Trophic Cascades: What Happened When Wolves Were Reintroduced to Yellowstone Park?

Lesson Question

How did the reintroduction of wolves into Yellowstone Park affect the other animals and plants in the ecosystem?

Lesson Tasks

Students analyze data to determine the effect of wolves on Yellowstone's elk population, on the plants that elk graze on, and on the animals that compete with elk for food. They write a report describing how the reintroduction of wolves has created a *trophic cascade*—not just a few direct changes in one food chain, but a series of indirect changes throughout the food web.

Standards

- HS-LS2-2 Ecosystems: Interactions, Energy, and Dynamics

NGSS Science and Engineering Practices

- Constructing Explanations and Designing Solutions
- Engaging in Argument from Evidence
- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments.

NGSS Disciplinary Core Ideas

- LS2.C: Ecosystem Dynamics, Functioning and Resilience
- ETS1.B: Developing Possible Solutions

Crosscutting Concepts

- Stability and Change, Patterns

Connections to Nature of Science

- Scientific knowledge is open to revision in light of new evidence.
- Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.

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OVERVIEW

Content Objectives

Students will understand

→ **Trophic cascades** can occur when a top predator is removed or introduced into a food web; the resulting changes in the relationships among species are not simply linear, but can be web-shaped.

→ **Trophic cascades** can and do have effects on other biotic and abiotic elements of the ecosystem.

→ **A population's abundance** fluctuates depending on its interactions with other species and with the environment.

Skill Objectives

Analytical Thinking

- Assessing evidence in relation to claims
- Generating claims based on data
- Integrating information across sources
- Reasoning with data

Data Communication

- Communicating ideas from data

Data Visualization/Interpretation

- Reading measurements from graphs or tables
- Identifying and describing data patterns

Math/Statistics

- Calculating statistics from a sample
- Evaluating and interpreting relationships between two variables

Instructional Sequence

Share this plan of action with students so they know what to expect from the lesson.

→ **HOOK** We will start by watching a video about what happened when wolves were reintroduced to Yellowstone National Park.

→ **BACKGROUND** Then we'll go over background information you'll need to understand the data you'll look at—about food webs, trophic cascades, and population dynamics.

→ **DATA ORIENTATION** Next you'll practice with tools for manipulating data on Yellowstone populations.

→ **INVESTIGATION** Then, working on your own or in pairs, you'll analyze data on trophic relationships among wolves, elk, aspen, berries, and bears. You'll build and analyze graphs and take notes on the patterns you see.

→ **WRITING** Finally, you'll write a report describing the trophic cascade you found—the way wolves influenced, in turn, elk, aspen, berries and bears. You'll present data to support your description.

Lesson Background for Teachers

This lesson is about the interactions among species within an ecosystem, and how these connections affect the abundance of those species. The lesson has four basic ideas:

- In an ecosystem, the interactions among organisms and the environment are dynamic and complex.
- Within a food web, there are food chains that describe trophic relationships from one organism to the next.
- Ecological relationships determine the population dynamics of the species.
- A trophic cascade can indirectly affect organisms that are not part of a food chain.

In the lesson, students investigate a set of trophic relationships in the Yellowstone food web. First, they trace the dynamic relationships among three species pairs—wolves and elk, elk and aspen, and elk and berry bushes— and construct a food chain consisting of wolves-elk-plants. Encourage students as they work to think about the population dynamics among these species.

Students then examine the cascading effect, beyond a simple food chain, of wolves on other organisms in the ecosystem—in this case, bears. This is where a *trophic cascade* becomes visible: Because elk and bears compete for some of the same plants, students are able to trace how the wolf population indirectly affects bears.

In their final writing, students describe a mini-food web with these organisms (wolf, elk, aspen trees, berry bushes and fruit, and bears), and write about the relationships they found among these species, using graphical data as evidence.

Three final notes: First, it may be helpful to tell students how the data was collected by scientists; this information can be found in "Background 1: Meet the Researchers" and at the beginning of each investigation.

Second, concepts maps in the form of food webs are used extensively in the lesson. One of the most useful roles of concept maps in science education is as a means of assessing student understanding of scientific concepts. We encourage you to use them in this way.

Finally, the video shown in "The Hook" is used to set the context of the study. It was created to educate the public about what happened when apex predators—wolves—were reintroduced to Yellowstone Park, and has had millions of viewers on the Web, along with some criticism that some of its claims are exaggerated or oversimplified. You may wish to point out that the video does not present actual data, and that the lesson gives students a chance to see if some of the claims are in fact true. If students are interested, there is more data available on both the same and different aspects of this trophic cascade, beyond what is included in the lesson..

Student Background Knowledge

Before beginning the lesson, students should know the following

- Food webs show the relationships among organisms in an ecosystem.
- Trophic cascades are caused by the addition or removal of an organism in a food web. They can affect organisms not just at various trophic levels (that is, in a single food chain), but throughout the food web.

The Hook

(Estimated time: 10 minutes)

How Wolves Change Their Ecosystem.

Purpose

- To engage students by showing a video about the effects of the reintroduction of wolves to Yellowstone National Park

Big Ideas

- The reintroduction of wolves to the park had a **wide and positive influence** in the park's ecosystem.

Facilitation Suggestions

- **After the video, ask students to write** their answers to the questions on the Hook screen—"What problem led to wolves being reintroduced to Yellowstone?" and "What is an interesting change that occurred in Yellowstone? How did the reintroduction of wolves lead to this change?" Ask some students to share and compare their responses, and be alert for misconceptions.
- **Tell students that the video summarizes the findings of scientists, but does not include data.** Their task is to examine real scientific data for evidence that some of the events described in the video are backed up by evidence. (The film was made by husband-and-wife filmmakers who say their mission is to "create inspiring video stories that evolve human consciousness by addressing the roots of our many sustainability crises." It has had tens of millions of views on the Web. https://sustainablehuman.org/).

TRANSITION TO BACKGROUND

Inform students that there are important concepts that they need to know in order to understand and interpret the data and results correctly.

Background

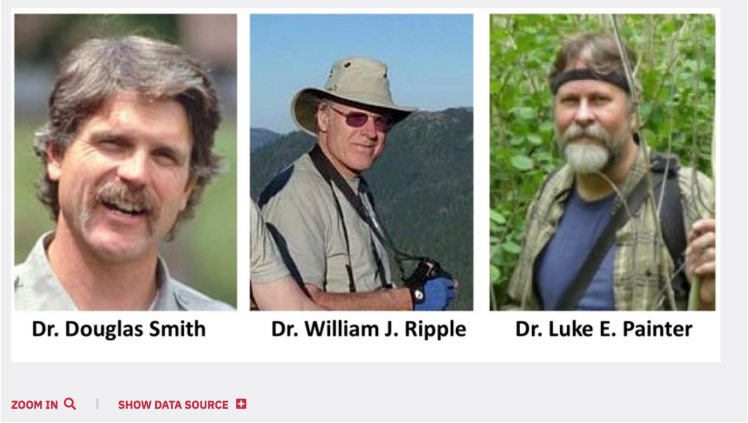
[Estimated time: 35 minutes]

Project the background slides to the class, and have students actively read and discuss the content and questions, so they develop background knowledge needed in the investigation.

Background 1: Meet the Researchers

Purpose

- To make the connection between the data presented and the scientists who produced it.



Big Ideas

- Science is a collaborative endeavor and is based on past findings.

Facilitation Suggestions

- **Introduce** the researchers. This panel is an opportunity to **connect the students with the researchers,** where they work, and what their interests are.
- **Emphasize** that **research is a collaborative effort** by many people and institutions, and is always based on past investigations. The exact methods scientists use to study a phenomenon are different, but if the results are the same—if they are "corroborated"—then it strengthens the evidence that they are seeing something real.
- **Inform** students that they can **find more information** about the researchers by going to the links provided under their pictures, where it says, "show data source."

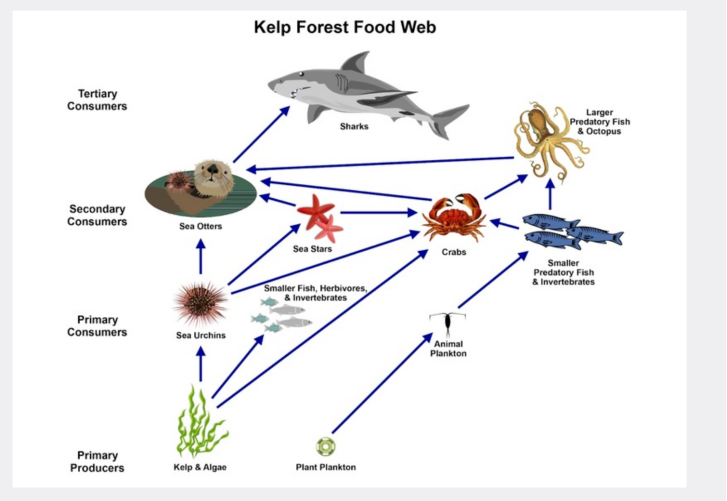
TRANSITION POINT

In order to understand the ecosystem that the investigators study, Yellowstone National Park, we need to find out the general structure and function of ecological networks such as food webs and trophic cascades.

Background 2: Food Webs and Trophic Cascades

Purpose

- To understand that ecosystems are composed of several interacting elements. These relationships can be depicted as a web
- To learn that subtracting or adding an organism to a food web causes ripple effects throughout the food web. This is called a trophic cascade



Big Ideas

- Changes on one element of the food web can have repercussions on other components of the food web.

Facilitation Suggestions

- **Go through the cartoon** of the kelp forest food web slowly, as it is important that students understand the structure and mechanics of a food web. **Point out** the trophic levels and ask students what they think the arrows mean.
- **Make sure** students know the definition of a food web: a depiction of the several interactions among the components of an ecosystem. Remember that the example provided is a cartoon simplification of a kelp forest food web.
- **Review the concept that a food web can have several food chains,** and explain how a food chain describes how one organism eats another and in turn this eats the next, going from a top predator to herbivores to plants. Notice that the arrows depict who feeds whom.
- **Pause for student input,** before students answer the question in step one. Give them time to think, and invite participation. Make sure students explain their answers and encourage them to use words like predation, competition, and trophic.
- **Assist students in understanding step two**. This is crucial, since they are supposed to **define trophic cascades** and make the **connection between trophic cascades and food webs**. It may be challenging to have students verbalize the relationship between trophic cascades and food webs: A trophic cascade can start at any trophic level within the food web and its effects may follow one or more food chains.
- In step three, students explore the **indirect effects of adding or removing a component** of the food web and how this affects specific interactions among the varioius organisms. **Make sure** students become familiar with these concepts, since they will be encountered in the lesson.
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TRANSITION POINT

Let us look more closely at the interactions between two trophic level organisms in a food web. We will examine closely the population dynamics of predation.

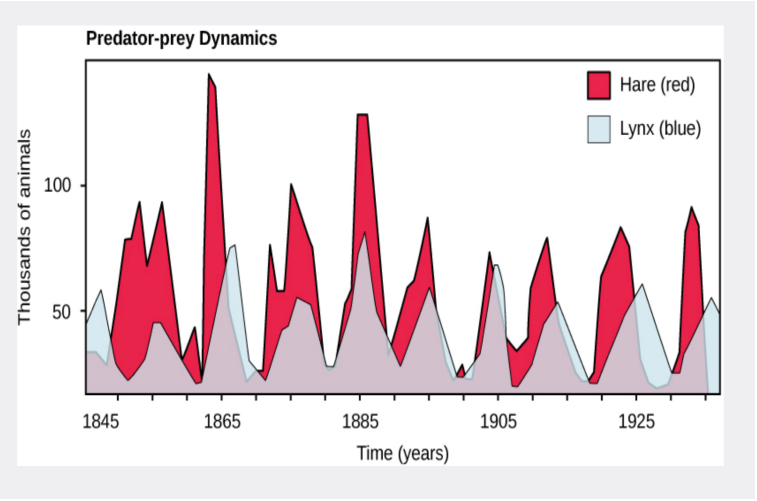
Background 3: Predator-Prey Dynamics

Purpose

- To emphasize the close relationship between the population cycles of two interacting species (predator-prey).

Big Ideas

- The oscillation observed in the abundance of predator and prey species is due to a time delay in their responses to each other's abundance.
- Population dynamics between species is determined by the type of ecological relationship (predation, competition, symbiosis, parasitism, etc.) as well as abiotic elements from the environment (harsh winter, wet spring).



Facilitation Suggestions

- After reading the text, **invite** **students to describe the pattern in the graph**. Encourage them to tell a story over time and to use scientific vocabulary. Ask students: Why are the peaks and valleys of the two populations out of phase?
- **Note** that in nature, these clean-looking cycles are not the norm because there are other issues that may affect the relationship—for example, disease, crowding, competing predators, or food shortage.
- **Point out** that while the diagram shows predator-prey cycles over 80 years, in the lesson **students will look at a much more narrow window,** only one cycle. They will have much less data from which to extrapolate about predator-prey dynamics.
- At this point, students **should be able to define what "predator-prey dynamics" means.** To make sure students are on the right track, you may spot check by asking a few students to share their responses

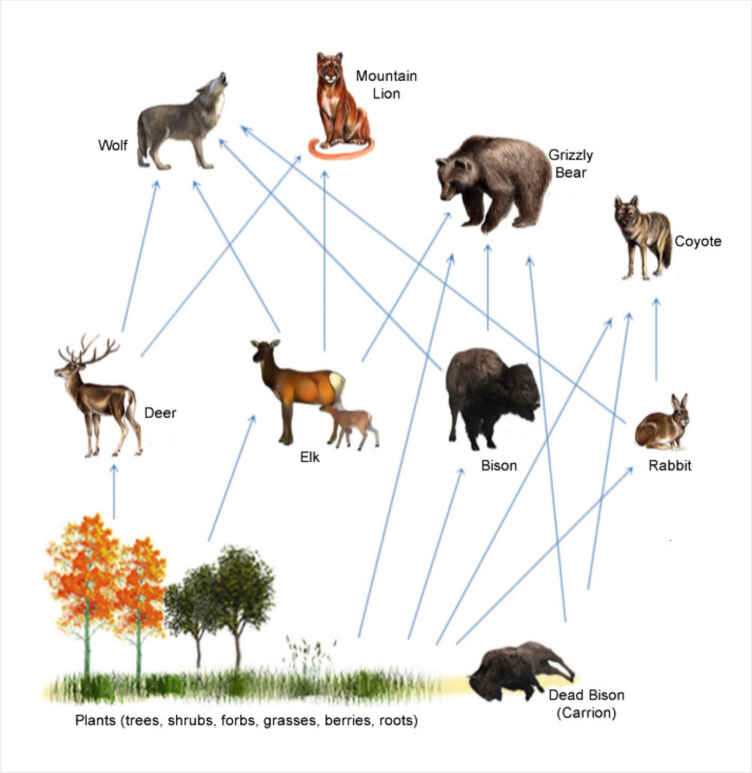
TRANSITION POINT

Before we go on to see the data, we will apply some of the concepts learned so far in the Background sections to the Yellowstone ecosystem.

Background 4: The Role of an Apex Predator in an Ecosystem

Purpose

- To apply the concepts learned by hypothesizing about the structure of a trophic cascade, using the animals in the picture



Big Ideas

- A trophic cascade involving wolves has repercussions on other components of the food web.
- Animals in the same trophic cascade often compete for the same food

Facilitation Suggestions

- This slide previews what students are going to do in the lesson. Remind them what they saw in the video, and ask them to make a hypothesis using the concepts learned in the Background sections.
- **Invite students to read** the text on the left-hand panel and examine the food web in the picture. Read the questions and direct students to **work with a partner** in constructing their hypothesis.
- **Point out the complexity of the food web.** Notice that there is more than one top predator, and that they will compete for the same prey.

TRANSITION POINT

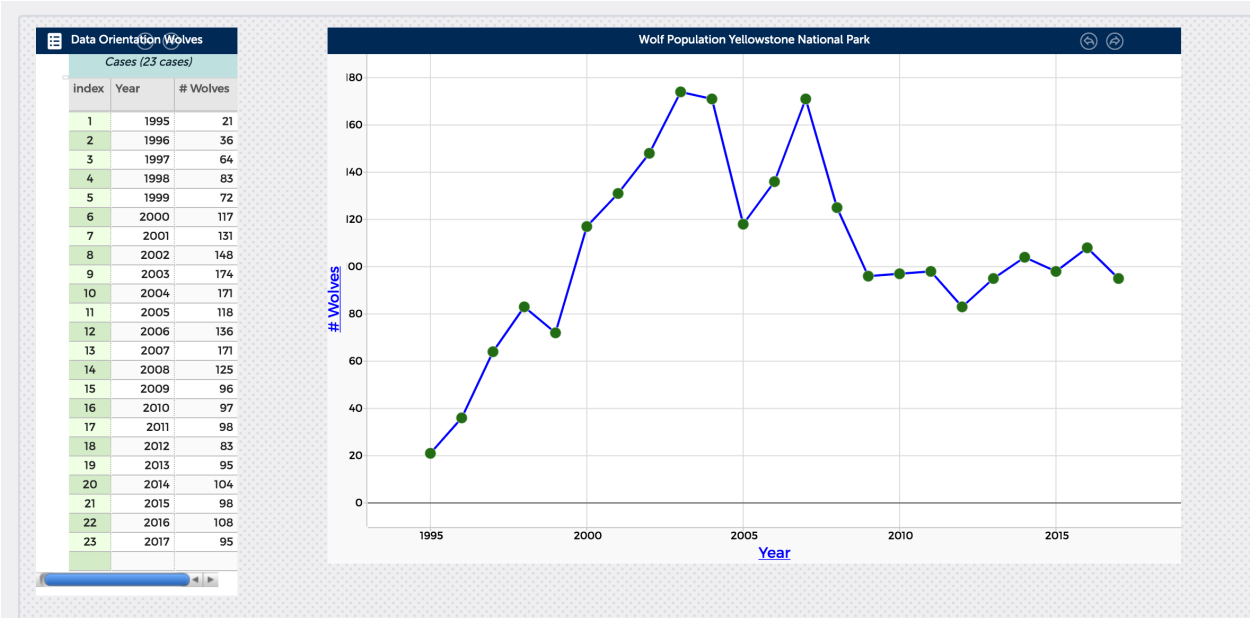
Remind students of the lesson task—to determine the effect of wolves on other Yellowstone organisms and write a report describing how the reintroduction of wolves has created a *trophic cascade*—and inform students that in the next section, the Data Orientation, they will be learning to use the necessary tools to analyze the data collected by the investigators.

DATA ORIENTATION

Estimated Time: 15 minutes

We suggest that you walk through the Data Orientation as a class, projecting your screen and guiding students as they practice manipulating the data. As students complete each exercise, show them how to use CODAP to construct a graph, and point out how the data in the table and the graph are related.

Data Orientation 1: The Table and the Graph



index	Year	# Wolves
1	1995	21
2	1996	36
3	1997	64
4	1998	83
5	1999	72
6	2000	117
7	2001	131
8	2002	148
9	2003	174
10	2004	171
11	2005	118
12	2006	136
13	2007	171
14	2008	125
15	2009	96
16	2010	97
17	2011	98
18	2012	83
19	2013	95
20	2014	104
21	2015	98
22	2016	108
23	2017	95

Purpose

- To familiarize the students with the data in the table and the source of the data
- To have students practice simple data manipulations they'll use in the investigation
- To learn how to use CODAP features and tools

Facilitation Suggestions

- **Go slowly** through the steps in the left-hand panel so that students are able to perform the operations by themselves—for example, dragging attributes from the table to the y-axis and x-axis on the graph.
- **Encourage** students to view the "Show Me" videos that guide them in each operation.
- **Encourage students to explore the connections between the data points represented in the graph and the table.** Click on the data points on the graph to see corresponding data in the table; click on rows in the table to see corresponding data points on the graph. Point out the connections between the table and graph. **Ask students** what each point on the graph means.
- **Inform students that they can go back** to any of the previous sections (Background, Orientation) by clicking on the top green panel. Show students that they can always undo or reset their work by clicking on these icons

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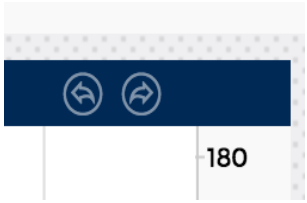
Start Over

Undo

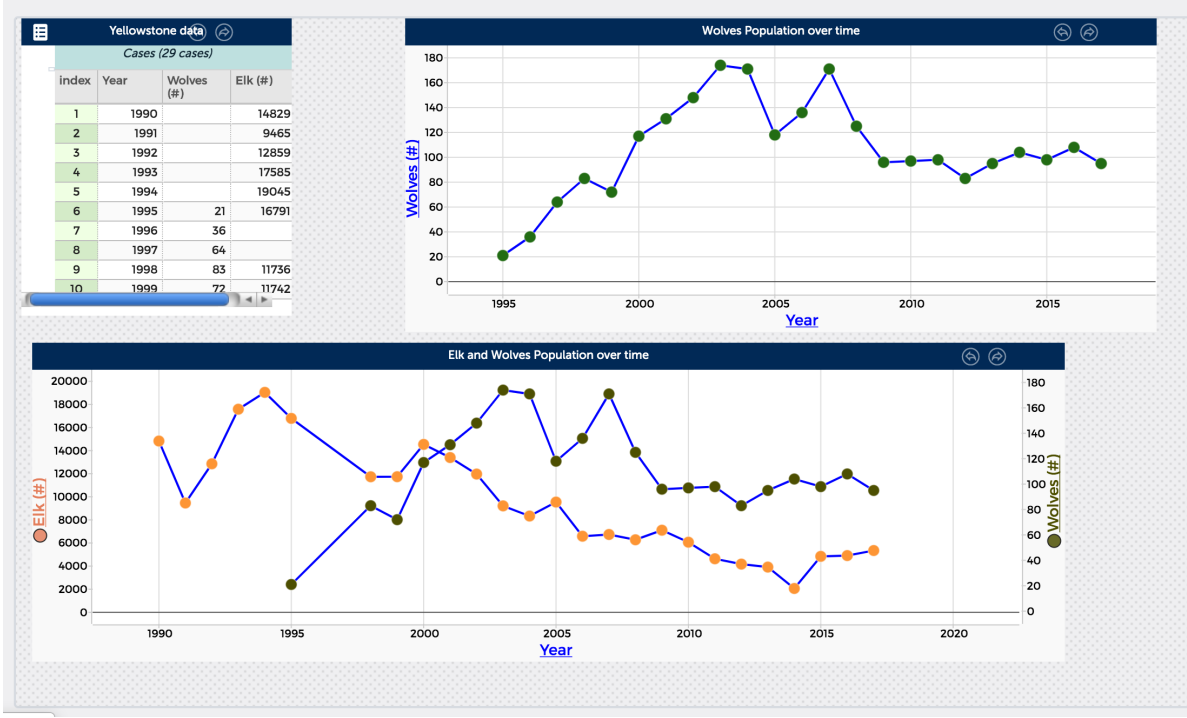


TRANSITION TO INVESTIGATION

Tell students that now that they know how to work with CODAP, they will continue to use these tools to work with the data on their own to answer the question, "*How did the reintroduction of wolves into Yellowstone National Park affect the other animals and plants in the ecosystem?*"

INVESTIGATION 1: Wolves-Elk Trophic Relationship?

Estimated Time: 15 minutes



Purpose

- To investigate the **population dynamics** between wolves and elk

Big Ideas

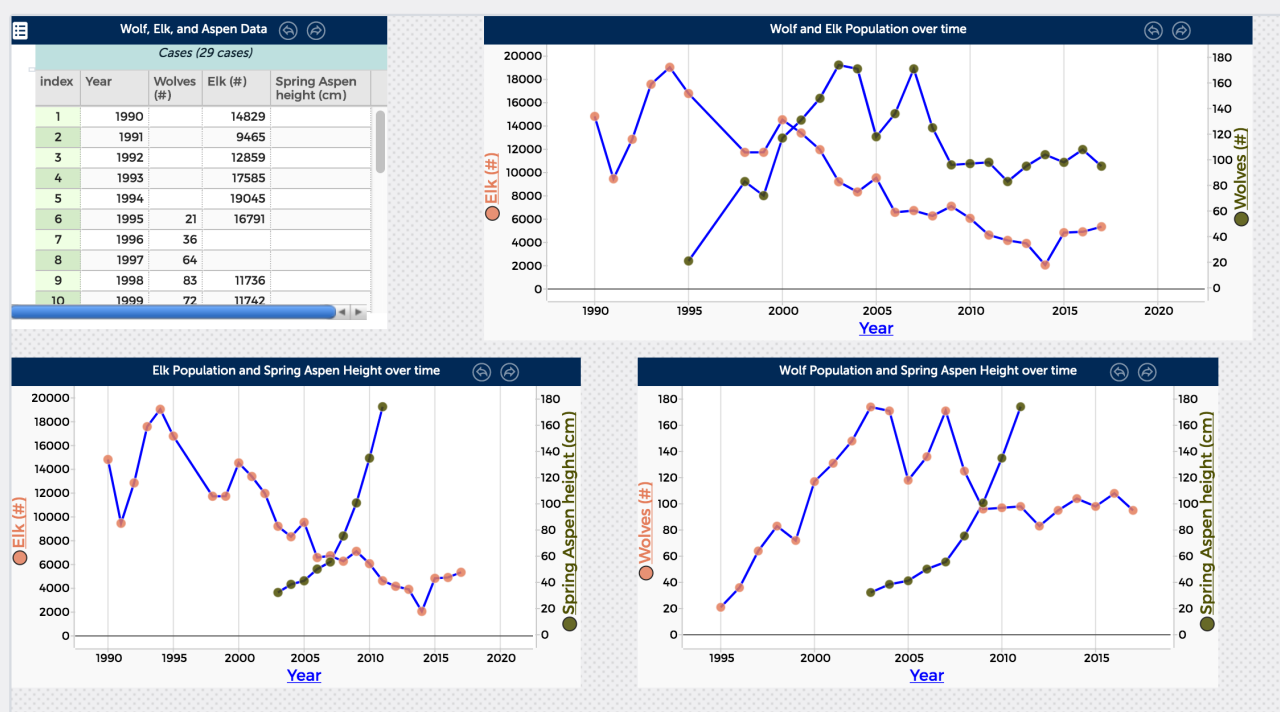
- The wolf-elk trophic relationship shows a classic predator-prey population dynamic.

Facilitation Suggestions

- **In the first step, students propose a hypothesis** about the trophic relationship between wolves and elk. Encourage them to use what they have learned in the Background section.
- **Help students construct three graphs** using the data in the table—wolf and elk population trends separately, and then both together—and analyze each. The questions are designed to help students be detailed in their examination.
- **Remind students to save the Elk-Wolf graph** in their notebook by taking a snapshot with the camera tool located in the graph's right-hand menu.
- **Point out that the numbers of elk and wolves are very different**. You may want to use the small exercise in the step four "Hint" to explain how the predator-prey ratio concept works.
- In step five, **make sure that students** use the concept of population dynamics correctly in the explanation of their results. Invite a few students to verbalize their answers.
- You may wish to use the last question for a small discussion; this may be useful in getting all students on the same page before going on to Investigation 2.

INVESTIGATION 2: Wolves-Elk-Aspen Trophic Relationship

Estimated Time: 30 minutes



Purpose

- To investigate the trophic relationships among wolves, elk, and aspen trees
- To construct a three-level trophic structure or food chain.

Big Idea

- The trophic cascade initiated by the reintroduction of wolves causes the decrease of its prey, the elk; in turn, there is an increase in one of the prey's food sources, aspen trees.

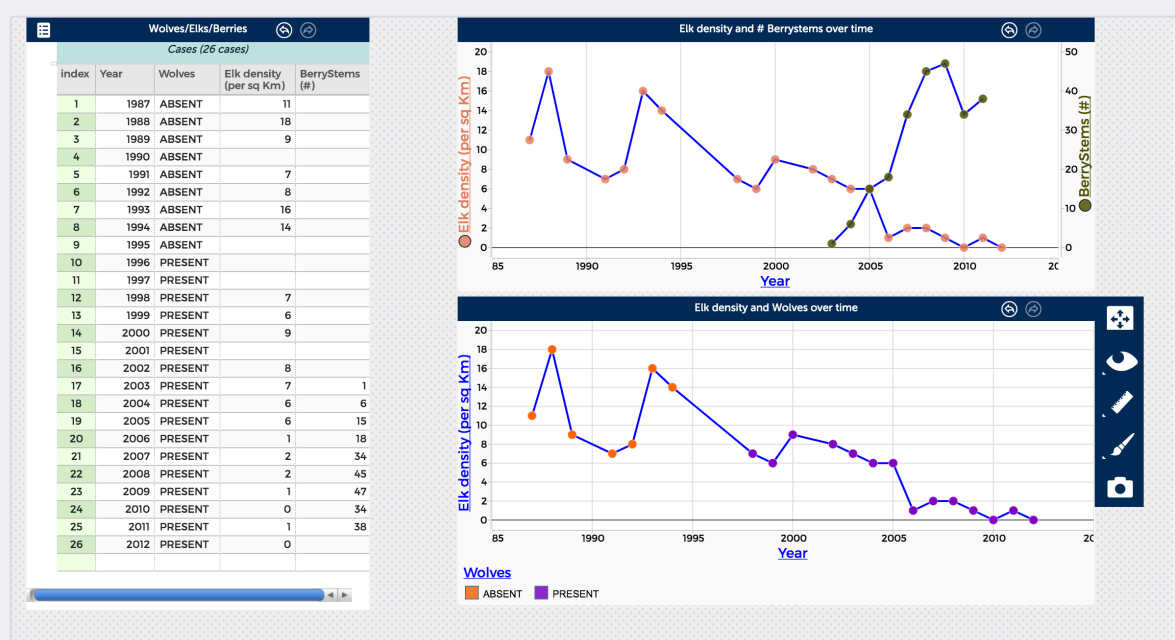
Facilitation Suggestions

- **In the first step, students predict** how the reintroduction of wolves will affect the elk's food—the aspen population—and why. Encourage them to use words and terms such as predation, trophic levels, and trophic cascade.
- **Note:** Since CODAP graphs display only two populations at a time, students will have to create and analyze multiple graphs on one screen in order to understand relationships among three organisms. This may be challenging, as the prompts ask them to consider each graph one by one. **It would be helpful to project the graphs and go through the analysis with students**. It may be helpful to have students work in pairs before writing their responses individually.
- **Remind students to save their graphs (elk-aspen and wolves-aspen)** in their notebook by taking a snapshot of each with the camera icon.

- **You may wish to note** that the data show only eight years of spring aspen height. Ask students whether they think it is valid to extrapolate from the available data. For example, "Do you think the aspen height trend will keep increasing/decreasing? Why?"
- **Point out** **that the nature of real data is that often the trends are not smooth**. Other elements may come into play to upset the trend; for example, disease, migration, environmental events that positively or negatively affect the organism's health.
- **Invite students to read aloud** **the paragraph in step five**. Here students put together their thoughts and write about the dynamics of the interactions among the wolves, elk, and aspen trees. You may have students talk in pairs, then direct them to answer the prompt in the box using the information from the graphs.

INVESTIGATION 3: Wolves-Elk-Berries Trophic Relationship

Estimated Time: 15 minutes



index	Year	Wolves	Elk density (per sq Km)	BerryStems (#)
1	1987	ABSENT	11	
2	1988	ABSENT	18	
3	1989	ABSENT	9	
4	1990	ABSENT		
5	1991	ABSENT	7	
6	1992	ABSENT	8	
7	1993	ABSENT	16	
8	1994	ABSENT	14	
9	1995	ABSENT		
10	1996	PRESENT		
11	1997	PRESENT		
12	1998	PRESENT	7	
13	1999	PRESENT	6	
14	2000	PRESENT	9	
15	2001	PRESENT		
16	2002	PRESENT	8	
17	2003	PRESENT	7	1
18	2004	PRESENT	6	6
19	2005	PRESENT	6	15
20	2006	PRESENT	1	18
21	2007	PRESENT	2	34
22	2008	PRESENT	2	45
23	2009	PRESENT	1	47
24	2010	PRESENT	0	34
25	2011	PRESENT	1	38
26	2012	PRESENT	0	

Purpose

- To investigate whether the reintroduction of wolves has had an effect on the elk's food, the berry bushes

Big Idea

- A trophic cascade can be traced from the wolves to the elk and in turn to the primary producers, berry bushes.

Facilitation Suggestions

- In the first step, students predict what effect the reintroduction of wolves might have on the availability of berry bushes.
- **Point out** that in this investigation we are not using **elk number** but **elk density**, a different way to measure the elk. You may wish to discuss **the importance of corroboration in science,** and the fact that different ways of measuring a phenomenon should point to the same outcome.
- As in the prior investigation, students are asked here to answer questions by putting together the information from two different graphs**. Tell students to go step by step and study each graph alone, then in combination with the others.** For example, after establishing the relationship between elk and berry bushes (step three), go over the graph showing the density of elk in the presence/absence of wolves. Then put these two results together by answering the questions on step four. This section may feel repetitive in the sense that we are looking at predator-prey/primary consumer- primary producer/plants as in investigation 2. However, we are looking at the berry bushes because of the competition of elk and bear for the berry bushes that will be studied in investigation 5.
- **Tell students to make sure** to save their graphs in their notebook by taking snapshots.

INVESTIGATION 4: Summarizing Your Results

Estimated Time: 15 minutes

Wolf Population	Elk Population	Spring Aspen Height	Berries Population
Up	Down	Up	decreasing
Down	Up	Down	increasing

Purpose

- To stop and think about the results collected so far and how they fit into the idea of a trophic cascade
- To construct a three-level trophic cascade using the results to this point.

Big Idea

- The reintroduction of wolves causes a decrease in the elk population, allowing the elks' food—aspen trees and berry bushes—to thrive.

Facilitation Suggestions

- **Make time for students to briefly discuss**, in pairs or table groups, the trophic relationships among the creatures in the table.
- **Ask students to construct a trophic cascade using all the animals in the table**. You may want to invite students to draw a trophic cascade and to discuss as a class what animals go in what trophic levels and how are they ecologically related.

TRANSITION POINT

Inform the students that the next investigation is going to be wider in scope, looking at other animals that may be influenced indirectly by the reintroduction of wolves into Yellowstone Park.

INVESTIGATION 5: Interactions Within Trophic Cascades

Estimated Time: 15 minutes

Purpose

- To investigate whether the reintroduction of wolves to Yellowstone Park has had an *indirect* effect on other animals and plants in the ecosystem

Big Idea

- The presence of wolves in Yellowstone Park favored bears because it decreased the competition between elk and bears for food resources.

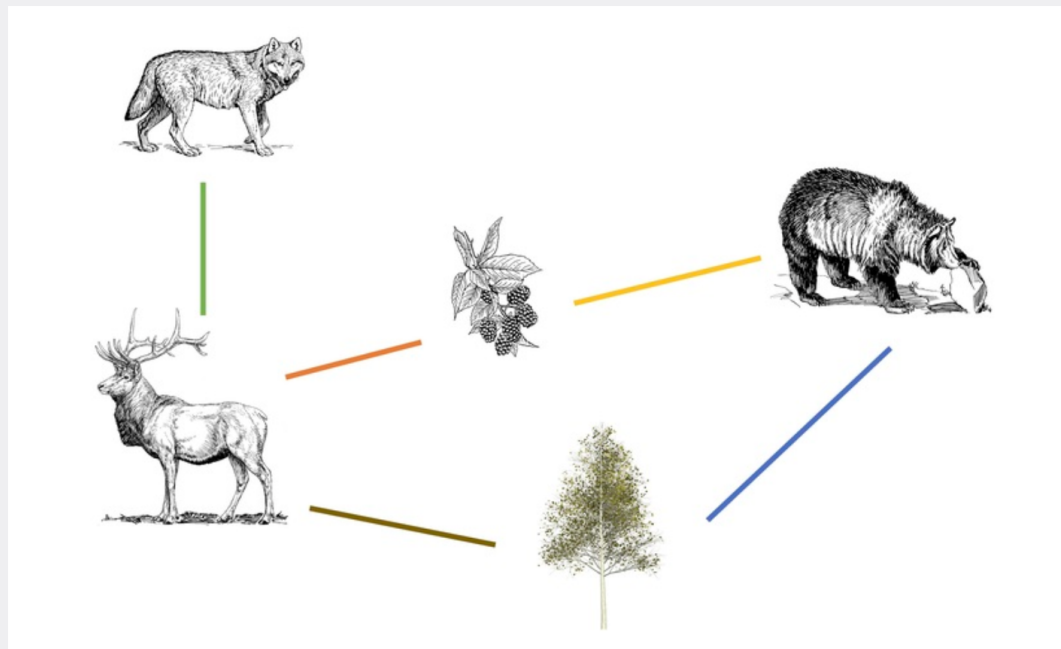
Facilitation Suggestions

- In the first step, students predict how the reintroduction of wolves will affect the competitive relationship between elk and bears.
- In the data analysis, students are asked to establish whether there is a correlation between elk numbers and fruit in the bears' diet. **Go over the significance of the slope—and particularly whether it is positive or negative.** Ask students to put the relationship into words.
- **Remind students to save both graphs** in their notebook by taking snapshots of them.
- **Note** that because we do not have direct data on the number of bears, we are using a **proxy variable**—the amount of fruit in the bears' diet. Our assumption is that if there is more fruit in their diet (by scat measures), this suggests that bears are eating more, will thrive, and thus there will be an increase in their number.

- Before going to step three, **remind students** that the number of elk in Yellowstone Park depend on whether there are wolves around. Ask students what they would expect the percentage of fruit in bears' diet to be when wolves are present versus when they are absent. Make sure students explain their answers and frame their responses using the graph and results from previous investigations.
- Students can find whether their answers were correct by looking at the amount of fruit eaten by bears when wolves were present versus when they were absent. **Ask students to put these results together and decide: Is there enough evidence to say that there is competition between elk and bear? That wolves have an effect on this relationship?** If students think there is not enough evidence, ask them what additional experiments or observations would help to establish such relationships.

INVESTIGATION 6: Summarizing the Results

Estimated Time: 15 minutes



Purpose

- To integrate the ideas and concepts learned in the lesson by completing the concept map depicting the animals in the Yellowstone trophic cascade

Big Idea

- The reintroduction of wolves to Yellowstone Park directly affected the abundance of elk. This in turn has implications for the elk's food—the aspen and berries—as well as for animals, such as bears, competing for this food.

Facilitation Suggestions

- **Direct a class discussion aimed at filling out the concept map.** Students should be able to establish trophic relationships by filling in the boxes on the left-hand side panel. Encourage students to verbalize their ideas and to give the reason for their ideas .
- **To encourage participation, you may wish to ask,** "What is the trophic relationship between the wolf and the elk? If elk were not there, what would happen to the berries, the aspen trees, the bears?"

TRANSITION TO WRITING

Inform students that this last exercise will help them get ready to write an essay about the trophic cascade initiated by the reintroduction of wolves to Yellowstone National Park.

WRITING TASK: How Wolves Have Affected the Yellowstone National Park Ecosystem?

Estimated Time: 30 minutes

Purpose

- To produce a piece of writing using evidence from the investigations to answer the question, "*How did the reintroduction of wolves into Yellowstone Park affect the other animals and plants in the ecosystem?*"
- To use the learned concepts and results in order to write a memo which makes an argument supported by evidence?

Big Idea

- Effectively communicating scientific findings is as important as conducting the investigations themselves.
- Presenting data, explaining what the data mean, and making a concise story of the result in writing is the concluding piece of any scientific investigation.

Facilitation Suggestions

- **Re-engage students with the main question they are addressing—**"How did the reintroduction of wolves into Yellowstone Park affect the other animals and plants in the ecosystem?"
- **Remind students to use their notes** and to draw their evidence from the snapshots and the answers they saved.
- **Students may have to be reminded** that each paragraph is a coherent piece of writing composed of a topic sentence, a body that develops the idea using evidence, and a conclusion.
- **Preview the "Writing" page** and the outline that students will follow in constructing their essay..

1. *Intro Paragraph*— You will introduce your audience to the reason wolves were reintroduced to Yellowstone National Park and describe what is meant by a "trophic cascade.".
2. *Claim Paragraph*— Briefly summarize the trophic cascade you constructed from the data investigations—the relationships among wolves, elk, aspen, berries, and bears.
3. *Evidence and Reasoning Paragraphs*— You'll write three short paragraphs presenting data that on (a) wolf-elk food chain effects, (b) wolf-elk-plants food chain effects, and (c) ecosystem effects. In each paragraph, you will
    - present a data snapshot (saved in your Notebook);
    - describe the data in words, and say how they support your claim;
    - discuss the population dynamics operating between species.
4. *Conclusion Paragraph*— You will answer the question, "Do you think the trophic cascade involving wolves as top predators in Yellowstone National Park has positively affected the ecosystem?" Also, students judge whether the results are similar to those presented by the *How Wolves Change Rivers* video we watched at the beginning of the lesson.

Sample Writing Product

How Wolves Have Affected the Yellowstone National Park Ecosystem

Wolves were reintroduced in Yellowstone National Park with the hope of re-establishing the ecosystem's biodiversity. The hypothesis was that, when all the wolves were hunted down, the food web was disrupted and the ecosystem deteriorated. In the absence of wolves, too many elk in the park had negative implications. For example, uncontrolled browsing of many plants by elk caused the disappearance of other animals because their habitats and food supply were destroyed by the elk. As I learned in the Background section, a trophic cascade is an event that has consequences throughout a food web. It is caused by adding or taking away a component in a food web—in this case, the top predator, the wolves. A food web describes trophic relationships among components of an ecosystem; and within a food web we can trace many food chains.

Overall, the investigation shows that the reintroduction of wolves was positive for the Yellowstone Park ecosystem. These effects are consistent with a trophic cascade, where reintroduction of a predator has had cascading or chain effects on other animals and plants. The reintroduction of wolves into Yellowstone National Park had a negative impact on elk. The wolves are the top predators and they prey on the elk; these two animals have a predator-prey relationship. By controlling the elk population, other organisms in the ecosystem, like aspen trees and berry bushes, recovered. The elk consume plants—the berry bushes and the aspen trees. The elk and the bears compete for the berries, and the wolves indirectly favor the bears by eating the elk. This allows more berries to be produced, which are available for the bears to eat before hibernating.

The population dynamics between wolves and elk shows an out-of-phase undulating relationship between these two species. As the prey, elk, are readily available, the predator's population, wolves, increases because there is plenty of food to eat. My results in investigation 1 (snapshot) show that in 1995 there were 16,791 elk—plenty of food for the 21 wolves. After 1995, the number of wolves increased, from 21 up to 185 in 2004 and, as a response, the population of elk decreased. But eventually the wolf population also started to decrease, perhaps because there were fewer elk to eat. There are no data after 2017, but if we extrapolate the trend, we may see that the reciprocal relationship continues. There is a second piece of evidence that shows the same wolf-elk relationship trend (Investigation 3 snapshot). In the presence of wolves, the elk density was only 0-1 elk per square kilometer compared to the high elk density of 16 per square kilometer when the wolves were absent. Taking these two pieces of data together, my results suggest that the reintroduction of wolves reduced the number of elk because wolves killed them.

One interesting consequence of the wolves eating the elk is that the plants that the elk eat increased. The two plants under study are aspen trees and berry bushes. My results show that between 2003 and 2011, as the number of wolves increased, the number of elk decreased, and the height of aspen trees increased (Investigation 2 snapshot). After 2011, the number of wolves reached a plateau; however, the aspen trees kept growing. This result can be explained by the observation that elk can reach leaves only to a height of about 100 centimeters. If the tree gets taller than that, then it is safe from elk and keeps growing. A similar trend is observed between the wolves, elk, and berry bushes. There are not only more berry bushes, but they get taller and produce more berries (Investigation 3 snapshot). The relationship between these species, herbivores and plants, also shows a reciprocal relationship.

As I learned in the Background section, in a food web there are many direct and indirect interactions among its components; trophic cascades usually are not linear. In this study, we identified one indirect effect of the reintroduction of wolves to Yellowstone National ParkP: Wolves and bears interact via the elk and berry bushes. There is a strong negative correlation (r^2=0.731, snapshot) between elk numbers and bear fruit diet. As the number of elk increased, the percentage of fruit in the bears' diet decreased. Bears eat as much as they can, especially during late summer and fall before they go into hibernation (Investigation 5 snapshot). My results in Investigation 5 show that when there were no wolves (but a lot of elk), the bears had a total of only 10% fruit in their diet during August and September. As discussed above, this is because the elk ate the berry bushes, and the inference is that the bears had no fruit left to eat. After the reintroduction of wolves (resulting in much fewer elk), the percentage of fruit in the bears' diet increased to 28%, with August being the month when the bears ate lots of fruit (15%).

In conclusion, my results are consistent with the idea in the video that the reintroduction of wolves to Yellowstone National Park positively influenced other components of the food web, and made the ecosystem healthier. Even though we have studied a small part of the components that make up the Yellowstone Park ecosystem, we can extrapolate these results and hypothesize that the positive effects of the reintroduction of wolves to the park may have a wider reach. For example, more birds will be able to nest in the aspen trees and small mammals and birds will come back to the park to eat the berries.

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ASSESSMENT

Writing Product Assessment

Look for the following when evaluating students' writing tasks.

INTRO PARAGRAPH:

- ❑ Begins by stating why wolves were reintroduced to Yellowstone National Park
- ❑ Defines what is a trophic cascade

CLAIM PARAGRAPH

- ❑ Describes the trophic cascade constructed in the lesson
- ❑ Identifies and describes the trophic relationships among wolves, elk, and plants
- ❑ Identifies and describes the competitive relationship between elk and bears.

EVIDENCE AND REASONING PARAGRAPHS

- ❑ There should be three paragraphs—on wolves-elk, on wolves-elk-plants, and on the indirect effects of the trophic cascade
- ❑ Each paragraph should present evidence *and* explain how it supports the claim. For example, by including
    - o a summary sentence on the trophic relationships;
    - o a description of the results, citing data and including picture from the notes;

CONCLUSION PARAGRAPH

- ❑ States whether the reintroduction of wolves was positive to the ecosystem of Yellowstone National Park
- ❑ Judges, based on the evidence, whether the information shown in the video is credible.

Key Question Notes

We suggest that teachers use these Key Notes to find out whether students understand the concepts and whether students are keeping pace with the rest of the class.

Key Question 1. In your own words, write a definition for trophic cascade?

Where: Background 2: Food Webs and Trophic Cascades

Understanding: Students should be able to apply the concepts of food webs and food chains from the Background section to define a trophic cascade.

Answer: A trophic cascade is an event that happens when an organism is added or taken away from a food web.

Key Question 2. Look at the three graphs you constructed side by side and write a paragraph about what happened to the trophic cascade wolf-elk-aspen after the wolves were reintroduced to Yellowstone National Park in 1995

Where: Investigation 2. Wolf-Elk-Aspen Relationship

Understanding: Based on the results obtained to this point, students should be able to extend the concept of a trophic relationship from two to three organisms.

Answer: In the first trophic relationship, the wolves' population increases and, as a result of predation, elk population decreases. Since elk browse on aspen, the presence of wolves would allow the aspen population to increase. The trees survive and become taller.

Key Question 3. Do you think there is enough evidence for food competition between elk and bears?

Where: Investigation 5: Interactions Within Trophic Cascades

Understanding: In the answer to this question, students should be able to choose appropriate data, and they may require help interpreting the least square line.

Answer: Yes, the competitive interaction between bears and elk is affected by wolves. There is a strong negative correlation ($r^2 = 0.731$) between fruit in the bear diet and number of elk, suggesting that the elk eat the berries and thus the bear goes hungry. However, when wolves are present the percentage of fruit in the bear diet increases from 6% to 15%.