16 Ecosystems Out of Balance

INVESTIGATION • 1–2 CLASS SESSIONS

OVERVIEW

In this activity, students interpret population graphs as they investigate four fisheries that are altering surrounding ecosystems. Students advise the fisheries on the consequences of their fishing and how to make their fishery more sustainable.

KEY CONTENT

1. Relationships between species in an ecosystem are interdependent.
2. Changes in the population of a species within an ecosystem affect other species in that ecosystem.
3. Removing a species from an ecosystem can have unintended consequences.
4. Some fisheries have significantly damaged associated ecosystems.
5. Changes in the population dynamics of an ecosystem can be a factor in an invasive species becoming established within that ecosystem.
6. Sustainable management of ecosystem services depends on continual input from scientists and other experts.

KEY PROCESS SKILLS

1. Students graph and analyze data.
2. Students interpret data.
3. Students identify and describe trends in data.
4. Students make accurate interpretations, inferences, and conclusions from text.

MATERIALS AND ADVANCE PREPARATION

For the teacher

transparency 16.1, "Pacific Halibut Population"

transparency 16.2, "Pacific Halibut Food Web"

transparency 16.3, "Pacific-Halibut-dominated Ecosystem Graph"

transparency of Scoring Guide: ANALYZING DATA (AD)

transparency of Scoring Guide: UNDERSTANDING CONCEPTS (UC)

For each student

Student Sheet 16.1, "Cod-dominated Ecosystem Graph"

Student Sheet 16.2, "Tiger-shark-dominated Ecosystem Graph"

Student Sheet 16.3, "Orca-dominated Ecosystem Graph"

Student Sheet 16.4, "Caspian-seal-dominated Ecosystem Graph"

Scoring Guide: ANALYZING DATA (AD) (optional)

Scoring Guide: UNDERSTANDING CONCEPTS (UC) (optional)

**Not supplied in kit*

Masters for Scoring Guides are in Teacher Resources IV: Assessment.

TEACHING SUMMARY

Getting Started

- Review the population graphs for an ecosystem with a sustainable fishery.

Doing the Activity

- Students formulate hypotheses on the impact of fishing on four ecosystems.
- (AD ASSESSMENT) Students analyze how sustainable fishery practices might alter the effects seen in the fisheries' ecosystems.

Follow-up

- (UC ASSESSMENT) (AD ASSESSMENT) The class discusses why sustainable practices are not currently implemented in all fisheries.

BACKGROUND INFORMATION

Scientists have documented many instances of the effect of ecosystem disruption due to species removal. Some ecosystems have a keystone species, which if removed, critically disrupts the balance for the ecosystem. One of the best-known examples of this is the sea otter and the kelp forests. Sea otters were hunted so much in the 18th and 19th centuries that by early in the 20th century they were near extinction. At this point scientists documented that the numbers of sea urchins, once prey for the otters, increased dramatically, consuming kelp forests and leaving rocky barrens devoid of the vast array of species that had resided there previously. This is referred to as a cascade effect, where the removal of one species causes a number of associated species to be affected as a result. The cascade effect is not limited to removal of a species, but can also occur with the introduction of an invasive species or as the result of an ecological disturbance. In the case of the sea otter, when they were no longer hunted, the populations eventually began to recover, and the kelp forests and associated ecosystems slowly returned as well. It should be noted, however, that in most instances the interactions are much more complex.

Initial theories approached the cascade effect as either "top down" (when the apex predator[s] of a food chain was removed) or "bottom up" (when the producers for an ecosystem were removed). As scientific understanding of ecosystem interactions has deepened, it has become clear that ecosystems can compensate to a degree if disrupted, but that too much disruption throws the ecosystem out of balance, causing a cascade effect. This can occur due to the loss of one species, or the reduction of several species.

Fisheries have been found to have a major impact on many ecosystems, although the effects are often not immediately apparent. For example, if an apex predator, such as a shark, were heavily fished, the species it had preyed on would increase due to lack of pressure from predation. As that species increases, its prey will decrease, and so on. In some instances the removal of a species (due to overfishing or other factors) has led to shifts in ecosystems whereby species are consuming less desirable prey. Stellar sea lions off Alaska, for example, have switched from eating herring to eating pollock, which have a lower nutritional value. In other cases overfishing has led to complete ecosystem collapse, such as off the coast of Namibia in Africa where overfishing of most fish in the ecosystem is believed to have led to massive jellyfish blooms due to the cascade effects of overfishing.

It is also important to note that ecosystems are in a constant state of flux. Scientists once believed that a "healthy" ecosystem exhibited only minor fluctuations unless there was some kind of disturbance. They have now found that many populations regularly undergo large fluctuations, and not necessarily in response to major disturbances such as volcanic eruptions or floods.

GETTING STARTED

1 Start by asking students, *What do you think population levels would look like if you graphed them for an ecosystem that had no pressure from fisheries?*

Students' answers should point out that while population levels of the species in the ecosystem might fluctuate a bit, they should remain fairly constant. Then ask students, based on what they have studied, *What do you expect to happen to the graph if an important species within the ecosystem were overfished?*

They should point out that the levels of all populations might change, either going up if they were a prey species, relative to the organism being fished, or down if they were a predator species. Ask the students, *If the fishery were sustainable, would you expect the same results?*

Students should answer that they would not expect to see as much of an impact, if any. If necessary, remind students that a fishery would be considered sustainable if it allows the ecosystem to remain in a relatively stable state.

16 Ecosystems Out of Balance

1 ORGANISMS WITHIN an ecosystem interact at all levels, depending on each other for their survival, either directly for food or shelter, or indirectly through the carbon cycle. As you saw in the previous activity, both native and introduced species have a significant effect on the ecosystem around them. The entire ecosystem is a complex network that can be drastically altered if the population of one (or more) species goes into a decline or a surge. In this activity you will take on the role of a fisheries biologist and determine how to make several fisheries more sustainable.

2 *You are a fisheries biologist who has, in the past, advised the Pacific halibut* (Hippoglossus stenolepis) *fishery, which is known for its successful sustainable practices. The Pacific halibut fishery is carefully monitored, and each year you and other fisheries biologists make a new set of recommendations on where and how many fish can be caught. The limits are adopted by the entire fishery. Several other fisheries have asked for your expert advice. These fisheries would like you to examine population data and other information for the species they fish and the species' ecosystems and, if they are not sustainable, to advise on how to make them more sustainable.*

A fisherman weighs the Pacific halibut he caught.

Challenge

3 ▶ How does information about relationships among organisms help to determine the sustainability of a species and an ecosystem?

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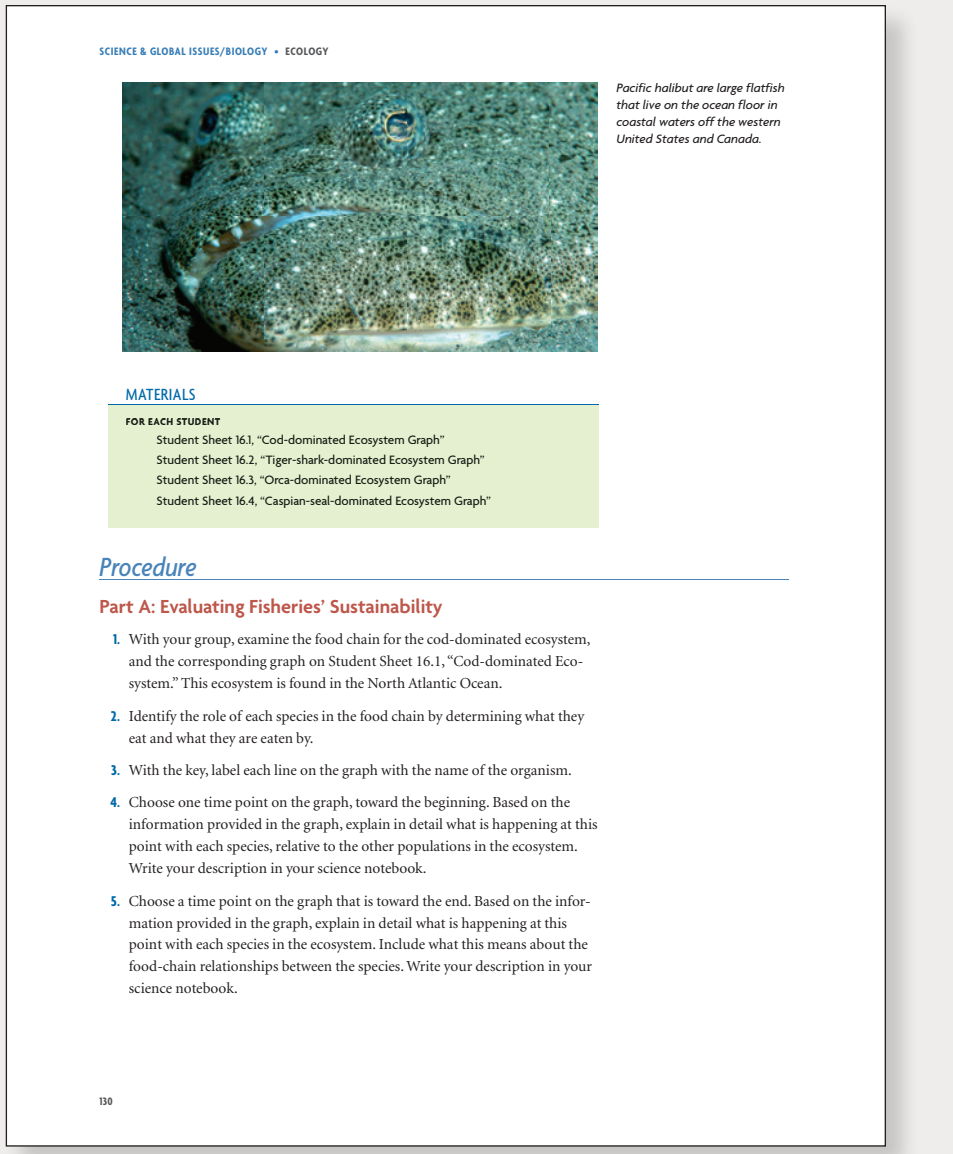
Project Transparency 16.1, "Pacific Halibut Population." Discuss the graph, noting the labels on the axes and what is happening to population levels. Next, project Transparency 16.2, "Pacific Halibut Food Chain." Review the food chain with the students and have them suggest the roles of the organisms in the food chain. Now project Transparency 16.3, "Pacific-halibut-dominated Ecosystem." Have students identify which line correlates with each organism, and what the different axes of the graph show. Ask the students, *Do you think this is a stable, healthy ecosystem? What evidence supports your thinking?*

Students should answer yes because the population levels for all organisms stay fairly steady with slight fluctuations relative to each other. Be sure to clear up any misconceptions about the slight fluctuations in the population levels. Students should understand that population levels will normally not be a flat line, and some fluctuation is normal. Ask the students, *What do you notice about the population levels for the different organisms?*

Students should point out that the brittle stars and Pacific halibut follow the same pattern, and that the sablefish do the opposite. Then review the food chain with the students. Remind them that an upward arrow indicates that the organism above gets energy from (eats) the organism below. Have the students examine the graph at two specific points in time, one from the beginning of the graph and one from the end. Ask the students to describe what the data show at each point. If necessary, model a statement for them. For example: In 1975, the halibut and brittle star populations were about the same, and they were larger than the sablefish's. In 2000, the sablefish population was greater while the halibut and brittle star populations were lower, but still about the same as each other.

2 Ask the students, *Based on the information in the food chain we saw, what do you think is happening within the ecosystem?*

Guide the students, as necessary, to the conclusion that as the Pacific halibut population increases, they consume more sablefish, so the sablefish population decreases. Have the students take a top-down approach, and have them start with the apex predator, in this case the halibut, and work their way down the food chain. (This tactic will make the activity run more smoothly than if they started just anywhere in the chain.) Students should determine that as the sablefish population decreases, the brittle star population increases because fewer of them are being eaten by sablefish. Students should also notice that there comes a point when this relationship changes, likely due to an abundance of brittle stars (prey for sablefish) and relative scarcity of halibut to prey on the sablefish, and the pattern reverses. Over time, the pattern repeats itself, so that overall, all of the populations in the ecosystem remain fairly steady.



SCIENCE & GLOBAL ISSUES/BIOLOGY • ECOLOGY

Pacific halibut are large flatfish that live on the ocean floor in coastal waters off the western United States and Canada.

MATERIALS

FOR EACH STUDENT

Student Sheet 16.1, "Cod-dominated Ecosystem Graph"
Student Sheet 16.2, "Tiger-shark-dominated Ecosystem Graph"
Student Sheet 16.3, "Orca-dominated Ecosystem Graph"
Student Sheet 16.4, "Caspian-seal-dominated Ecosystem Graph"

Procedure

Part A: Evaluating Fisheries' Sustainability

1. With your group, examine the food chain for the cod-dominated ecosystem, and the corresponding graph on Student Sheet 16.1, "Cod-dominated Ecosystem." This ecosystem is found in the North Atlantic Ocean.
2. Identify the role of each species in the food chain by determining what they eat and what they are eaten by.
3. With the key, label each line on the graph with the name of the organism.
4. Choose one time point on the graph, toward the beginning. Based on the information provided in the graph, explain in detail what is happening at this point with each species, relative to the other populations in the ecosystem. Write your description in your science notebook.
5. Choose a time point on the graph that is toward the end. Based on the information provided in the graph, explain in detail what is happening at this point with each species in the ecosystem. Include what this means about the food-chain relationships between the species. Write your description in your science notebook.

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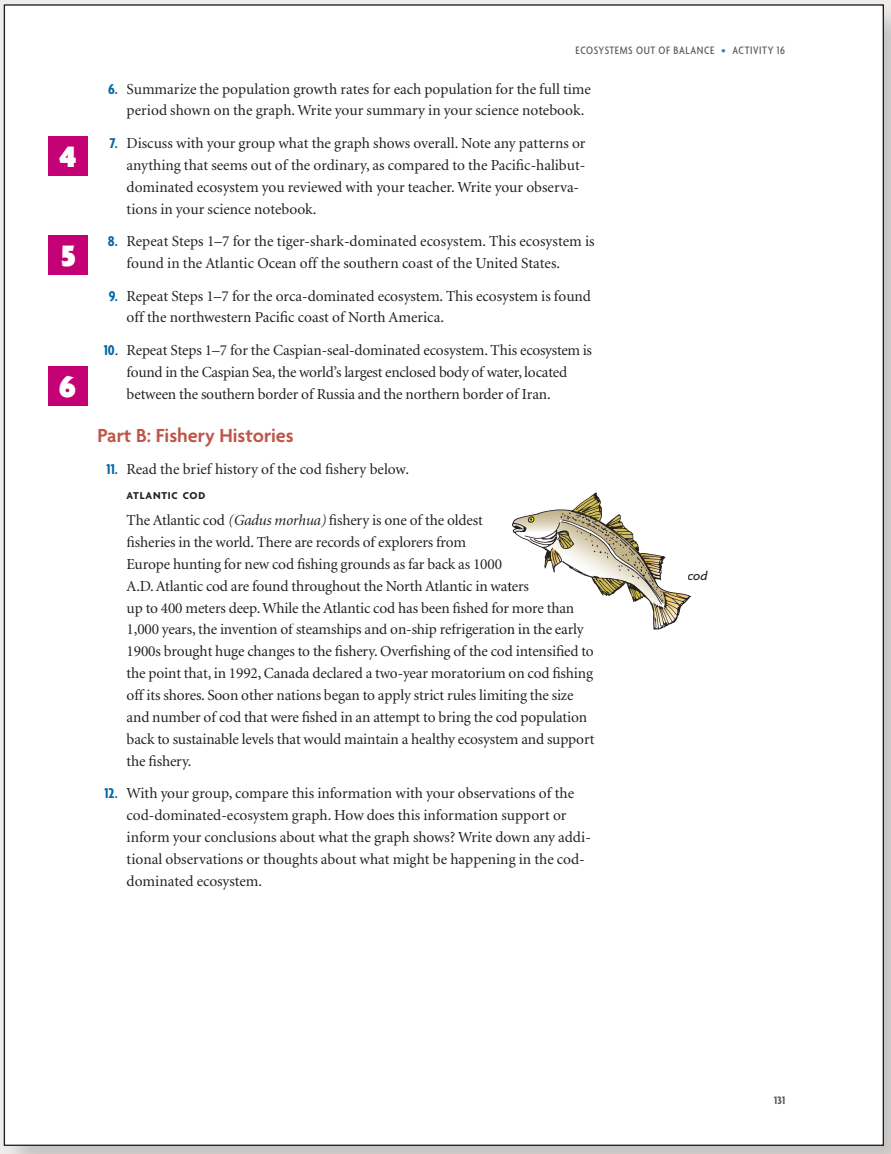
3 After students read the introduction, tell them that Pacific halibut comprise a large, commercial fishery off of the west coasts of the United States and Canada. Ask students, *Based on what you have seen, do you think this is a sustainable fishery? What indicators are you looking at to determine this?*

Students should answer that the fishery is sustainable, which is indicated by the continued relatively steady population levels for both the halibut and the other organisms within its ecosystem. Ask the students, *What would you expect to be different on a population graph for an ecosystem of a fishery that is not sustainable?*

Students should answer that they expect the population levels to change and not follow the same patterns. They should recognize that the population levels would not stay relatively steady.



ECOSYSTEMS OUT OF BALANCE • ACTIVITY 16

6. Summarize the population growth rates for each population for the full time period shown on the graph. Write your summary in your science notebook.

4 7. Discuss with your group what the graph shows overall. Note any patterns or anything that seems out of the ordinary, as compared to the Pacific-halibut-dominated ecosystem you reviewed with your teacher. Write your observations in your science notebook.

5 8. Repeat Steps 1–7 for the tiger-shark-dominated ecosystem. This ecosystem is found in the Atlantic Ocean off the southern coast of the United States.

9. Repeat Steps 1–7 for the orca-dominated ecosystem. This ecosystem is found off the northwestern Pacific coast of North America.

6 10. Repeat Steps 1–7 for the Caspian-seal-dominated ecosystem. This ecosystem is found in the Caspian Sea, the world's largest enclosed body of water, located between the southern border of Russia and the northern border of Iran.

Part B: Fishery Histories

11. Read the brief history of the cod fishery below.

ATLANTIC COD

The Atlantic cod *(Gadus morhua)* fishery is one of the oldest fisheries in the world. There are records of explorers from Europe hunting for new cod fishing grounds as far back as 1000 A.D. Atlantic cod are found throughout the North Atlantic in waters up to 400 meters deep. While the Atlantic cod has been fished for more than 1,000 years, the invention of steamships and on-ship refrigeration in the early 1900s brought huge changes to the fishery. Overfishing of the cod intensified to the point that, in 1992, Canada declared a two-year moratorium on cod fishing off its shores. Soon other nations began to apply strict rules limiting the size and number of cod that were fished in an attempt to bring the cod population back to sustainable levels that would maintain a healthy ecosystem and support the fishery.

12. With your group, compare this information with your observations of the cod-dominated-ecosystem graph. How does this information support or inform your conclusions about what the graph shows? Write down any additional observations or thoughts about what might be happening in the cod-dominated ecosystem.

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DOING THE ACTIVITY

4 (AD ASSESSMENT) Procedure Step 7 is an opportunity for you to use the ANALYZING DATA Scoring Guide to asses students' ability to correctly identify and describe trends and relationships between variables. Sample Level-3 responses for each ecosystem are shown on the next page. Students may need varying levels of support, depending on their comfort level with analyzing graphs, particularly the orca-dominated ecosystem where the relationships are more complex. If students need assistance analyzing the graphs, you may want to suggest that they look first at what is happening with the population that is being fished and work up or down the food chain from there, or that they work their way through the graph asking themselves, "If species X is declining and it eats species Y, what is happening to species Y?" If students question the initial rise in the bay scallop population in the tiger-shark-dominated ecosystem, you might point them to the brief reading, which tells them that there was a bay scallop crash in the early 1960s, before the graph began, but the population began to recover in the early 1970s. Or ask them to speculate on what might be happening with the scallops, and discuss it with them after they have formed their own hypotheses. Depending on your students' abilities to analyze the graphs and food chains, you may opt to have them begin on Part B of the Procedure to help them interpret the graphs. The brief readings on the history of each fishery may help them in drawing their conclusions about the ecosystems.

5 If necessary, review with students that correlation does not necessarily mean causation. Reinforce this concept by reminding them that while fishing may be the cause of the population-level shifts on the graphs, there is no direct evidence of causation. You might want to give them an analogy to further illustrate this. For example, if 75% of students are wearing blue shirts on Friday, someone might infer that the students are wearing blue shirts because the school color is blue and there is a big football game after school. However, the true cause might be that the local pizza place is giving a special discount that day for everyone wearing a blue shirt.

6 Students should eventually reach the following conclusions:

Sample Level-3 Response

Cod-dominated Ecosystem

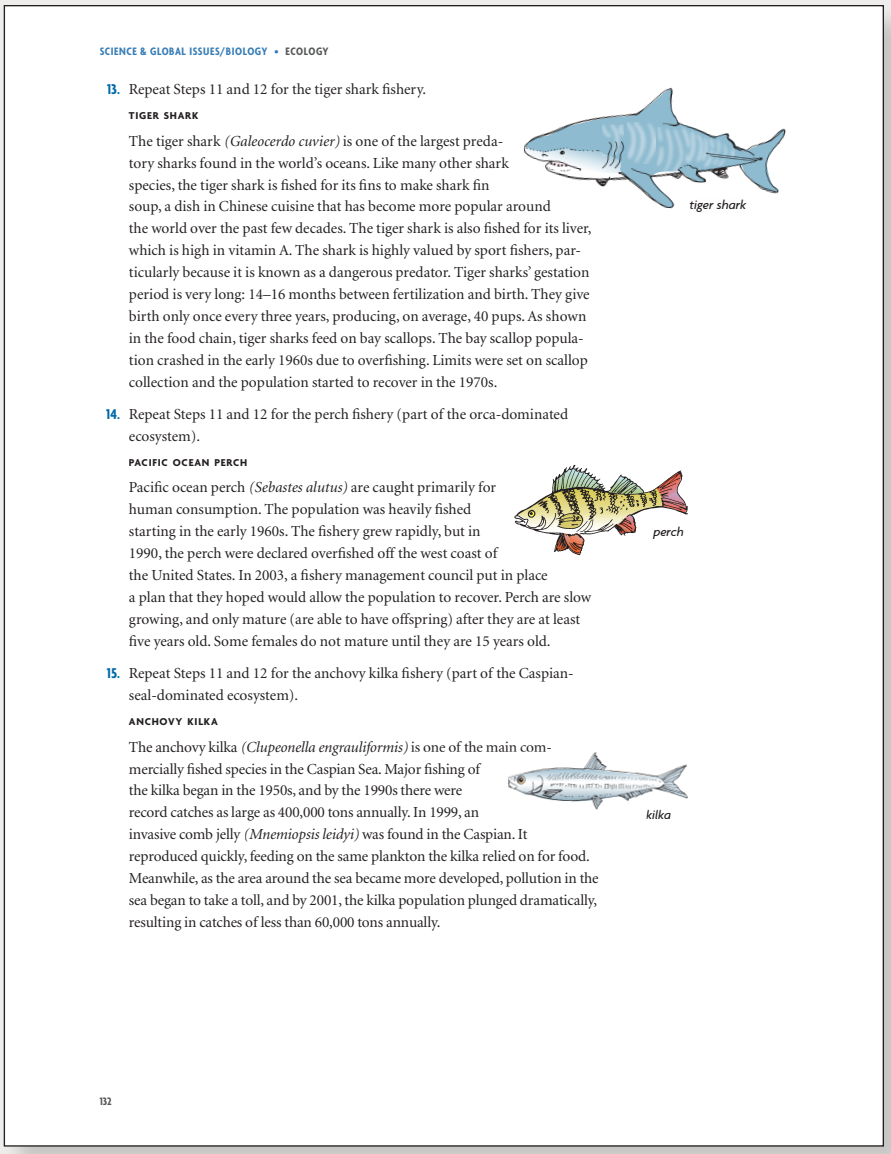
As the cod population decreased, there were more northern snow crabs because they were not being preyed on. As the northern snow crabs increased, they consumed more zooplankton, which in turn meant that fewer phytoplankton were eaten, and so their population increased.

Tiger-shark-dominated Ecosystem

As the tiger shark population decreased, the cownose rays were increasing. The bay scallops, which were increasing, started to decrease as the cownose rays increased and consumed more of them.

Orca-dominated Ecosystem

As the perch population decreased, the sea urchin population increased. This kept the sea otter and algae populations steady for a while, but the orcas did not have as much perch to eat. The orcas began preying on otters, and the otter population dropped, which meant the urchin population continued to rise. Eventually the orcas did not have enough perch or otters, and their population dropped. The algae population stayed steady because, while the perch population dropped, the urchin population rose, which meant that there was the same amount of pressure on the algae, but from different predators.



SCIENCE & GLOBAL ISSUES/BIOLOGY • ECOLOGY

13. Repeat Steps 11 and 12 for the tiger shark fishery.

TIGER SHARK

tiger shark

The tiger shark *(Galeocerdo cuvier)* is one of the largest predatory sharks found in the world's oceans. Like many other shark species, the tiger shark is fished for its fins to make shark fin soup, a dish in Chinese cuisine that has become more popular around the world over the past few decades. The tiger shark is also fished for its liver, which is high in vitamin A. The shark is highly valued by sport fishers, particularly because it is known as a dangerous predator. Tiger sharks' gestation period is very long: 14–16 months between fertilization and birth. They give birth only once every three years, producing, on average, 40 pups. As shown in the food chain, tiger sharks feed on bay scallops. The bay scallop population crashed in the early 1960s due to overfishing. Limits were set on scallop collection and the population started to recover in the 1970s.

14. Repeat Steps 11 and 12 for the perch fishery (part of the orca-dominated ecosystem).

PACIFIC OCEAN PERCH

perch

Pacific ocean perch *(Sebastes alutus)* are caught primarily for human consumption. The population was heavily fished starting in the early 1960s. The fishery grew rapidly, but in 1990, the perch were declared overfished off the west coast of the United States. In 2003, a fishery management council put in place a plan that they hoped would allow the population to recover. Perch are slow growing, and only mature (are able to have offspring) after they are at least five years old. Some females do not mature until they are 15 years old.

15. Repeat Steps 11 and 12 for the anchovy kilka fishery (part of the Caspian-seal-dominated ecosystem).

ANCHOVY KILKA

kilka

The anchovy kilka *(Clupeonella engrauliformis)* is one of the main commercially fished species in the Caspian Sea. Major fishing of the kilka began in the 1950s, and by the 1990s there were record catches as large as 400,000 tons annually. In 1999, an invasive comb jelly *(Mnemiopsis leidyi)* was found in the Caspian. It reproduced quickly, feeding on the same plankton the kilka relied on for food. Meanwhile, as the area around the sea became more developed, pollution in the sea began to take a toll, and by 2001, the kilka population plunged dramatically, resulting in catches of less than 60,000 tons annually.

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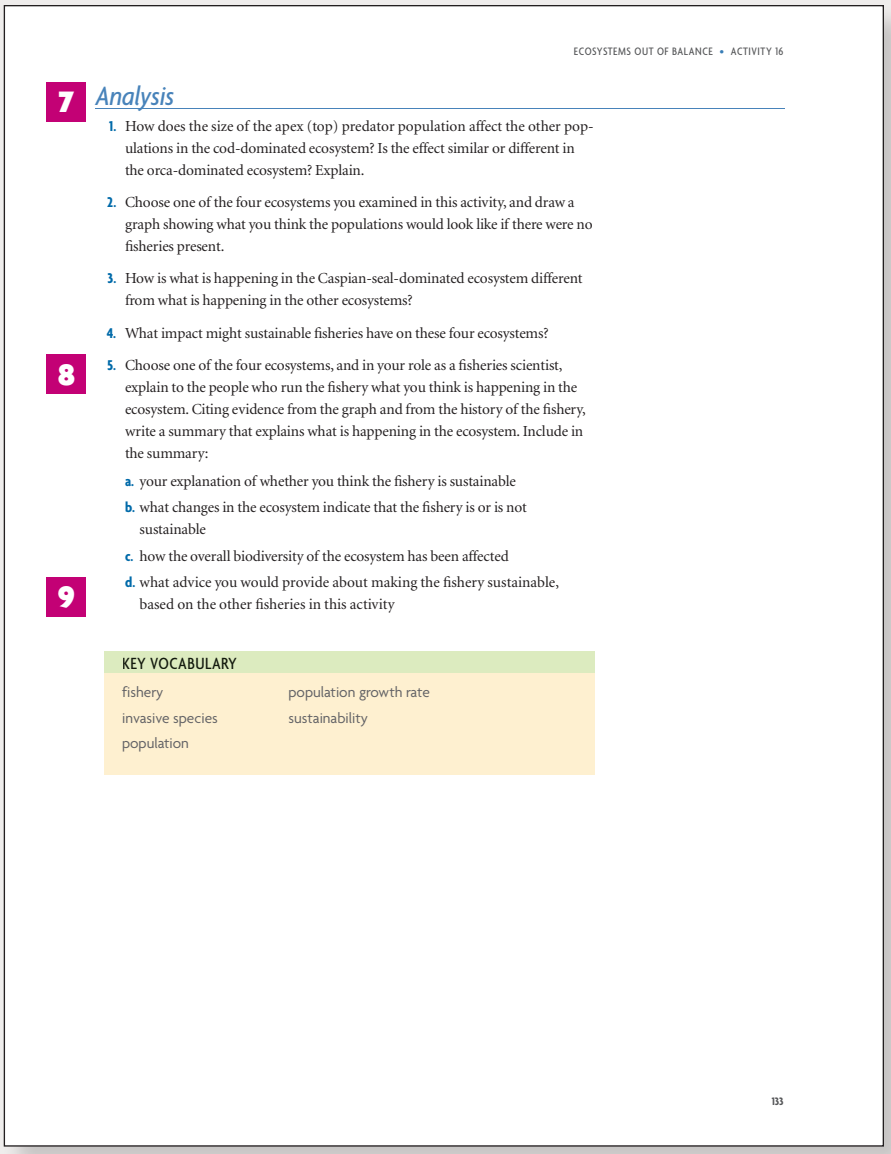
Caspian-seal-dominated Ecosystem

The seal population decreased as the kilka population decreased. In 1999, when these two populations were already far into decline, an invasive comb jelly was found, and it increased extremely rapidly. The zooplankton decreased, and the phytoplankton (not having its natural predators) rose rapidly. The plankton populations have leveled off somewhat, but the comb jelly population is still very high, and the kilka and seal populations are still declining.

7 Ask the students, *What other causes might there be for these population changes besides overfishing?*

Students' answers will vary, but may include disease, natural disaster, or another phenomenon that could harm the population being fished, which would then cause the cascade of effects seen in the graphs. You may want to have them discuss this in their groups and then as a whole class.

8 (AD ASSESSMENT) Parts a and b of Analysis Question 5 are opportunities for an ANALYZING DATA (AD) Assessment. Students will analyze one of the ecosystems they have investigated and explain their analyses to the people running the fishery. Students should use evidence from the graphs to support their analyses.



ECOSYSTEMS OUT OF BALANCE • ACTIVITY 16

7 *Analysis*

1. How does the size of the apex (top) predator population affect the other populations in the cod-dominated ecosystem? Is the effect similar or different in the orca-dominated ecosystem? Explain.
2. Choose one of the four ecosystems you examined in this activity, and draw a graph showing what you think the populations would look like if there were no fisheries present.
3. How is what is happening in the Caspian-seal-dominated ecosystem different from what is happening in the other ecosystems?
4. What impact might sustainable fisheries have on these four ecosystems?

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5. Choose one of the four ecosystems, and in your role as a fisheries scientist, explain to the people who run the fishery what you think is happening in the ecosystem. Citing evidence from the graph and from the history of the fishery, write a summary that explains what is happening in the ecosystem. Include in the summary:
   - a. your explanation of whether you think the fishery is sustainable
   - b. what changes in the ecosystem indicate that the fishery is or is not sustainable
   - c. how the overall biodiversity of the ecosystem has been affected
   - d. what advice you would provide about making the fishery sustainable, based on the other fisheries in this activity

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KEY VOCABULARY

fishery
invasive species
population
population growth rate
sustainability

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FOLLOW-UP

9 Discuss with students the difference in what they saw in the Pacific halibut fishery and the other fisheries. Ask, *Why do you think all fisheries do not follow the practices that the Pacific halibut fishery follows?*

Accept all answers. Then ask the students, *Would it change your answer if I told you that the Pacific halibut fishery operates near shore, and only in the United States and Canada?*

Students may speculate that this is a fairly small area and easier to monitor. They may also suggest that it is easier to work together when they are not working in the open ocean with many different countries. Remind students of the Tragedy of the Commons concept, introduced in Activity 5. They should think about the idea that the more parties involved and the bigger the common, the harder it may be to manage. They should also consider the fact that the more pressures there are on an ecosystem and a fishery, the more challenging it may be to fish the species sustainably. Students will re-examine this concept in the final activity of the unit.

SAMPLE RESPONSES

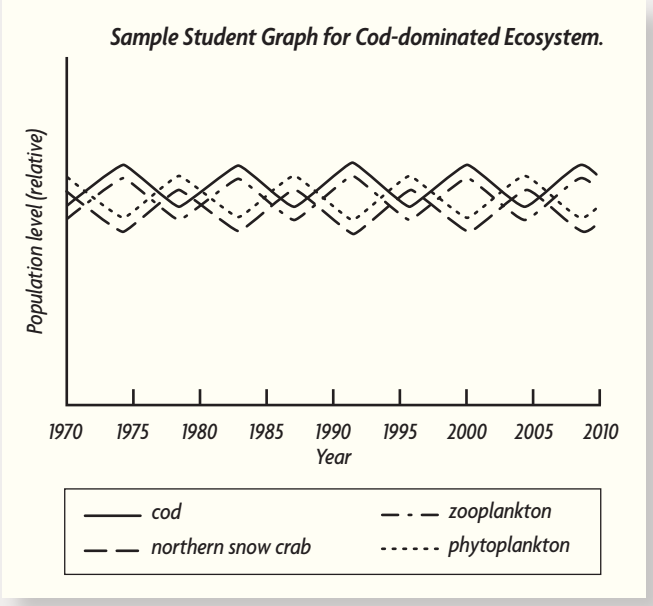
1. (UC ASSESSMENT) Answers will vary. A correct and complete answer would state that if the apex predator population decreases, the population levels of the organisms below it on the food chain or within the food web will change because the ecosystem is no longer balanced. Students should point out that the orca-dominated ecosystem response is more complicated, but ultimately the effect is the same.

   Sample Level-3 Response

   The cod is the apex predator in the cod-dominated ecosystem. Instead of all the populations remaining fairly even, when the cod population decreased, the northern snow crab population increased because it had no predators. That meant that the zooplankton population decreased because it was being eaten by more crabs, which also caused the phytoplankton population to increase because they were no longer being eaten. By fishing out the cod, the fishery put the entire ecosystem out of balance. This is the same in the orca-dominated ecosystem, because eventually all the species in the ecosystem were affected when there were fewer perch. It just took longer because the orcas could eat sea otters or perch, and so they had another food when the perch first declined.

2. Students' graphs should roughly resemble the "Pacific-halibut-dominated Ecosystem Graph" they reviewed earlier. There will be some variety depending on the ecosystem they chose. All population levels should remain steady with minor fluctuations. Students may show in the Caspian-seal-dominated ecosystem that the introduction of the comb jelly still has an impact on the other populations in the ecosystem, particularly by shrinking the plankton population, which would cause a decrease in the anchovy kilka population. Some research indicates that invasive species might not have the same impact if there were no pressure from fishing, but other research indicates that invasive species would still have a strong impact.

   The following graph is a sample response for the cod fishery.



3. In the Caspian-seal-dominated ecosystem there was the added stress of the invasive comb jelly eating all the zooplankton, so the kilka had less food. In the other systems, the only stress that we knew of was fishing.
4. Students' answers will vary but should point out that if fishing is likely what is causing each ecosystem to become unbalanced, more sustainable fishing practices should improve the state of the ecosystems. Students may also note that this would take a long time in fisheries where the organisms are slow to mature and reproduce.

5. (AD ASSESSMENT) Answers will vary. A correct and complete answer would include evidence from the graph and the brief history of the ecosystem being described to explain why the fishery is unsustainable. Students should discuss population levels as indicators that the fishery is unsustainable, and may also include information about the balance in the ecosystem. Students' advice on how to make the fishery more sustainable will vary.

Sample Level-3 Response

a. I do not think the perch fishery is sustainable because the population has decreased dramatically.

b. In the orca-dominated ecosystem you can tell the perch were overfished because the population started a steep decline. When the perch were overfished, the otter population declined. You can see from the graph of the orca-dominated ecosystem that when the perch population started to decline it most likely led to other drastic population changes in the ecosystem.

c. The total number of species has stayed the same, but the population size of each species has changed. If the perch were being fished sustainably, the line would have stayed fairly steady or moved up and down around the same total amount of fish. The otters probably declined after the perch because the orcas needed them as a source of food when the perch became scarce. Since there were fewer otters and perch to eat the urchins, the sea urchin population got much bigger. The history tells us that the perch are starting to recover, and they will have plenty of urchins to eat, but for now several populations are lower than they were before the fishing started.

d. I would suggest that the perch fishery remain closed for several years, because perch take a long time to mature and reproduce. Once the perch levels go back up, it is important to keep the fishing limits low, and to monitor all of the population levels in the ecosystem carefully to make sure the ecosystem recovers and stays stable.

REVISIT THE CHALLENGE

Have a discussion with the class comparing the Pacific halibut fishery with the other fisheries they studied during the activity. Students should be able to explain how changes in one population will affect another population within the ecosystem. Ensure that students are able to articulate how the analysis of the data from each fishery in the activity could inform fisheries-management decision-making.