the Forager game (see below), and then have students answer the questions.

FORAGER GAME

To help students develop hypotheses about where sperm whales should be found, have them play the Forager game. This game will let them use simple math to make quantitative predictions about how many animals should be in each of two habitats. For this game, you will need small rewards for the students (it could be tokens). Start by creating two habitats with the rewards – one with more than the other. Use a total of ten rewards combined between the two habitats to make the math easier. Explain the rules:

1. Students will be chosen to play the game one at a time.
2. When selected, each player must choose one of the two habitats in which to forage.
3. Once players have chosen a habitat, they cannot move.
4. Nobody can get a reward (forage) until the teacher says "FORAGE!"
5. When they hear "FORAGE!" all players in a habitat must split the rewards equally among themselves. No mad scrambles for the rewards (there are lots of modifications to this game to simulate competition or predation, but that is for another time).
6. The goal is to get the most rewards possible.

Let's use an example where you put six rewards in one habitat and four in the other. Since the students don't know how many players you will pick before saying "FORAGE!" the first student will likely pick the habitat with six rewards. The second student should pick the habitat with four rewards because he or she will get more there than splitting the reward in the habitat with six. Sometimes you might want to ask the class (or the student) to explain a particular choice. Keep picking students one at a time until ten students have chosen habitats (or five in small classes). Then tell them to forage.

1. How many rewards did each forager get in the two "habitats"?

The exact number will depend on the dynamics of the game. The calculations are number of rewards divided by number of foragers.

2. Which habitat was better for an individual forager? Use evidence to support your answer.

They were the same; each forager got the same amount of food in the end.

3. Once ten foragers were playing, would it have been beneficial for a forager to switch habitats? Why or why not?

If foragers wanted the most food possible, they would not want to switch habitats. If they switched they would have had less food because they would have needed to split the food in more ways.

4. How did the proportion of foragers relate to the proportion of food in each habitat?

The proportion between foragers and food in each habitat is the same.

Playing the game and answering the questions should have students ready to make hypotheses about where the sperm whales should be based on the prey data from the sonar. Explain that animals looking for food make decisions similar to the decisions they made in choosing a habitat to forage in the game.

Extending the lesson: Play a second round before the students start to develop hypotheses about where the sperm whales should be found. This time, make sure that one habitat has more than twice the number of rewards as the other. For example, put eight in one and two in the other. This time highlight what the second and third players do (chooses the habitat with eight rewards). This shows why some habitats even with food might not have any foragers in them.

ACTIVITY 3: A BIOMASS OF PROBLEMS

Sperm whale numbers in the eastern Caribbean Sea are declining even though they are not hunted. There are several possible reasons they are in trouble. Maybe they are not getting enough food to eat. Many animals, especially top predators, choose habitats where there is the most food for them. The first step is to see where their food (mostly deep-sea squid) is found.

The team used sonar to detect fish and squid at different depths off the west coast of Guadeloupe. They drove along transects, or parallel observational lines, at different distances from shore. They passed over each transect multiple times.

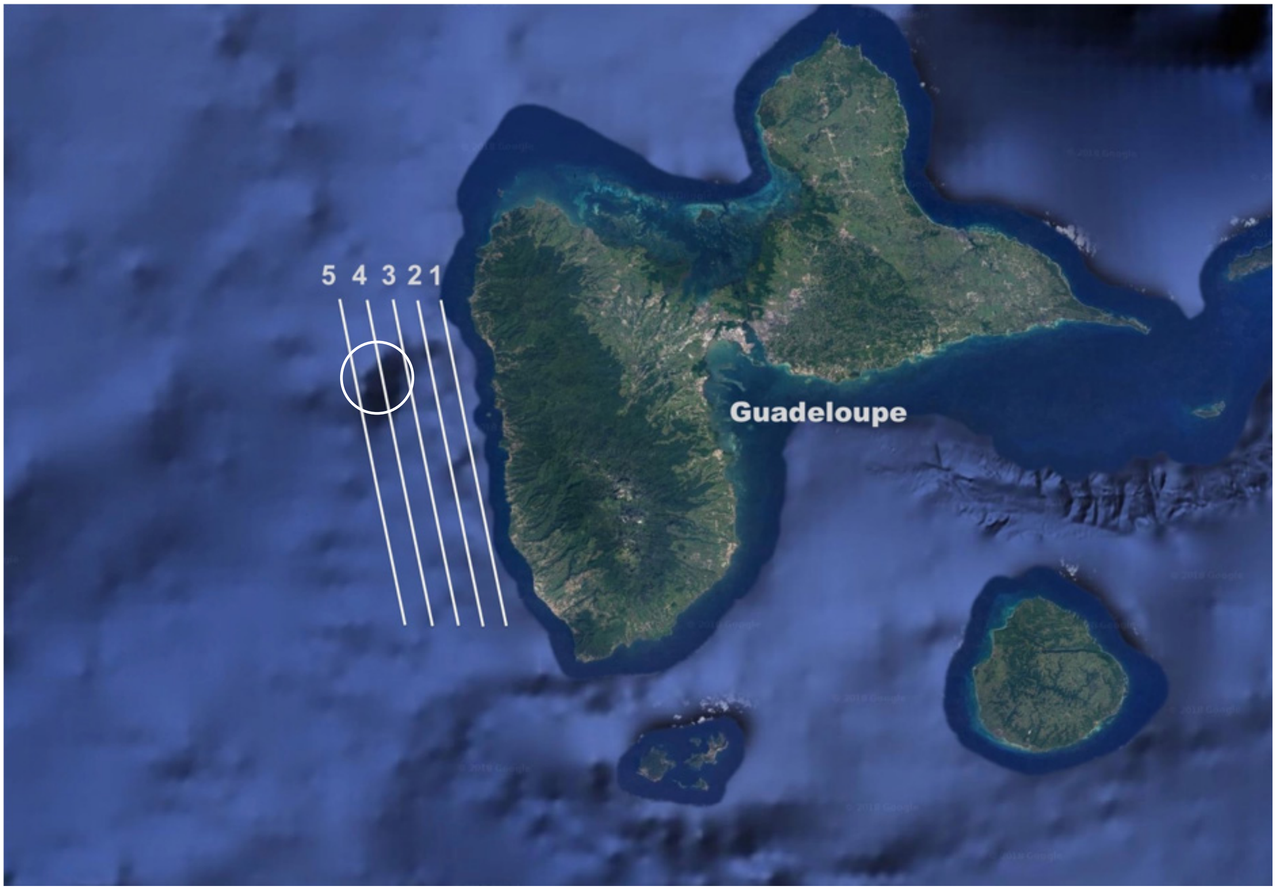


Figure 1. Map of Guadeloupe Island in the Caribbean Sea

The lines show where the team towed the sonar to measure prey. Each of these "transects" is numbered on the map. Each transect is 20 km long and 2 km wide. The transects are right next to each other so the study area is 20 km long and 10 km wide. The team also did more detailed surveys around the seamount that is circled on map under transects 3, 4, and 5.

1. Calculate the average biomass (mass of organisms) per transect in Table 1 below.

Table 1. Average sperm whale prey biomass per square kilometer (tons/transect)

Transect #	1	2	3	4	5
Average Depth	400	700	1,000	1,300	1,600
Prey, Run 1	1	13	31	4	4
Prey, Run 2	0	13	24	6	4
Prey, Run 3	2	17	12	5	2
Prey, Run 4	1	15	21	6	8
Prey, Run 5	1	12	32	9	7
Average	1	14	24	6	5

2. Use the information in the caption of Figure 1 and the data in Table 2 to calculate the total biomass of sperm whale prey in the study area. Describe how you made your calculation and fill in Table 2 below.

Students should be able to calculate Total Prey Biomass by multiplying the average per square kilometer biomass by 40 sq. km per transect.

Table 2. Biomass of prey on each transect

Transect #	Average Biomass per km^2	Total Prey Biomass (tons)
1	1	40
2	14	560
3	24	960
4	6	240
5	5	200
Total Biomass	———	2,000

3. Sperm whales use a lot of energy swimming to great depths, moving from island to island, and keeping their bodies warm. That means that, like other animals, only about 10% of the biomass produced by their prey ends up being converted into mass of sperm whales. Based on this information, and the information in Table 2:

   A) Calculate the total mass of sperm whales that the prey in the area can support. Show how you calculated your answer.

   The area can support 200 tons of sperm whale mass. 2,000 tons • 0.10 = 200 tons.

   B) If the average sperm whale weighs 15 tons, how many sperm whales could be supported by the amount of prey in the study area? Give your answer in whole whales and show your work.

   The number of sperm whales that could be supported by the prey in this area is 13.
   200 tons / 15 tons = 13.33 whales

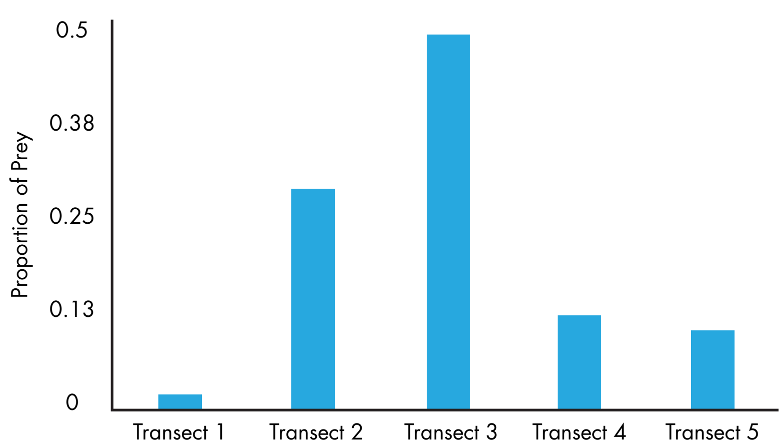
4. Sperm whale are not always found in the waters off Guadeloupe. Based on your answer in 3B, provide a hypothesis to explain this observation.

There isn't enough food to support many whales, so they probably have to search for food all over the place.

5. Make a bar graph that shows the proportion of total prey found in each transect shown in Table 2. Use the space below to do your calculations. Be sure to write a figure caption.

Transect 1 = 40 tons/2000 tons = 0.02
Transect 2 = 560 tons/2000 tons = 0.28
Transect 3 = 960 tons/2000 tons = 0.48
Transect 4 = 240 tons/2000 tons = 0.12
Transect 5 = 200 tons/2000 tons = 0.10

To differentiate instruction, you could provide students with the graph below and ask them to interpret the results.



Proportion of prey biomass in each transect

6. Based on the bar graph you made and the game you played, think about where sperm whales might spend their time. Considering only food source, order the transects from where you would expect to see the most number of sperm whales to the least number of sperm whales.

   3 > 2 > 4 > 5 > 1

7. Imagine if sperm whales behaved according to the rules of the forager game in an attempt to get the most food possible. Predict how many sperm whales would be feeding in each transect if there were 50 sperm whales off the west coast of Guadeloupe. Show your work. Describe why you made these predictions.

Whales should be distributed in proportion to the amount of food in each habitat:
Transect 1: 50 whales • 0.02 = 1 whale
Transect 2: 50 whales • 0.28 = 14 whales
Transect 3: 50 whales • 0.48 = 24 whales
Transect 4: 50 whales • 0.12 = 6 whales
Transect 5: 50 whales • 0.10 = 5 whales

8. How would you test your hypothesis?

I would conduct surveys of whales in different areas and compare the proportion of sperm whales to the proportion of food.

ACTIVITY 4: HOW DEEP SHOULD A WHALE DIVE?

Now that we know how sperm whales move around based on location of their prey, let's explore how deep whales should dive.

1. Why do you think it was important for the team to deploy many different cameras on many different individual whales?

Different individuals may do different things or sometimes a small number of individuals will behave in ways unlike others. If you don't have a large sample size it is hard to determine the average or typical behavior.

Below is a graph that shows the average depth of the most dense patches of potential prey during the day and during the night in transect 3.

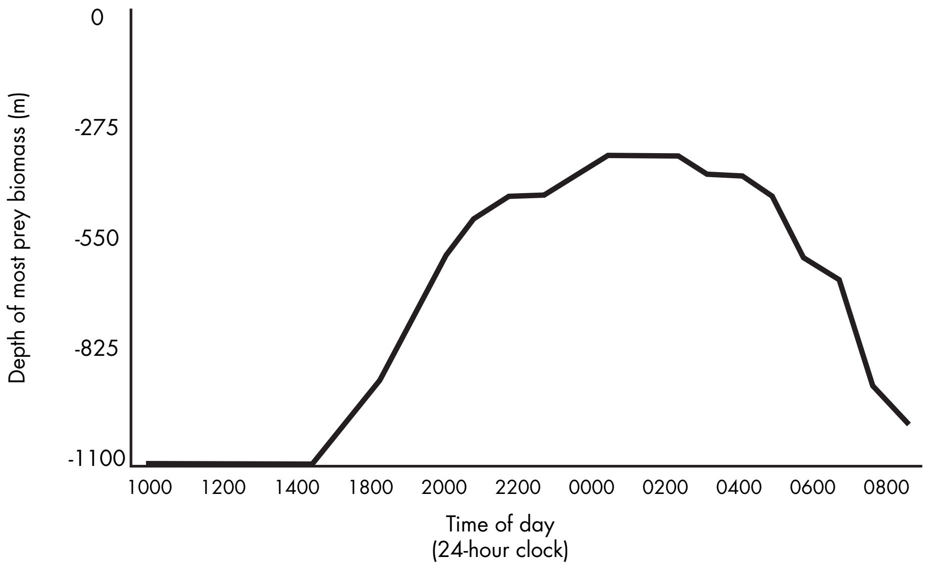


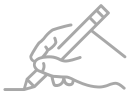
Figure 2. Depths of potential prey from 10:00 am (1000) to 9:00 am (0900) the next day in transects 3 and 4

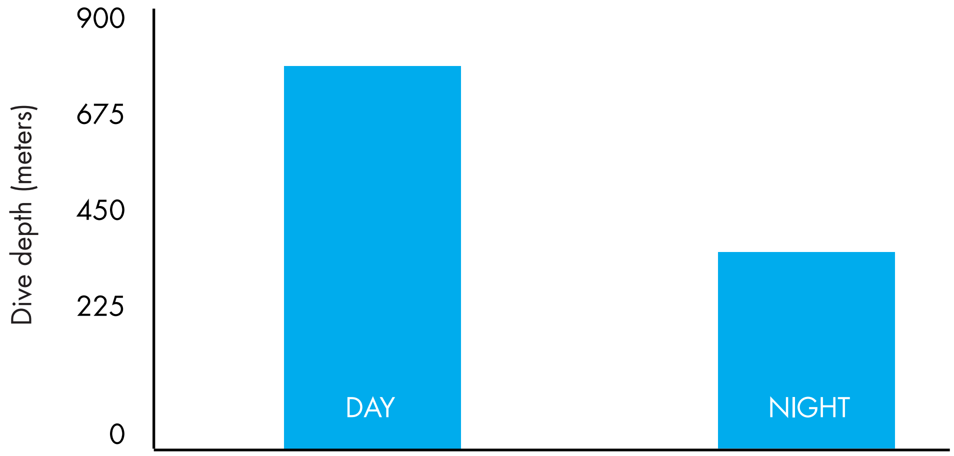
2. Calculate the sperm whales' average number of foraging dives and foraging dive depths during the day and at night in Table 3.

Table 3. Dive data from whalecams for 10 sperm whale (daytime dives were between 0700-1800)

Whale	# Foraging Dives (day)	Daytime Foraging Dive Depth (average)	# Foraging Dives (night)	Nighttime Foraging Dive Depth (average)
1	2	900	8	400
2	2	800	7	400
3	3	1,000	8	450
4	6	1,000	4	400
5	0	0	9	350
6	1	1,100	8	600
7	2	900	7	650
8	1	1,000	9	450
9	2	900	8	500
10	1	500	7	400
Average				

3. **Draw** a bar graph showing the average dive depths during the day and at night.





Dive depths of sperm whales during the day and at night

4. **Describe** how sperm whales behave during the day and at night. Are these patterns similar to those of their prey? Provide evidence from the data to support your idea.

Sperm whales dive very deep during the day – on average to 900 m. At night their dives are shallower. These patterns relate to tracking prey. During the day, both prey and sperm whales are deep (around 900 m). At night, the whales dive deeper than most of the prey. This may be because they are looking for specific prey, not just where there is the most.

Accept all reasonable answers here. For example, if students say the patterns aren't the same because they don't always go to where there is the most food, that is fine as long as they support their statements with data from the tables and figure. Take the opportunity to discuss this question and even consider what other data they would need to answer the question. For example, it could be useful to track giant squid to see where the sperm whale's favorite food goes.

5. Why do you think sperm whales behave this way?

Accept reasonable answers based on what answer they gave in the previous question; generally, sperm whales should be diving to the same depths as their prey.

6. Did all sperm whales behave in the same way? Why was it important to collect samples from more than one whale? Use the table to support your answer.

In general, they did. However, there were some differences. For example, one whale dove shallow during the day and the number of foraging dives varied quite a bit among individuals. That variation makes it important to collect multiple samples. For example, if only Individual 5 was tagged, you would think sperm whales don't dive during the day.

7. What do you think the whales would do if the amount of prey declined off the coast of Guadeloupe? Why?

Answers could include: 1) move to where there is more prey; or 2) make more dives to get enough food. Accept all reasonable answers.

8. How would you test your prediction from question 6?

You might consider this question as a discussion point since students may have trouble coming up with ideas individually, and answers will vary based on ideas they developed in question 6. Any reasonable answer is acceptable, but students might suggest looking at how whales behave in different areas that have different amounts of prey, or to monitor behavior across times with more and less food. Students might also make suggestions about manipulating the amount of prey. Even if this answer isn't practical, it demonstrates appropriate lines of thinking with respect to the scientific method.