Keystone Species in an Ecosystem
Using Connection Circles to Tell the Story:
The Shape of Change

The text of
Lesson 11: Keystone Species in an Ecosystem
Using Connection Circles to Tell the Story
From the books

The Shape of Change

and

The Shape of Change: Stocks and Flows

By Rob Quaden and Alan Ticotsky
With Debra Lyneis
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The Shape of Change

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http://www.clexchange.org

milleras@clexchange.org.

Introduction

Ecosystems are built upon complex interrelationships among organisms and their habitats. Often, a change in the population of one species causes unexpected changes in other species. Understanding and representing a web of changes is challenging for the scientists who study them, let alone for readers who try to comprehend these complex situations. In this lesson, students read a chapter from a skillfully written science book and use connection circles to unravel a mystery of nature.[1]

As in previous lessons, students will frame their inquiry with these questions: *What* is changing? *How* is it changing? *Why* is it changing?

Materials

- Overhead projector or display board
- Several different colored markers for each student
- Connection Circle template for each student (page 15)
- Posted copy of "Connection Circle Rules" (page 16)
- Copies of "The Case of the Twin Islands" from ***The Shape of Change*** (2008), page 137.

How It Works

In her informative and entertaining book, *The Case of the Mummified Pigs and Other Mysteries in Nature*,[2] Susan E. Quinlan has written fourteen true stories that describe the research of ecologists who puzzle out how and why ecosystems behave as they do. Readers discover the interesting and often surprising connections among organisms through the work of detectives who find clues to nature's riddles.

The chapter, "The Case of the Twin Islands," examines why the ecosystems in the waters off two neighboring Aleutian Islands are so different. As students use connection circles to trace causal relationships in the story, they discover the role of a keystone species, a species vital to the stability of the whole ecosystem. Students learn how feedback loops maintain a delicate balance in an ecosystem and what happens when that balance is disturbed.

Connection Circles

The purpose of a connection circle is to help students focus on the problem presented by the author and to uncover its causes. Here is a quick overview:

- First, students briefly define the problem: What is the author concerned about? What is the main problem? *What* is changing over time?
- Next, *how* is it changing? In a few words, or with a quick behavior over time graph, students describe how the problem is increasing or decreasing over time.
- Finally, students look for elements in the story that contribute to the problem. They use a connection circle to organize their thoughts, find cause and effect relationships, and trace the feedback loops that tie them together to explain *why* the problem occurs.

Procedure

1. Read “The Case of the Twin Islands,” reprinted with permission in the Appendix of ***The Shape of Change*** (2008) beginning on page 137. Students may read independently, share reading, or listen to it read aloud.

2. Create connection circles summarizing the situation described in the story. If students are drawing connection circles for the first time, follow the procedure detailed in Lesson 10, “Do You Want Fries with That?” in ***The Shape of Change*** (available from www.clexchange.org).

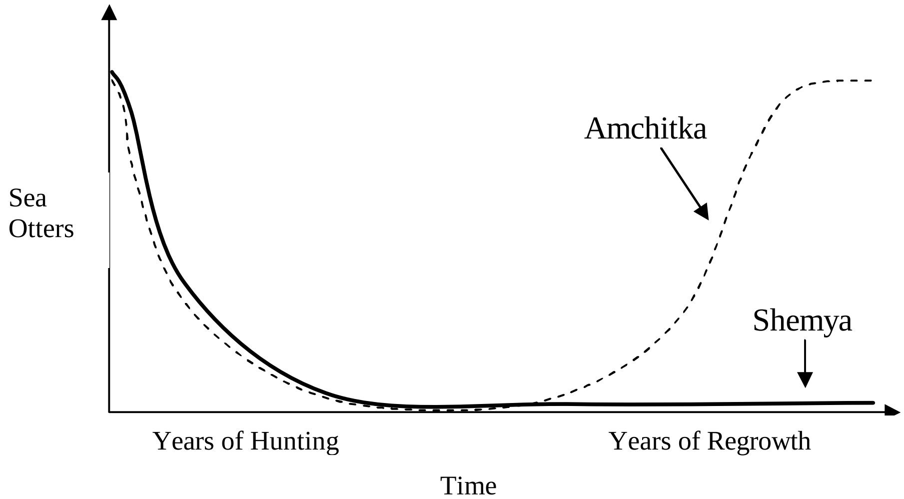
If students are already familiar with connection circles, give each student a Connection Circle Template (page 15), review the rules, and ask pairs of students to begin choosing elements for their circles. See the Appendix (page 16) for a larger copy of the rules to post in your classroom for easy reference.

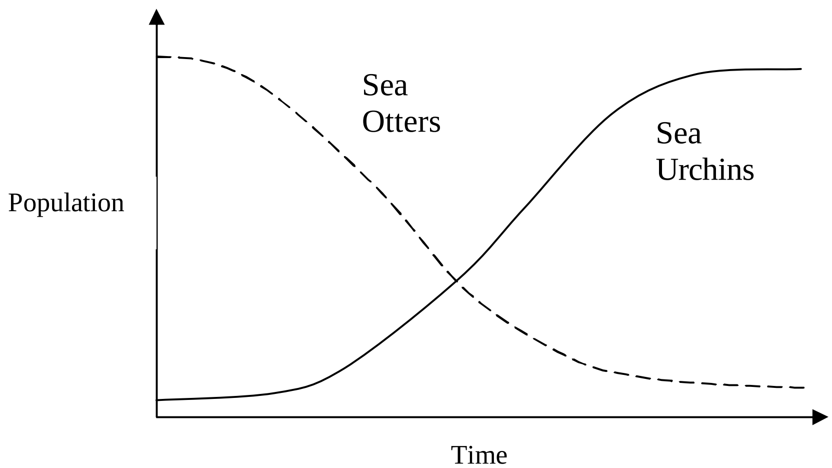
CONNECTION CIRCLE RULES

1. What’s the problem: *What* is changing? *How* is it changing?
2. Choose elements of the story that satisfy ***all*** of these criteria:
   - They contribute to the problem.
   - They are nouns or noun phrases.
   - They increase or decrease over time.
3. Write your elements around the circle. Include no more than 5 to 10.
4. Find elements that cause another element to increase or decrease.
   - Draw an arrow *from* the cause *to* the effect.
   - The causal connection must be direct.
5. Look for feedback loops. Tell their story.

3. **What’s the problem?** *What* is changing? Ask students to quickly identify the problem that the author is presenting. They may say, “The sea otters have disappeared from the waters around Shemya while the sea urchin population has grown there.”

Ask students to define the problem more precisely by describing *how* the populations changed over time in a graph or briefly in words. These are examples on the following page. They are just quick rough sketches of the general patterns of behavior. (Students may prefer to sketch separate graphs for each population.)





A behavior over time graph is a line graph sketch that shows how something changed over time.
What was the general pattern of the behavior?

4. Remind students to choose elements that describe the problem and its possible causes. Here, our main concern is the sea otter population that has decreased over time. The population of sea urchins is also important. Other variables in the story contribute to the increase and decrease of these species.

Precise language and clear thinking go hand in hand with connection circles.

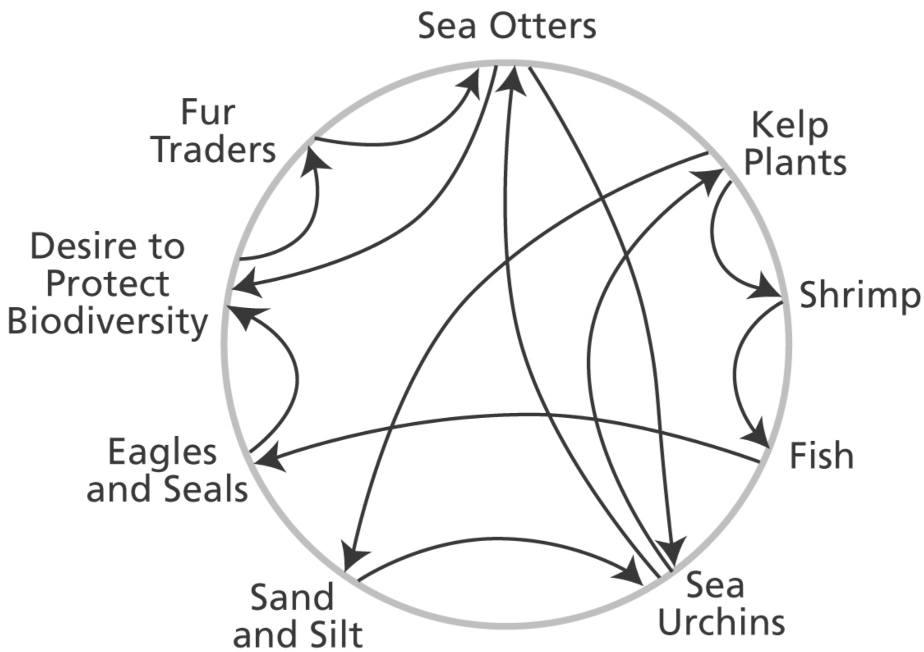
- Elements must be nouns or noun phrases, quantities that can increase or decrease over time, like the number of sea otters or the amount of sand deposited.
- Do not use words like "more" or "less" in the titles.
- Remember that elements can be tangible, like the number of fur traders, or intangible, like the desire to protect the environment. Often the intangible variables are keys to the problem.
- Connection circles may vary. The words around each circle do not have to be the same nor in the same order, but they should all be things that work together to contribute to the problem.
- Students are always free to change, add or delete elements as they refine their thinking.

5. Once students have drawn their connection circles with causal arrows, share them as the focus of a class conversation.
   - Draw a large circle on the board or overhead projector.
   - Have each team suggest an element to put on the circle.
   - As a class, refine the list to include *no more than five to ten* elements.
   - Ask each team to describe a causal arrow and explain their reasoning for direct causality. Encourage other teams to ask clarifying questions. Students should refer to the text when explaining their reasoning.

Again, you may want to review the more detailed instructions in Lesson 10, "Do You Want Fries with That?"

Remember, a connection circle is a thinking tool,
a way to surface and examine mental models.
It is not a mold for one "right" answer.

Here is one example of a connection circle for "The Case of the Twin Islands." Expect student examples to vary.



Ask students to explain their arrows: How did a change in one element cause a change in another?

- An *increase* in the number of fur traders caused a *decrease* in the number of sea otters because traders hunted and killed sea otters. Also, a *decrease* in traders caused an *increase* in sea otters because they could multiply unharmed.
- An *increase* in the shrimp population caused an *increase* in the number of fish because fish eat shrimp. A *decrease* in the number of shrimp caused a *decrease* in the number of fish.
- An increase in kelp plants caused an *increase* in sand and silt because kelp calmed the waters allowing sediment to be deposited. The increased sediment then buried the sea urchins causing them to decrease. Students might draw an arrow suggesting that an increase in kelp caused a decrease in urchins, but this is not a *direct* cause. Remind students to be very careful in their thinking about what caused what.

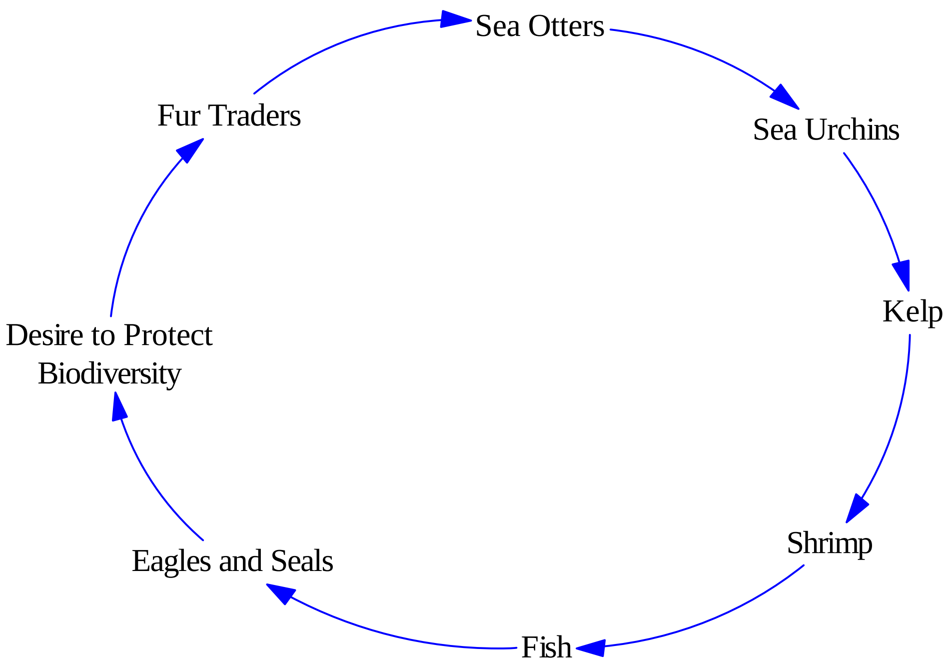
Remember, these are only sample drawings.
Let students present their own ideas and encourage them to weigh the ideas of others.
Students are always free to change their drawings
as they continue to refine their mental models together.

6. Ask teams of students to trace a closed "loop." Can they start at one element, follow the arrows around the circle and return to where they started? Each of these pathways is a *feedback loop* that tells part of the story. Trace each loop in a different color. (It helps to start with an element that has many connections to and from it.)

After students trace a loop, ask them to draw a simplified drawing that includes only the elements from the traced loop, as shown in the following examples. Again, student drawings will vary.

Do not present these examples to students. Allow them to discover the feedback in the story for themselves. Let representatives from each team present feedback loops and share their stories with the class.

The circle below shows one large feedback loop. *Tracing the feedback loop reveals why the problem occurred; don't skip these steps.*

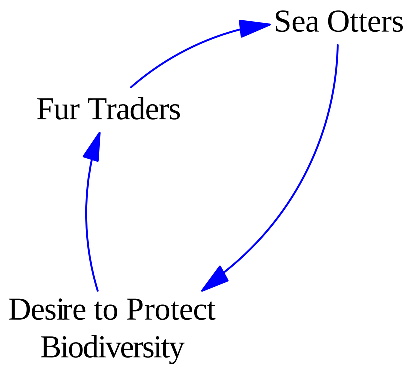


Starting at the top, an *increase* in sea otters caused a *decrease* in sea urchins because sea otters eat urchins. Fewer urchins allowed the kelp plants to *increase*. An *increase* in kelp caused an *increase* in shrimp, which then caused an *increase* in fish, which then caused an *increase* in eagles and seals. With abundant wildlife, people were less worried about biodiversity. A *decrease* in the desire to protect biodiversity allowed the number of traders to *increase*, so the number of sea otters began to *decrease.*

This is a ***balancing feedback loop***. We started with an increase in sea otters, but going around the loop, the chain of events caused sea otters to decrease. If we traced the loop again, the decrease in sea otters would then become an increase, balancing back and forth each time around the loop.

7. Look for other feedback loops. Here are some examples:

Otters and Fur Traders
Here is a possible loop linking otters and fur traders.



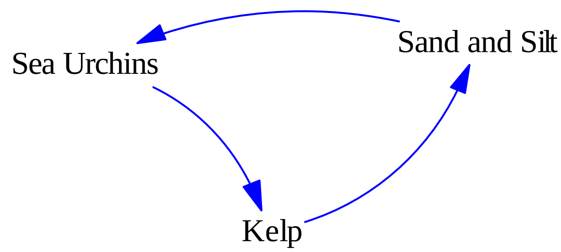
Tracing the loop, an *increase* in fur traders in the 19th Century caused a *decrease* in sea otters to dangerously low levels. An awareness of the decline caused an *increase* in the desire to protect biodiversity. This led to a *decrease* in hunting. This is also a ***balancing loop*** – any change works to restore itself around the loop again.

Note: Students trace the different loops on their original connection circles in different colors before drawing separate feedback loops. They can draw these loops freehand without using connection circles as templates.

The story gets complicated, but don't worry.
It is easier when students construct and talk about their own circles.
This is the reason for doing connection circles in the first place:
Students can understand and communicate ideas that are difficult to express using more conventional tools.

Sea Urchins and Kelp

Here is another feedback loop. Sea urchins eat kelp plants. The kelp plants calm the water movement and trap sand and silt on the ocean bottom. Sand and silt smother sea urchins.



Tracing the loop for the circumstances around Shemya Island, an *increase* in sea urchins caused a *decrease* in kelp plants. Fewer kelp plants meant less sand was deposited. A *decrease* in sand provided a more suitable habitat for a *further increase* in sea urchins and *another decrease* in kelp plants. In this spiral, the sea urchins continued to multiply and the kelp disappeared.

However, around Amchitka Island, the opposite occurred. An initial *decrease* in sea urchins caused an *increase* in kelp plants. More kelp caused more sand. More sand meant *even fewer* sea urchins and *more and more* kelp. This time the spiral drove the sea urchin population *down* and the kelp thrived to harbor greater biodiversity.

This is a good example of a ***reinforcing loop*** – sometimes also called a virtuous or vicious cycle. Any change gets amplified over and over again, spiraling either up or down.

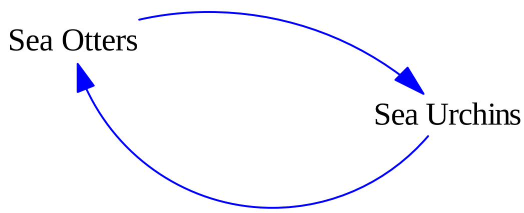
Feedback Loops

Reinforcing loops drive accelerating growth or decline in systems.
Balancing loops work to keep reinforcing loops in check.

When something disrupts this delicate balance in an ecosystem, a reinforcing loop can spur a rapid growth or decline of a species – a clue to the mystery in our story.

Sea Otters and Sea Urchins: Predators and Prey

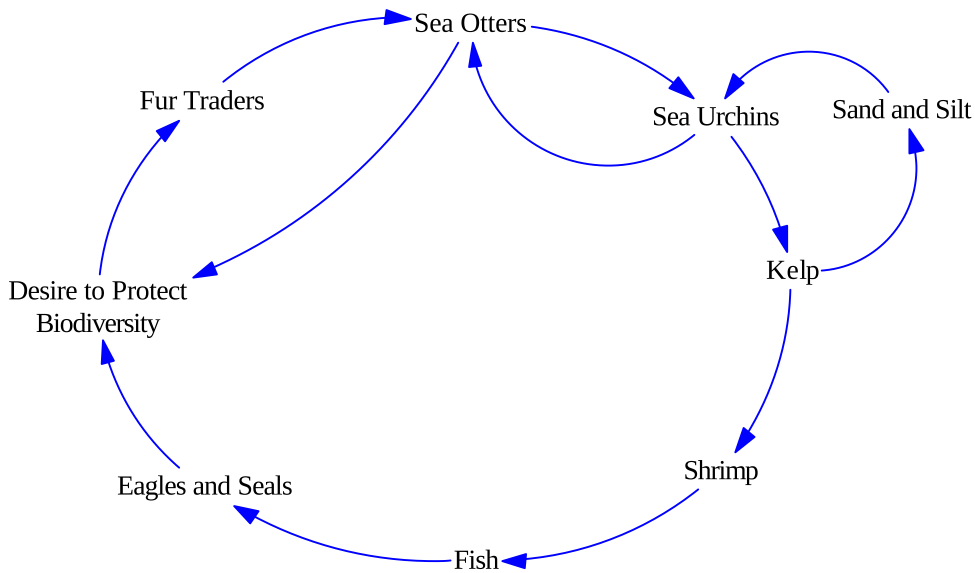
Because sea otters prey upon sea urchins, an *increase* in sea otters causes a *decrease* in sea urchins. A *decrease* in urchins then causes a *decrease* in otters as their food supply dwindles. Tracing around the loop again, a *decrease* in otters allows the urchins to reestablish themselves. This is another *balancing loop* – any change restores itself, balancing back and forth each time around the loop.



This feedback loop is typical of predator/prey feedback loops in nature. The populations balance each other. Too many predators will reduce the prey population to levels that will cause the predators to run short of food. When the prey population expands too much, more predators will hunt them and bring down their numbers.

8. While sharing feedback loops with the whole class, look for elements that appear in more than

one loop. Most stories contain overlapping loops. This diagram connects all the previous loops.



Tracing the intertwined loops, notice how kelp plants provide food for shrimp, triggering a biodiversity increase, while also causing sand and silt to build up. The sand and silt loop drives the sea urchin population down, further enabling the kelp to grow. In this diagram, sea urchins and sea otters both have two arrows leading from them, signifying multiple outcomes caused by changes in their populations.

*Tracing the story of each loop explains **why** the problem changed over time.*

9. Ask students to revisit their original behavior over time graphs defining the problem, or have each team choose an element from the circle and sketch how it changed from the time when hunters arrived in the late 1800s to the time when "The Case of the Two Islands" was written. Emphasize that the general shape of the graph is important – it cannot be precise because we have no specific data. Share the graphs and ask students to explain how they relate to the feedback loops they have uncovered.

An ecosystem is a delicate balance of many feedback loops.
As students uncover these interdependencies,
they begin to appreciate the complexity of natural systems.

BRINGING THE LESSON HOME

Give students a chance to bring the lesson full circle. What did they learn? Posing stimulating questions like these will help students ask better questions themselves.

? Many things were happening at once in this story. How did the connection circle help you sort them out?

The mystery of the twin islands often seems baffling at first. Encourage students to reflect on their thinking and on the process of understanding complexity by looking for the interwoven causal loops underlying the problem.

In using connection circles, the thinking process is important – not just the product.

? Did you solve the mystery of the twin islands? What effect did sea otters have on the sea urchin population and the balance of the two ecosystems?

Around Amchitka Island, the sea otter population increased. This caused a decrease in the number of sea urchins. That allowed the kelp forests to grow thickly because they were not being destroyed by sea urchins. The kelp provided habitat for shrimp, which fed many fish. The fish became food for seals and eagles. The increased kelp also sheltered the deposits of sand and silt on the ocean floor, which smothered the bottom dwellers who might try to live there.

In contrast, sea otters had not returned to Shemya Island and a large population of sea urchins lived in the waters there. The sea urchins prevented the growth of kelp, so few shrimp and fish could survive in the inhospitable environment. Bottom dwellers thrived since the sand and silt did not build up over the ocean floor, but these creatures were not desirable food for most fish species. With few fish to attract them, seals and eagles did not colonize Shemya Island and its surrounding waters.

Feedback Loops Tell the Story

Feedback loops explain *why* the ecosystems were so different.

An ecosystem is a delicate balance of feedback loops. Positive loops drive rapid population growth or decline, but nature provides balancing loops to keep positive loops from spiraling out of control.

When hunters disturbed the balance by removing the sea otters from the ecosystem, the sea urchin population boomed causing many other changes to the ecosystem.

? How did hunters affect the islands' ecosystems?

Fur traders hunted sea otters to the brink of extinction. The decline of the sea otter population allowed sea urchins to proliferate, and the urchins devastated the kelp forests. When kelp forests decrease, many marine animal species are deprived of habitat and their numbers decline as well. Without hunters, sea otters could thrive around Amchitka Island.

? Author Susan Quinlan calls the sea otter a "keystone species." What does she mean?

When the sea otter was removed from the Aleutian Islands, the ecosystem collapsed and became barren of many species. Similarly, if the keystone in an arch is removed, all the other stones will fall. Any species that is disproportionately important (i.e., compared to its population) in the maintenance and balance of an ecosystem, and whose removal disrupts or destroys the food web, is thought to be a keystone species. Some scientists believe that only predators can be keystone species but others disagree.

? What are the keystone species in ecosystems where we live?

Among animals generally considered to be keystone species are prairie dogs, beavers, freshwater bass, gray wolves, and salmon.

? Where can we learn more about how the feedback structure of the Twin Islands ecosystem caused the problem we observed?

For more information on this lesson and its next steps, see Lesson 11 in our next book, ***The Shape of Change, Stocks and Flows****, also available from the Creative Learning Exchange at www.clexchange.org.*

Additional Background Information

Students often generate many good questions that go beyond the original story. Here is some more background information that might be helpful.

? Why had sea otters come back to Amchitka but not Shemya?

The story only tells us that a few otters had escaped hunters but "they had not returned yet to Shemya Island." Researchers have proposed several theories to explain the abundance of sea otters on some islands and their scarcity on others. Among the causes hypothesized are coastal currents, algae production, complex factors affecting otter prey, predation on otter pups, and environmental contamination. Interested students can pursue this story further.

? In the absence of sea urchins, do sea otters eat so much of another species that it becomes depleted?

Sea otters can deplete their food sources rapidly. As is the case with other species, feedback loops in the environment operate to reduce otter populations when food is scarce and allow it to increase when prey is abundant.

? What is currently happening to the sea otter population in the Aleutian Islands?

James Estes and other scientists have continued to study the sea otter population and discovered more threats since 1990. It was estimated that between 150,000 to 300,000 otters lived in the Pacific Coast region before the hunters arrived in the 19th Century. A treaty in 1911 stopped hunting but only about 1,000 otters were left.

In the 1970s, the otter population near Alaska was estimated to have recovered to over 100,000. But in the years leading to the beginning of the 21st Century, they declined again. The culprit this time may be a different species of hunter – killer whales. Killer whales usually prefer to eat sea lions and seals, but those populations have declined due to reduced fish stocks. Killer whales have turned to sea otters and have reduced their numbers to dangerously low levels again. Kelp forests have been noted to be in serious decline by year 2000. Students will recognize familiar feedback relationships in these stories too.

Students have used connection circles to define the problem and find the causes of change over time.

With practice, they will eventually learn to recognize the feedback loops in the systems around them without the need of this tool.

Name____________________

Connection Circle Template

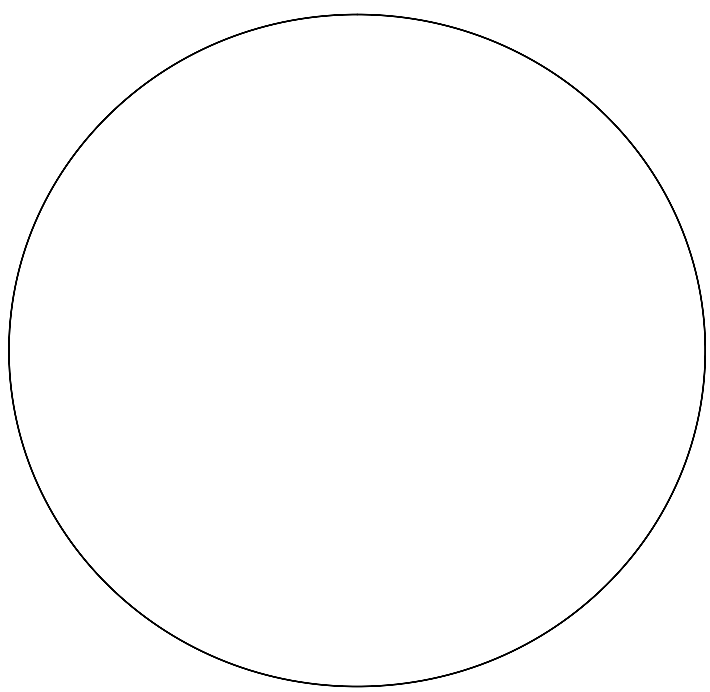
1. What's the problem: *What* is changing? *How* is it changing?

2 Choose elements of the story that satisfy ***all*** of these criteria:
   - o They contribute to the problem.
   - o They are nouns or noun phrases.
   - o They increase or decrease in the story.

3. Write your elements around the circle. Include no more than 5 to 10.

4. Find elements that cause another element to increase or decrease.
   - o Draw an arrow *from* the cause *to* the effect.
   - o The causal connection must be direct.

5. Look for feedback loops. Tell their story.



Connection Circle Rules

1. What's the problem:
   What is changing? *How* is it changing?

2. Choose elements of the story that satisfy ***all*** of these criteria:

   They contribute to the problem.
   They are nouns or noun phrases.
   They increase or decrease in the story.

3. Write your elements around the circle. Include no more than 5 to 10.

4. Find elements that cause another element to increase or decrease.

   Draw an arrow *from* the cause *to* the effect.

   The causal connection must be direct.

5. Look for feedback loops. Tell their story.

[1] We have revised this lesson from the version in the earlier edition of *The Shape of Change* (2004) to make our explanation of connection circles more clear. For more information on this lesson and its next steps, also see Lesson 11 in *The Shape of Change, Stocks and Flows* (2007) by Quaden, Ticotsky and Lyneis, also available from The Creative Learning Exchange at www.clexchange.org.

[2] "The Case of the Twin Islands" is a chapter from *The Case of the Mummified Pigs and Other Mysteries of Nature*, by Susan E. Quinlan, illustrated by Jennifer Owens Dewey, published by Caroline House, Boyds Mills Press, Inc., 1995. For your convenience, the chapter is reprinted with permission on page 137. We urge you to get the book and use connection circles to explore its many other intriguing stories.

All of the lessons in ***The Shape of Change, Stocks and Flows*** *build directly on classroom activities and lessons presented in* ***The Shape of Change****, also by Quaden, Ticotsky and Lyneis (2004), available from The Creative Learning Exchange. These lessons also build on one another sequentially.*

The Shape of Change

In Lesson 11 of ***The Shape of Change***, students read "The Case of the Twin Islands" by Susan E. Quinlan.[1] They used connection circles to examine why the ecosystems surrounding two neighboring islands are so different. See Pages 117-127 in ***The Shape of Change*** for the complete lesson.

Overview

Ecosystems are built on complex webs of interconnections among many organisms. Each organism can be considered a stock, a population that can increase and decrease. Over time, nature tends to achieve a delicate balance among the stocks: Reinforcing feedback loops drive accelerating growth and decline, while balancing loops work to maintain the balance by keeping the reinforcing loops in check. Drawing a stock/flow map of the ecosystem will help students understand this balance. When the balance is upset, students will be able to trace the causes and the consequences.

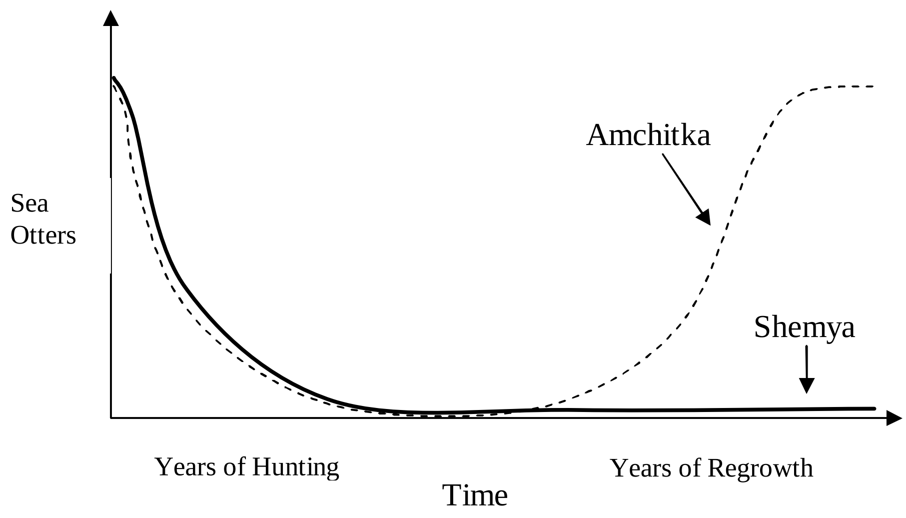
In this lesson, students will build the stock/flow map from the ground up, rather than converting the feedback loop as they did in the previous lesson.

What's the Problem?

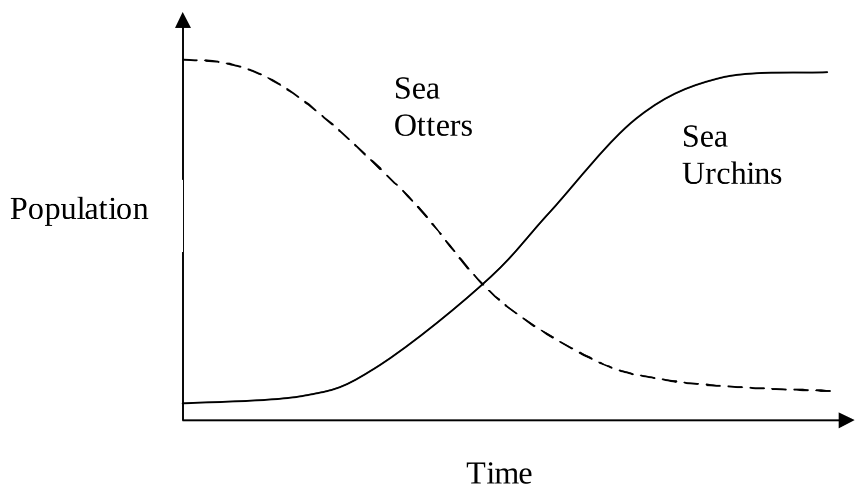
What problem has Quinlan presented to us in "The Case of the Twin Islands?" Can we capture the problem in a behavior over time graph to look at it more closely? We learned from the story that sea otters were once plentiful in the waters off two neighboring islands until hunters killed them off for their furs. The otter population rebounded around Amchitka Island where kelp forests also flourish, but there are no otters in the barren waters around Shemya today. Why are the two ecosystems so different?

Ask students to sketch important changes over time in the story. Drawing graphs helps students focus on the problem and its causes.

> Behavior over time graphs are rough sketches of the patterns of behavior we have observed.



Students may also draw graphs of the changes observed in numbers of seals, eagles, sea urchins, and kelp plants. Some of these patterns will be similar to the pattern for the sea otter population. Sea urchins, however, increased as the otters decreased near Shemya.

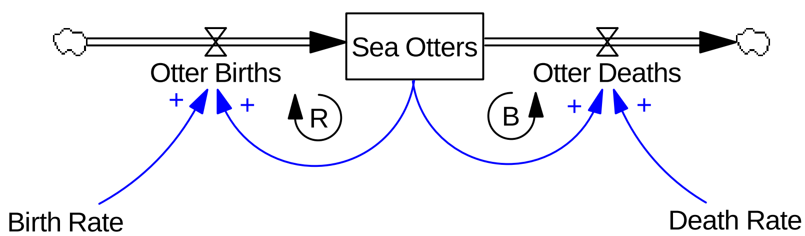


These graphs define the problem. They describe the behaviors we are trying to understand.

Seeing the Structure

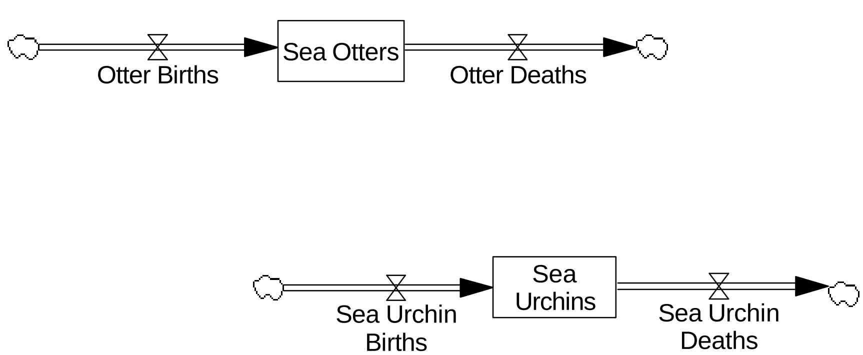
1. The sea otter is one of the key species in the story. Students should be able to construct a simple stock/flow map of otter population.

In population stock/flow maps, the size of the population affects the number of births and deaths each year. In the Mammoth Game lesson, for example, births were determined by the number of mammoths in the stock and the rate at which they had babies. Deaths could be seen in a similar way. The reinforcing loop spurred exponential growth, while the balancing loop caused the population to approach zero.



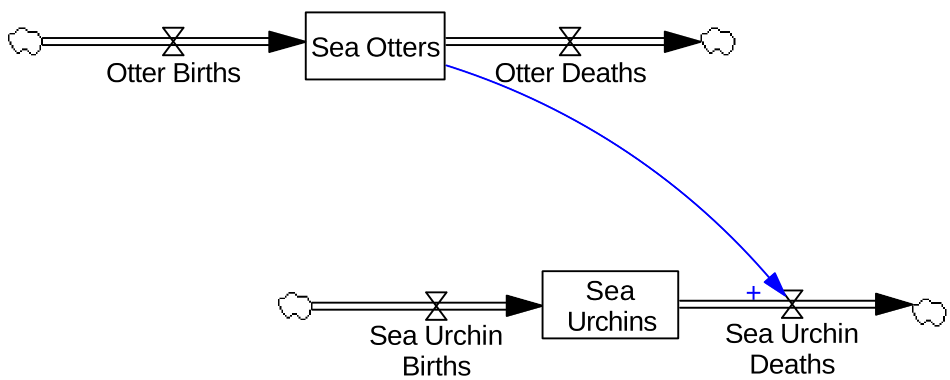
The Twin Islands story has so many population stocks that it is clearer to use the simplified structure of the first diagram above. All of the animals and plants in the system increase and decrease according to their own birth, regeneration and death rates, driven by the feedback processes shown above. Recognizing that these processes are still at work in the background, we will leave these details out of the drawing for now while we focus on the bigger picture – the broader ecological balance among the species.[2]

2. Quinlan tells us that although sea urchins eat many kinds of marine animals, sea urchins are their favorite food. Sea otters prey on sea urchins. We can add a stock for sea urchins, since that is another population that increases and decreases over time in our story.

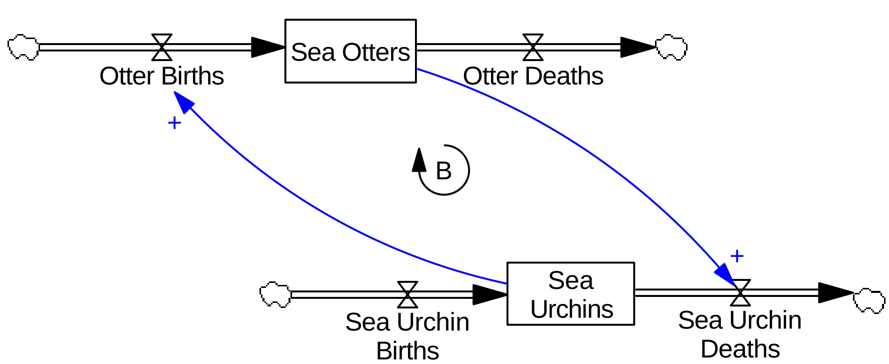


3. Sea urchins are “born” when females release many eggs into the water and some are fertilized and grow into adults. But, what causes sea urchin deaths? Ask students to think about how the populations of sea otters and sea urchins are linked, as told in the story. Sea otters eat the sea urchins. The more sea otters there are, the more sea urchins they eat, reducing the stock of sea urchins.

   (Sea otters deplete the sea urchin population, but sea otters have other food sources that are not represented in the story and the diagram.)



4. Is there more to the relationship between sea otters and sea urchins? Do the sea urchins affect the size of the sea otter population? Yes, when there are plenty of sea urchins to eat, the sea otter population can flourish.



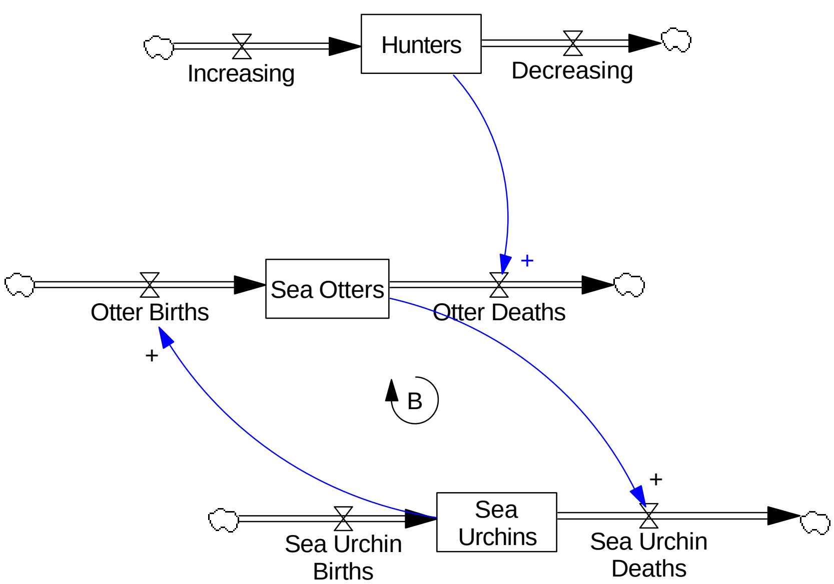
Predator and Prey

Can you tell the story of the relationship between predators and their prey from our stock/flow map of sea otters and sea urchins?

1. When there are plenty of sea otters, they eat many sea urchins. If sea urchins are eaten faster than they can be "born" then their population declines.
2. When there are few urchins left, the otters do not have enough to eat so their birth rates decline. (Students may notice that a shortage of urchins may also increase the sea otter death rate by starvation.) Eventually there are fewer sea otters around.
3. With fewer otters preying on them, the sea urchin population can grow again to its earlier abundance.
4. But eventually, with plenty of sea urchins to eat, the reduced population of sea otters can once again feast and grow. The cycle repeats again.

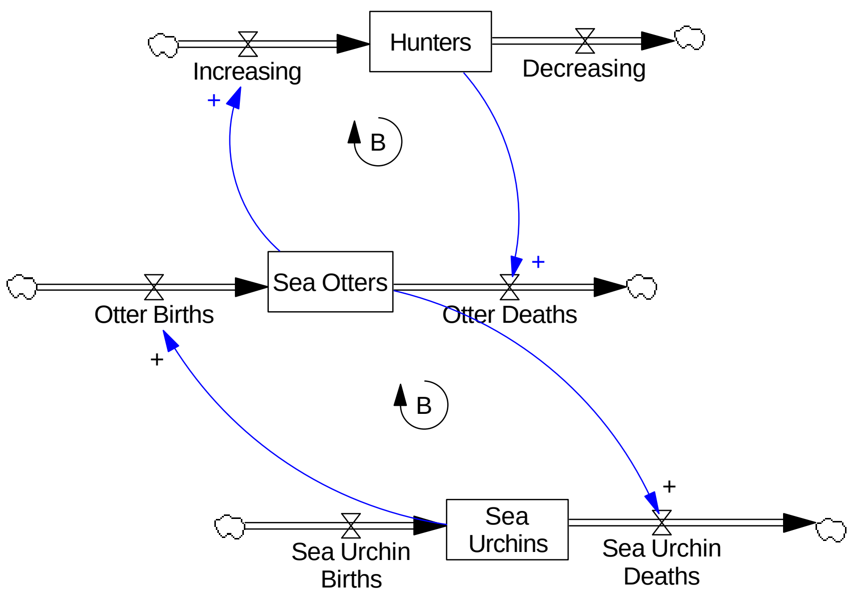
This balancing back and forth explains our behavior over time sketch of otters and sea urchins – before hunters upset the delicate predator/prey balance.

5. What else affected the population of sea otters? The author tells us that human hunters nearly drove sea otters to extinction. Show this by constructing a stock/flow diagram of hunters and indicating that the hunters killed the sea otters. The more hunters there were the more sea otters they caught.



The “clouds” are the boundaries of the system.
We are concerned with the number of hunters in our waters,
not where they came from or where they go after they leave.

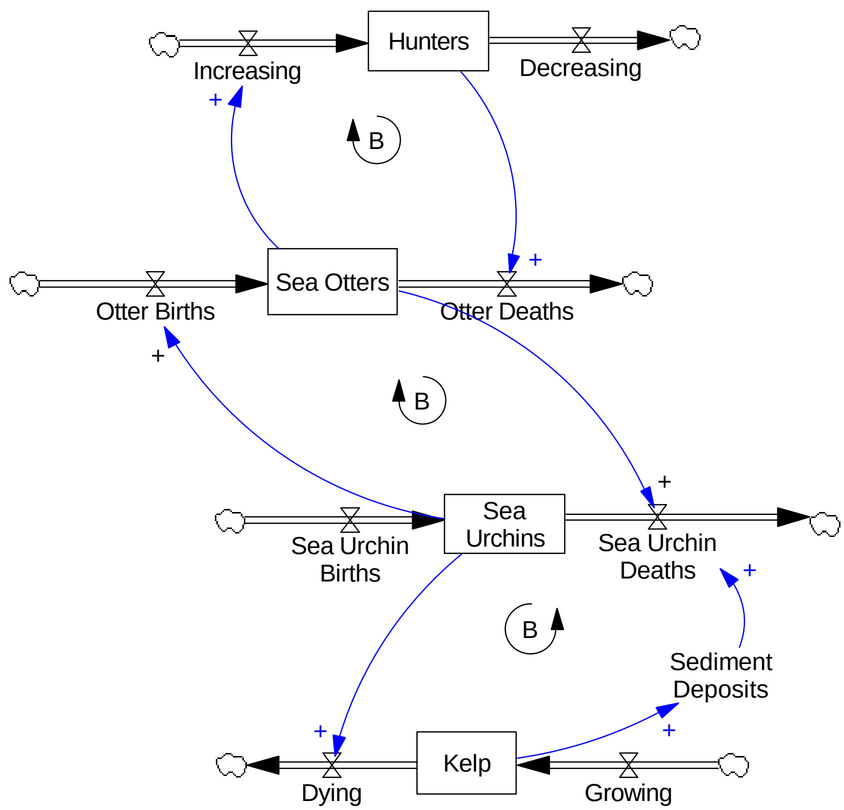
6. How did the sea otters influence the number of hunters? Hunters were attracted to places where otters were originally plentiful. Connect the sea otter stock to the flow that increases the number of hunters.



? **Does this structure look familiar? Trace the story of the loops to describe the predator/prey relationship between hunters and sea otters.**

When there were many sea otters, many hunters came. As hunters killed off the sea otters in our waters, there were fewer sea otters for hunters to catch, so they went hunting elsewhere. Without hunters, the sea otter population could grow again. If there were not laws against hunting now, hunters would be drawn back to catch their plentiful prey again.

7. What else can affect the population of sea urchins? What does the author tell us about the relationship between sea urchins and kelp plants? The sea urchins graze on the kelp, while the sediments deposited in the calm kelp forests keep the urchin population from growing too fast. When there were "hordes of sea urchins," however, they ate so much that they even gnawed through the bases of the kelp fronds, killing them all.



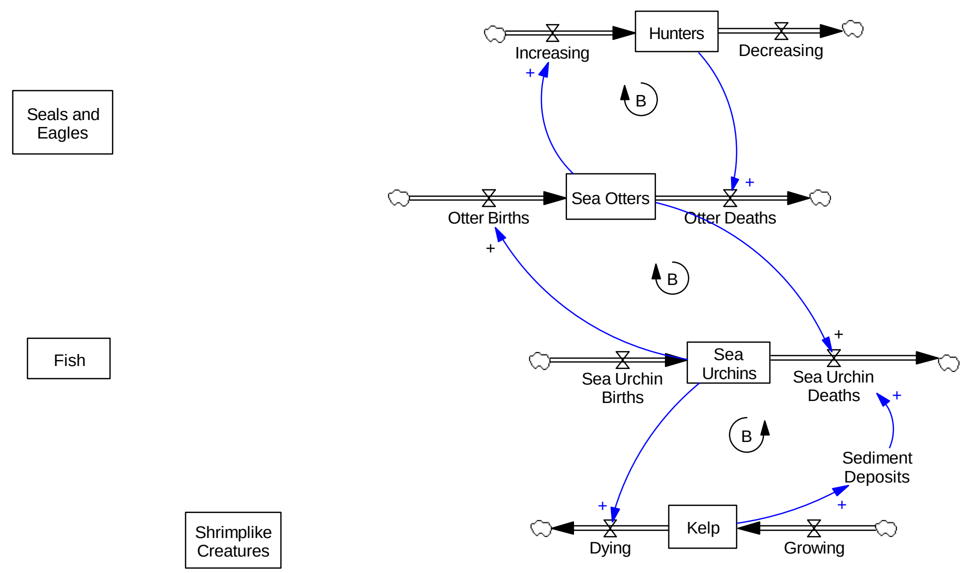
? **Can you tell the story of this loop to explain nature's delicate balance between sea urchins and kelp forests?**

When the ecosystem is in balance, the sea urchins eat the kelp, while the kelp causes sediment deposits that limit the sea urchin population. We saw this balance in the lush kelp forests near Amchitka Island.

However, if something causes a very big increase in the sea urchin population (like a decrease in sea otters), the sea urchins eat more and kill all the kelp plants. Without the smothering sediments, the sea otter death rate slows. If the sea urchin deaths fall below their "births," the population will grow exponentially (remember those population feedback loops). This is what happened around Shemya Island.

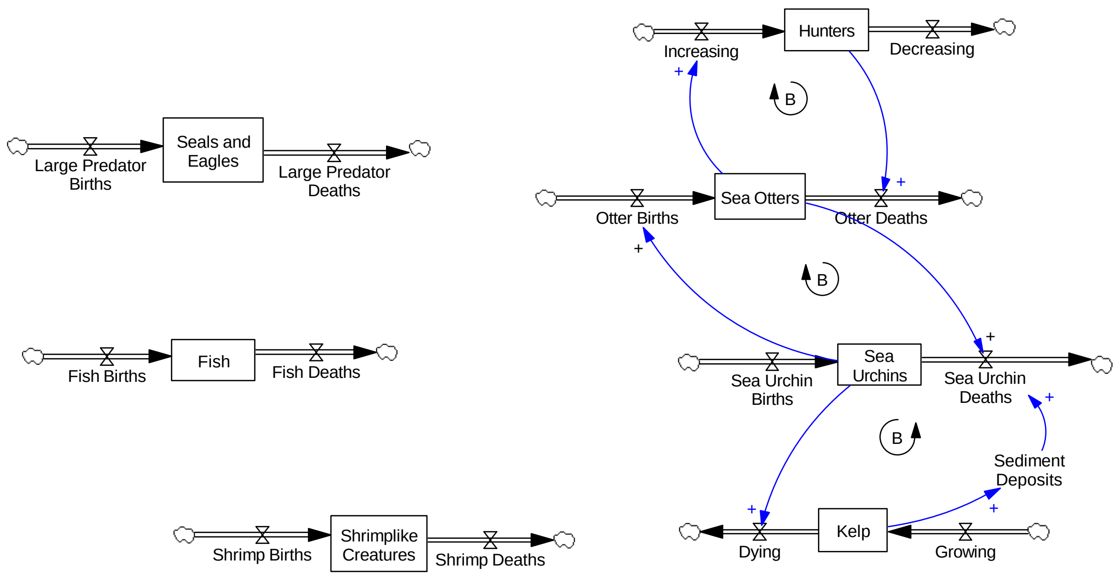
8. What else changed when kelp forests were lost? Using the causal loop diagrams students developed after reading "The Case of the Twin Islands," identify the other important stocks in the ecosystem.

   If you could take a snapshot of the ecosystem at one moment in time, what accumulations would you see?

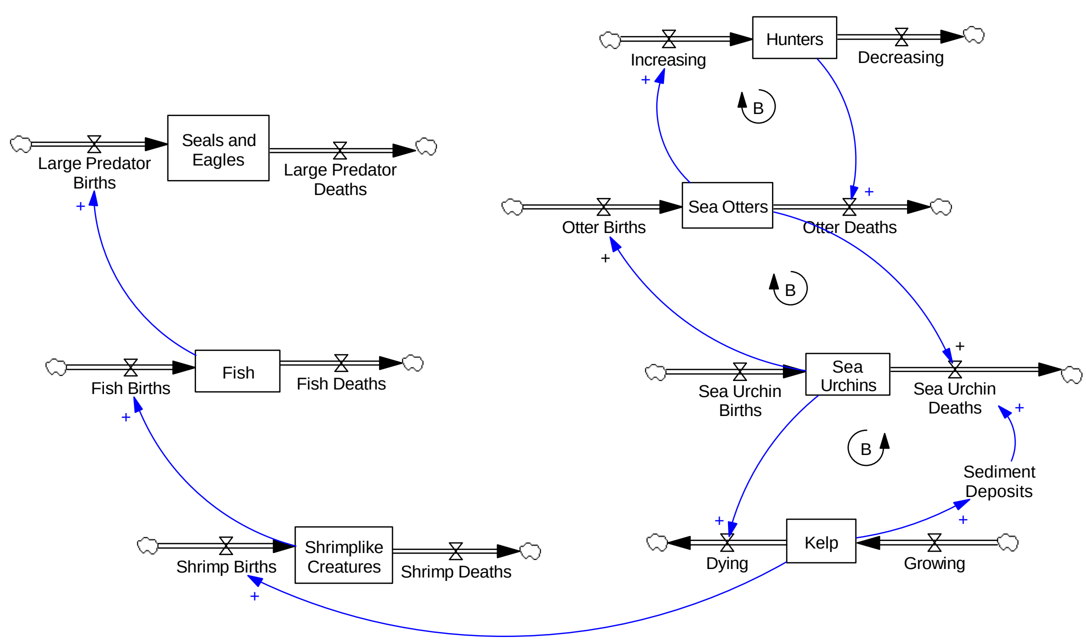


9. Each of these stocks can increase and decrease depending on the rates of their flows. See if students can create original names for inflows and outflows to the stocks. We use the term "births" loosely here, knowing that these species have very different reproductive systems.

   Although not shown in detail here, each population has a reinforcing feedback loop for "births" and a balancing feedback loop for deaths, just like our earlier otter population diagram.



10. Referring back to "The Case of the Twin Islands" and their causal loop diagrams, ask students to draw the connections among these population stocks. Tell the story of each connection.



A healthy kelp forest provides a safe habitat for shrimplike amphipods and isopods, so the more kelp plants there are, the more of these creatures there are. The shrimplike creatures provide food for fish – the more food, the more fish. Fish provide food for seals, bald eagles and other large predators.

? **Are there more predator prey relationships in our ecosystem?**
Yes, fish prey on the shrimplike creatures, and the large predators prey on the fish. Their relationships are similar to the delicate predator/prey balance we saw between sea otters and sea urchins.

Although students may draw and discuss these additional predator/prey connections, we do not need to include them to address our original problem (the increase in sea urchins and the absence of kelp around Shemya Island) because the shrimp population does not cause an increase or decrease in kelp. An absence of shrimp would not disturb the sea urchin/kelp balance, our problem focus.

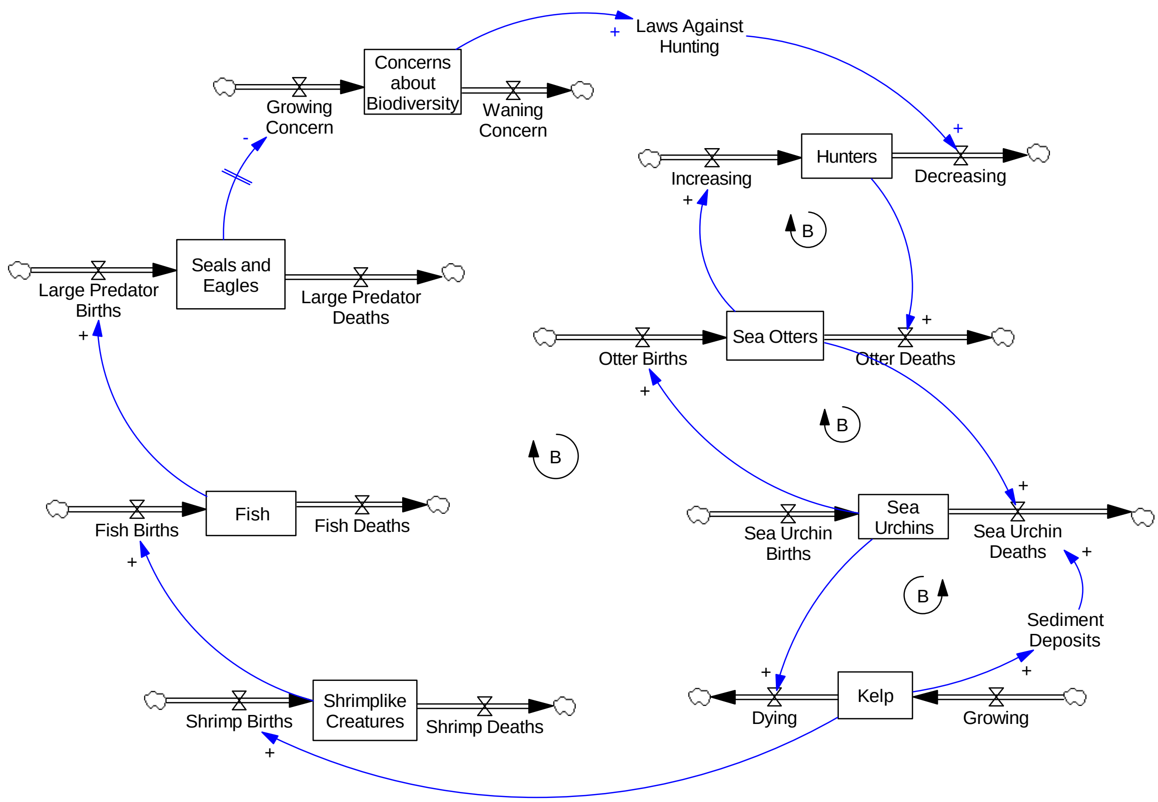
Our goal is to understand what is causing the problem – the sea urchin barrens – not to include everything we might know about the system. Keep a sharp focus on the problem.

11. What is missing to finish the story? Quinlan tells us that the ecosystems of sea otters, sea urchins and kelp were originally in balance around both islands. However, when the hunters moved in and caused a drastic outflow draining the stock of sea otters, the number of otters who were eating sea urchins declined. The stock of urchins grew as their outflow rate slowed, leaving more of the creatures to eat the kelp. The kelp had provided an environment supporting a strong population of shrimp, who in turn were prey for fish. Fish had their place in the food web, feeding seals and eagles.

    Eventually, environmentalists began to notice the decline of “popular” species such as sea otters, seals and bald eagles. They became alarmed by the decreasing biodiversity in the area and raised concerns about the ecological consequences hunting sea otters. When the environmental concerns got high enough, people supported laws to limit or ban hunting and changed their buying habits to use fewer products derived from sea otters.

    We can show this rising environmental awareness as a stock (recognizing that it is a simplification for our purposes). Notice that there is a delay in the time it takes people to recognize and acknowledge the problem.

A stock is not always an accumulation of tangible things. Environmental concerns about biodiversity can increase and decrease over time too.



This stock/flow diagram completes our story. As the number of large predators decreased, the environmental concerns eventually grew (a change in the opposite direction labeled "-") until people passed laws to curtail hunting.

? **How does our stock/flow map help us see the web of relationships within an ecosystem?**

Each stock influences at least one flow that is connected to another stock. Normally, nature maintains a balance. When one stock, or population, reaches a level so high or low that changes begin to ripple through the system, the connections to other flows help stabilize the ecosystem. For example, if the sea urchin population grows beyond a certain level, the kelp forest may be damaged by them. In a healthy ecosystem, the sea otters would feast on the abundance of urchins, and the kelp would have a chance to regenerate.

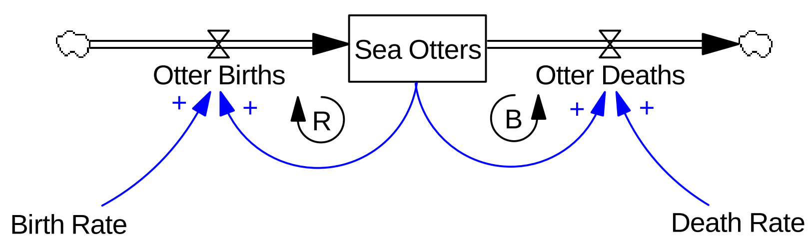
? **Why is our major feedback loop a balancing loop? From any starting point, trace the increases and decreases around the loop (or use the up and down arrows we introduced in Lesson 2).**

An initial increase in hunters causes a decrease in sea otters which then causes a decrease in kelp. Fewer kelp plants means fewer shrimplike creatures which causes fewer fish and then fewer large predators. As seals and eagles decline, environmental awareness rises, which leads to laws banning hunting, and therefore fewer hunters. So, an initial increase in hunters caused a decrease in hunters. Around the loop again, this decrease in hunters would lead to more sea otters, relaxed concerns and eventually an increase in hunters again. The change balances back and forth.

Remember, if an initial change reverses direction around the loop, it is a balancing loop.

? **If the balancing loops tend to balance the ecosystem, what causes growth or decline in the species?**

Reinforcing loops cause exponential growth. Remember that each of our population inflows is determined by the size of the population and its growth rate, just like the Mammoth births in Lesson 3 and our earlier sea otter diagram.



Whenever something causes births to exceed deaths any population will begin to grow exponentially. In nature, balancing loops in the system work to limit this unrestrained growth.

? **Why did the sea otters come back to Amchitka and not to Shemya?**

*As we read in **The Shape of Change**, scientists have many theories including differences in coastal currents, algae levels, predator relationships, and environmental contamination. Because sea otters are a keystone species, their presence holds together the diverse ecosystem around Amchitka.*

? **Could a vibrant kelp forest come back to Shemya? Look at our stock/flow map for clues.**

The stock of kelp plants is controlled by the number of sea urchins eating them. If a big storm or disease decimates the sea urchin population, the kelp can grow back. Scientists have found that sea urchin/kelp ecosystems alternate between relatively stable luxuriant kelp forests and sea urchin barrens.[3] *Our stock/flow map shows us how a disruption in one part of the feedback system can tip the balance from one state to the other.*

> Drawing a stock/flow map has helped us understand a complex web of interdependencies.
>
> It is not an "answer." It is a process of raising better and better questions about how systems work.

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[1] "The Case of the Twin Islands" is a chapter from *The Case of the Mummified Pigs and Other Mysteries of Nature*, by Susan E. Quinlan, illustrated by Jennifer Owens Dewey, published by Caroline House, Boyds Mills Press, Inc., 1995. The chapter is reprinted with permission in ***The Shape of Change***, page 133.

[2] To build a system dynamics computer simulation model of the system, we would include all the birth, regeneration and death rates (and many other details) to specify explicitly how the stocks increase and decrease over time.

[3] For more information, see "Ecological Role of Purple Sea Urchins," by John S. Pearse, *Science* 314, (2006). Also at www.sciencemag.org.