Keystone Predator

Introduction

A diversity of strange-looking creatures makes their home in the tidal pools along the edge of rocky beaches. If you walk out on the rocks at low tide, you'll see a colorful variety of crusty, slimy, and squishy-looking organisms scuttling along and clinging to rock surfaces. Their inhabitants may not be as glamorous as the megafauna of the Serengeti or the bird life of Borneo, but these "**rocky intertidal**" areas turn out to be great places to study community ecology.

An **ecological community** is a group of species that live together and interact with each other. Some species eat others, some provide shelter for their neighbors, and some compete with each other for food and/or space. These relationships bind a community together and determine the local **community structure**: the composition and relative abundance of the different types of organisms present. The **intertidal community** is comprised of organisms living in the area covered by water at high tide and exposed to the air at low tide.

This laboratory is based on a series of famous experiments that were conducted in the 1960's along the rocky shore of Washington state, in the northwestern United States. Similar intertidal communities occur throughout the Pacific Northwest from Oregon to British Columbia in Canada. The nine species in this laboratory's simulated rocky intertidal area include three different algae (including one you may have eaten in a Japanese restaurant); three stationary (or "sessile") filter-feeders; and three mobile consumers.

Ecological communities are complicated, and the rocky intertidal community is no exception. Fortunately, carefully designed experiments can help us tease apart these complexities, providing insight into how communities function. As will become apparent, understanding the factors that govern community structure can have serious implications for management. In this laboratory, you'll use simulated experiments to elucidate how interactions between species can play a major role in determining community structure. You will apply techniques similar to those used in the original

studies, in order to experimentally determine which species in the simulated rocky intertidal are competitively dominant over which others. You'll then analyze gut contents and use your data to construct a food web diagram. Finally, you'll conduct removal experiments, observing how the elimination of particular species influences the rest of the community. When you've completed this lab, you should have a greater appreciation for the underlying complexity of communities, and for how the loss of single species can have surprisingly profound impacts.

Food Chains, Food Webs and Trophic Levels

You probably know that herbivores eat plants and that predators eat herbivores. The progression of what eats what, from plant to herbivore to predator, is an example of a **food chain**. Omnivores eat both plants and animals. Within a community, producers, herbivores, predators, and omnivores are linked through their feeding relationships. If you create a diagram that connects different species and food chains together based on these relationships, the result is called a **food web diagram**.

Ecosystems can also be represented by a pyramid comprising a series of "trophic levels". A species' trophic level indicates its relative position in the ecosystem's food chain. **Producers** (including algae and green plants) use energy from the sun to produce their own food rather than consuming other organisms, thus they occupy the lowest trophic level. Since herbivores consume the producers, they occupy the next trophic level. Predators eat the herbivores, thus occupying the next higher trophic level. Omnivores occupy multiple trophic levels. The highest level is occupied by top-level predators, which are not eaten by anything (until they die). Generally, but not always, lower trophic levels have more species than do higher levels within a community.

Competition

Among community relationships, predation is perhaps the most obvious but certainly not the most important. Two species may also compete with each other for space or food. Stationary organisms in particular must often compete intensively for limited space. When one species is better at obtaining or holding space than another, or is able to displace the second species, the 'winner' is said to be **competitively dominant**. In the same way that you can draw a food web, you can also construct a diagram to illustrate which species are superior competitors within a community, called a **competitive dominance hierarchy**. In this lab, you will create competition dominancy hierarchy and food web diagrams to help you understand the community structure of the intertidal zone.

Dominant versus Keystone Species

In many communities, there is one species that is more abundant in number or biomass than any other, often referred to as the dominant species. For example, in a dense, old-growth forest, one type of late successional tree is often the **dominant species**. As you might imagine, such species greatly affect the nature and composition of the community.

However, a species does not have to be the most abundant to have the greatest impact on the community. Imagine an archway made of stones. The one stone at the top center of the arch supports all the other stones. If you remove that stone, called the "keystone", the arch crumbles. In some communities, the presence of a single species controls community structure even though that species may have relatively low abundance. These organisms are known as **keystone species**. An important characteristic of a keystone species is that its decline or removal will drastically alter the structure of the local community. For example, many keystone species are top predators that keep the populations of lower-level consumers in check. If top predators are removed, populations of the lower-level organisms can grow, dramatically changing species diversity and overall community structure, sometimes resulting in the collapse of the entire community.

The EcoBeaker® Model

If you're curious about how the simulated intertidal community works, here's the basic idea. In EcoBeaker models, each individual belongs to a "species" which is defined by a collection of rules that determine that species' behavior. For example, species that are mobile consumers follow rules that dictate how far they can move in a time step, what they can eat, how much energy they obtain from their prey, how much energy they use when they move, etc. When an individual consumer's energy runs out, it dies. Individuals within species all follow the same rules, but because the rules defining species include some random chance (e.g., which direction to turn), you will notice variability in what individuals are doing at any given time. Different species behave differently because they don't have the same "parameters" assigned for their rules (e.g., they might eat different species or move slower or faster).

The six stationary species in the model—the three algae and the three filter feeders (or "sessile consumers")—are modeled differently than the mobile consumers. The simulation uses a **transition matrix** for these six stationary species. The transition matrix is a set of probabilities that determine what happens from one time step to the next on a particular space on the rock. For each species, the transition matrix lists the probability of an individual of that species settling on top of bare rock, the probabilities of being replaced by each of the other species, and the probability of dying (and being replaced by bare rock). In addition, the transition matrix includes the probability of bare rock

remaining bare. For example, a patch of rock that contains Nori Seaweed (*Porphyra*) may do one of three things each time step: host a different species (that is, another organism displaces Nori Seaweed), continue to be occupied by Nori Seaweed, or become bare rock (the Nori Seaweed dies and is not replaced). Each of these changes, or transitions, has a probability associated with it included within the transition matrix. If one species out-competes another for space, this will be reflected in the relevant transition probability.

More Information

Links to additional terms and topics relevant to this laboratory can be found in the Keystone Predator Library accessible via the SimBio Virtual Labs® program interface.

Starting Up

If you've explored tide pools (a fun thing to do if you visit a rocky coast), you likely know that many of the plants and animals living in them are unusual. This section will introduce you to the different species you'll encounter in this lab.

[1]   Make sure that you have read the introductory section of the workbook. The background information and introduction to ecological concepts will help you understand the simulation model and answer questions correctly.

[2]   Start the program by double-clicking the **SimBio Virtual Labs®** icon on your computer or by selecting it from the Start Menu.

[3]   When **SimBio Virtual Labs®** opens, select the **Keystone Predator** lab from the **EcoBeaker®** suite.

When the **Keystone Predator** lab opens, you will see several panels on the screen:

–   The left side of the screen shows a view of an intertidal zone area. This is where you will be conducting your experiments and observing the action.

–   A bar graph on the right shows the population sizes of all of species in the intertidal area.

–   Above the graph is a list of the plant and animal species included in the simulation. You can switch between Latin and common names of each species using the tabs above the species list. The workbook will refer to common names.

–   In the bottom left corner of the screen is the **CONTROL PANEL**. To the right of the Control Panel is a set of **TOOLS** that you will use for doing your experiments. These will be described in the following exercises, as you need them.

[4]   Click on the names in the **SPECIES LEGEND** in the upper right corner of the screen to bring up library pages for each species. Use the library to answer the following question:

[4.1]   **If you slipped on a rock while exploring a tide pool and your knee became inflamed, which of the three algal species might help reduce the swelling?**

Nori   Black Pine   Coral Weed   **(Circle one)**

[4.2]   **Use the information in the Introduction and Library pages to fill in the blank spaces in the table at the top of the next page.**

★   *HELPFUL HINT: "producers" are organisms that generate their own food using energy from the sun, "filter-feeders" are consumers that extract food particles out of the water, and "stationary" (or "sessile") organisms do not actively move around (at least not as adults) — they permanently adhere to substrates such as rocks.*

COMMON NAME OF ORGANISM (GENUS)	TYPE OF ORGANISM	PRODUCER OR CONSUMER?	FILTER FEEDER? (YES/NO)	STATIONARY OR MOBILE?
Nori Seaweed (*Porphyra*)	Algae	Producer		
Black Pine (*Neorhodomela*)	Algae			Stationary
Coral Weed (*Corallina*)	Algae		NO	
Mussel (*Mytilus*)	Mollusk			
Acorn Barnacle (*Semibalanus*)	Crustacean			
Goose Neck Barnacle (*Mitella*)	Crustacean	Consumer		
Whelk (*Nucella*)	Mollusk			
Chiton (*Katharina*)	Mollusk		NO	
Starfish (*Pisaster*)	Echinoderm			Mobile

[5]   When you are done completing the above table, start the simulation by clicking the **GO** button in the **CONTROL PANEL**. Watch the action for a bit. Notice how the mobile consumers clear off areas of rock by eating, and how the stationary species recolonize those areas.

[6]   Click the **STOP** button to pause the simulation.

Look at the population graph. The **"Population Size Index"** represents the number of individuals of each species present in the simulation. For the three algal species, a more appropriate measure of relative abundance might be percent cover or biomass, because in the real world, a single alga can grow quite large. The EcoBeaker model simulates algal growth as individuals multiplying, which, though not exactly realistic, makes possible the comparison of population sizes for the three algal and six animal species.

[7]   Click the **RESET** button to return the community to its initial state. Then move your mouse over to the population graph and click on one of the bars. You will see the population size for that species displayed.

[7.1]   **Which species in the simulation has the largest population? _____**

[7.2]   **What is the size of the population for that species? _____**

[7.3]   **Which species in the simulation has the smallest population? _____**

[7.4]   **What is the size of the population for that species? _____**

Exercise 1: Flexing Your Mussels

In the **competitive dominance hierarchy** diagram below, the arrows point from weaker to stronger competitors. For example, the arrow pointing from Nori Seaweed to Black Pine indicates that Black Pine is dominant over (i.e., can displace) Nori Seaweed. The diagram also shows that any of the sessile consumers (the barnacles and the mussel) can out-compete any of the algae.
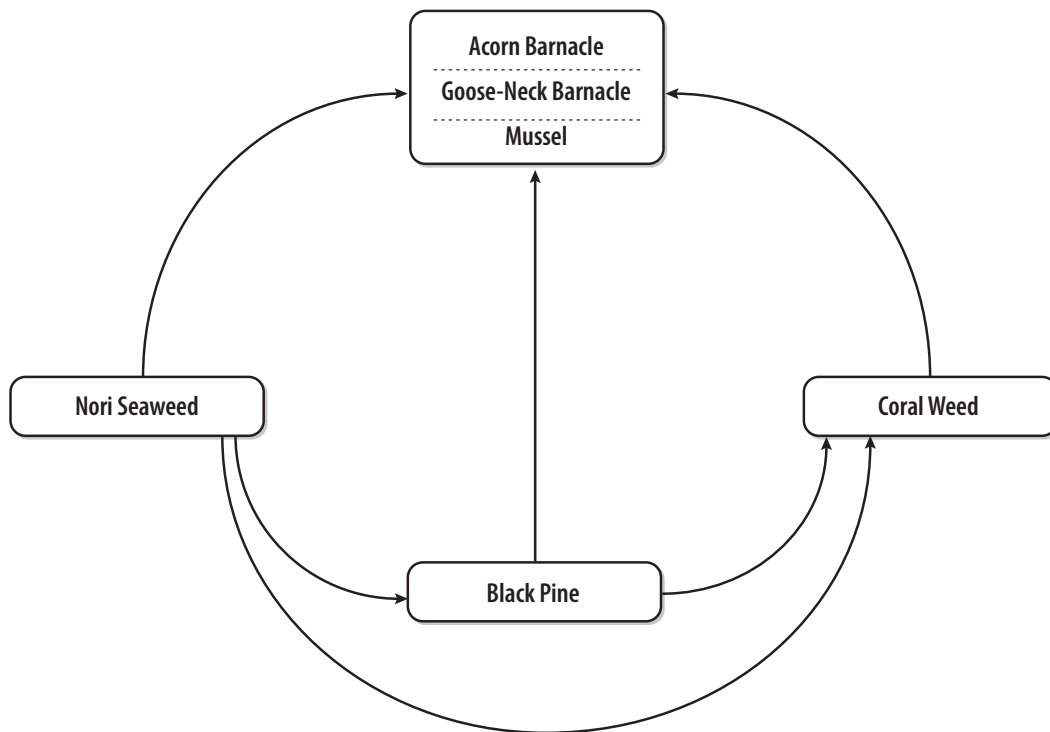
[1]   Examine the figure above and then answer the following question.

    [1.1]   **Which algal species is the strongest competitor?**

          Nori Seaweed Black Pine   Coral Weed   (Circle one)

The diagram *does not* indicate the dominance hierarchy among the three sessile consumers. Fortunately, you have some tools that will let you experimentally determine their competitive relationships. Your approach will involve creating patches of each sessile consumer on an intertidal rock and observing which of the other two sessile consumers successfully invades those patches.

[2]   Select **"Flexing Your Mussels"** from the **Select an Exercise** menu at the top of the screen to load the experimental system.

You should now see only the six stationary species in the simulation (three algae and three sessile consumers)—this is because your assistant is patrolling the shore and keeping the mobile consumers out of your experimental area. Excluding these predators will help you determine the competitive relationships among the sessile consumers.

[3]   Find and click the **ADD SESSILE CONSUMER** button in the **TOOLS PANEL**. If you have trouble finding a particular button in the lab, move your mouse over buttons and 'tool tips' will appear. The **ADD SESSILE CONSUMER** button will initially have an Acorn Barnacle picture on it. If a different species appears, click the downward arrow next to the picture and select the Acorn Barnacle.

[4]   Click somewhere in the Intertidal Zone area, hold down the mouse button, and then drag out a rectangle to create a solid patch of Acorn Barnacles. The rectangle should fill at least a third of the Intertidal Zone area and have no other species inside.

[5]   Use the **STEP** button to advance the simulation one week at a time for ten weeks and monitor which other species displace Acorn Barnacles through time. These species are stealing rock space from the Acorn Barnacles, and thus are competitively dominant.

[5.1]   **Circle the species which are competitively dominant over Acorn Barnacles:**

SESSILE CONSUMERS THAT ARE DOMINANT OVER ACORN BARNACLES

Goose Neck Barnacles	Yes / No (circle yes or no)
Mussels	Yes / No

[6]   **RESET** the simulation. Click the **ADD SESSILE CONSUMER** button and select the Goose Neck Barnacle.

[7]   Repeat steps 4 and 5 for Goose Neck Barnacles.

[7.1]   **Circle the species that are competitively dominant over Goose Neck Barnacles:**

SESSILE CONSUMERS THAT ARE DOMINANT OVER GOOSE NECK BARNACLES

Acorn Barnacles	Yes / No (circle yes or no)
Mussels	Yes / No

[8]   **RESET** the simulation. Click the **ADD SESSILE CONSUMER** button and select the Mussel.
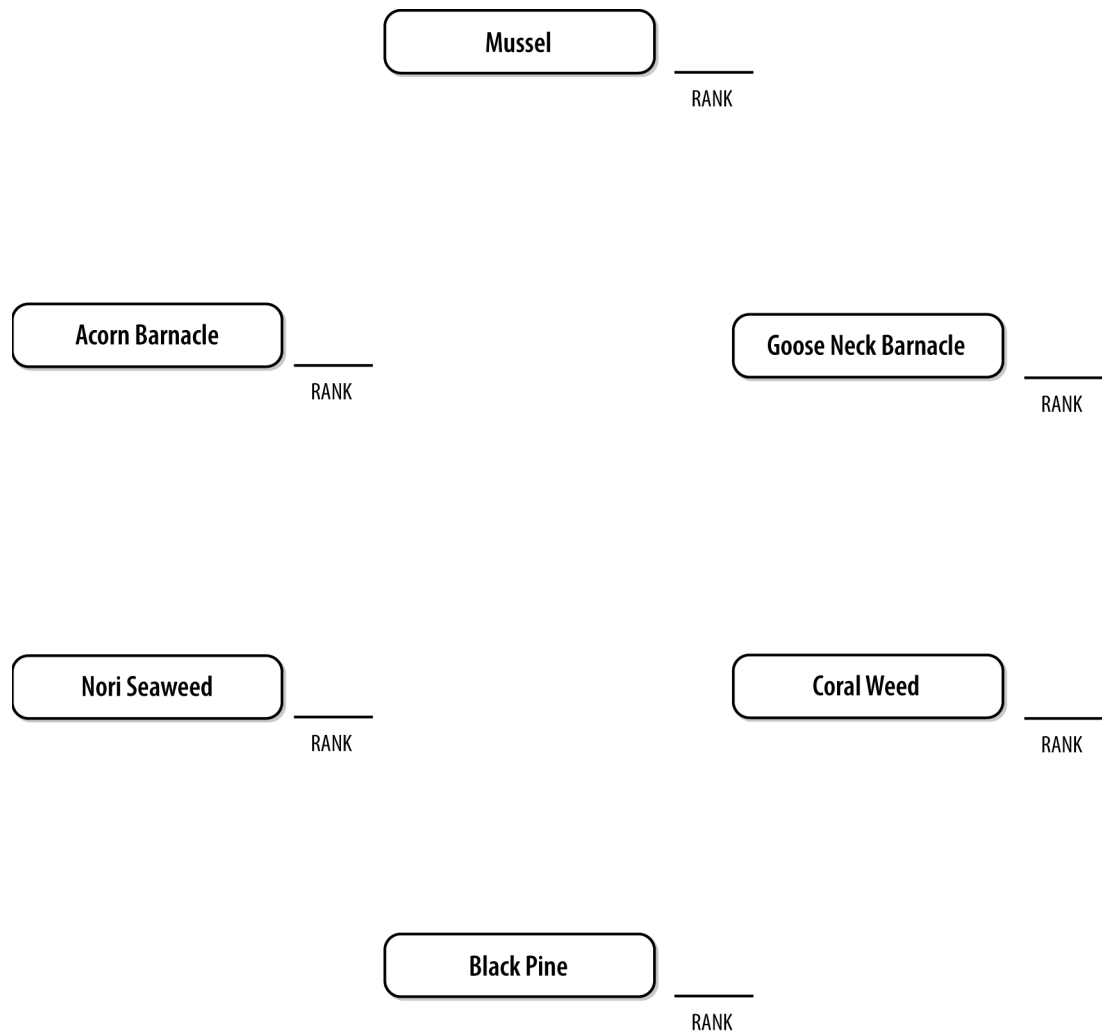
[9]   Repeat steps 4 and 5 for Mussels.

[9.1]   **Circle the species that are competitively dominant over Mussels:**

SESSILE CONSUMERS THAT ARE DOMINANT OVER MUSSELS

Acorn Barnacles	Yes / No (circle yes or no)
Goose Neck Barnacles	Yes / No

[10]   Construct a competitive dominance hierarchy diagram, by drawing arrows showing competitve relationships, using the information you have gathered from your experiments. Next to each species name, indicate how many arrows point to that species. The highest number indicates the most highly ranked and aggressive, or "best", competitor. If you do this correctly, each species should have a different rank.

Mussel _____
RANK

Acorn Barnacle _____
RANK

Goose Neck Barnacle _____
RANK

Nori Seaweed _____
RANK

Coral Weed _____
RANK

Black Pine _____
RANK

[11]   Click the **TEST YOUR UNDERSTANDING** button in the bottom right corner of the screen and answer the question in the window that pops up.

Exercise 2: You Are What You Eat

Now you will continue to investigate this intertidal community by determining what each of the mobile consumer species eats. One trick ecologists use to find out what creatures eat is to look at what's in their guts or excrement. If you eat something, it hangs around in your stomach for a little while, and then (later) the undigested parts come out the other end. Normally, when researchers look at gut contents they have to kill the animal, cut it open, and examine what is inside (people get paid to do this!). Within SimBio Virtual Labs there is a kinder and gentler method for determining gut contents.

[1]   Select "**You Are What You Eat**" from the **Select an Exercise** menu at the top of the screen.

[2]   You will now see all nine species in the simulation: three algae, three sessile consumers, and three mobile consumers: Starfish, Whelk, and Chiton.

[3]   Start running the simulation (click **GO**).

[4]   Watch the action for about 100 weeks and monitor the abundance of species in the population graph. Notice how the population index for each species fluctuates and eventually settles at a relatively stable level.

[5]   **STOP** the simulation.

[6]   Click the **MICROSCOPE** ("VIEW ORGANISM") button in the **TOOLS PANEL** to activate your mobile "Gut-o-Scope" (patent pending).

[7]   Click your favorite Starfish, Whelk, or Chiton — your choice!

A window will appear with gut content information for that individual, either identifying the predator's last prey item or indicating that the gut is empty (because the creature has not eaten recently). Note that if you click on organisms that don't have guts (algae or filter feeders), you won't see gut contents.

[8]   You will now conduct a survey of the three mobile consumers to learn which species they eat. The data forms below will help you record and summarize your findings. The forms are divided into three sections, one for each mobile consumer.

[8.1]   In each data table section, record gut content data for 10 randomly-selected individuals of that species. Ignore individuals that have not eaten recently (indicated by gut contents labeled "empty"). If recorded correctly, each row of the data form should have one species circled. At the bottom of each section, record the total number of individuals circled in each column.

GUT CONTENT DATA FOR WHELK

1.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
2.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
3.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
4.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
5.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
6.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
7.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
8.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
9.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
10.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
	#_____	#_____	#_____	#_____	#_____	#_____	#_____	#_____	#_____

GUT CONTENT DATA FOR CHITON

1.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
2.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
3.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
4.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
5.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
6.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
7.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
8.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
9.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
10.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
	#_____	#_____	#_____	#_____	#_____	#_____	#_____	#_____	#_____

GUT CONTENT DATA FOR STARFISH

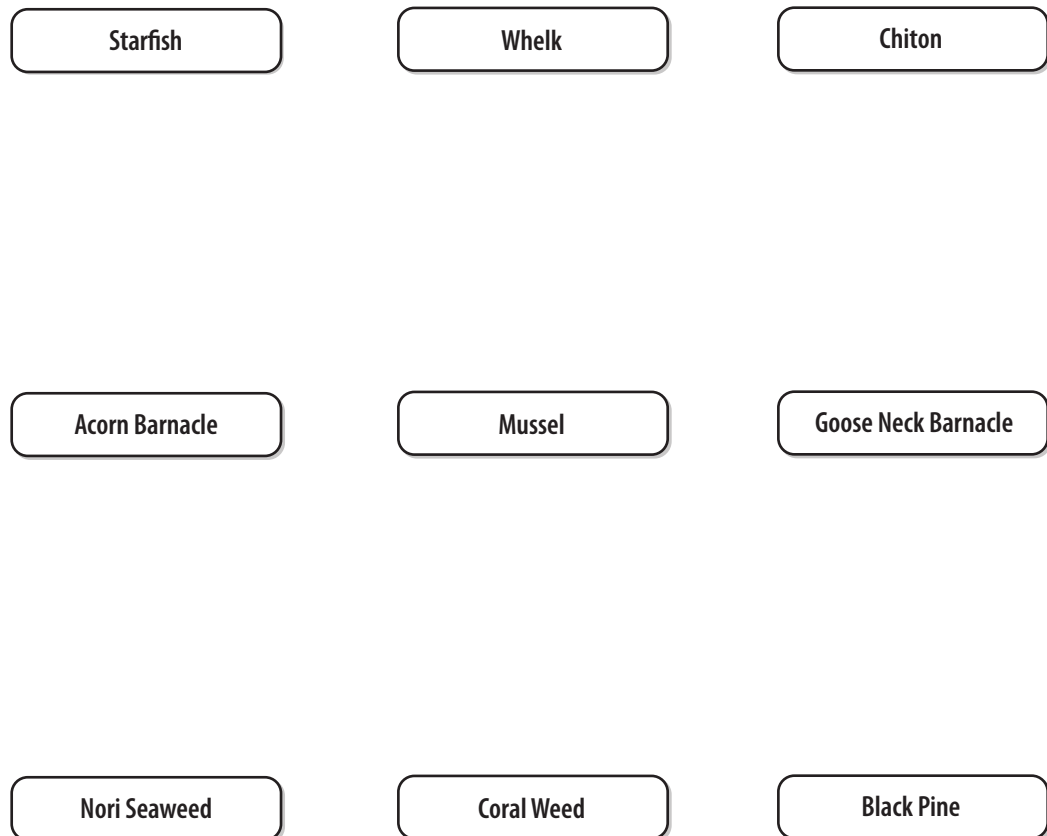|									
1.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
2.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
3.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
4.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
5.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
6.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
7.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
8.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
9.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
10.	Nori	Black Pine	Coral Weed	Mussel	Acorn	Gooseneck	Whelk	Chiton	Starfish
	#_____	#_____	#_____	#_____	#_____	#_____	#_____	#_____	#_____

[8.2] **For each mobile consumer species below, record its prey and the percentage of diet each prey species comprises for that consumer (e.g., 4 out of 10 samples = 40%). The numbers in each column should add up to 100%.**

	WHELK	CHITON	STARFISH
Prey Species:			
Percentage of Diet:			
Prey Species:			
Percentage of Diet:			
Prey Species:			
Percentage of Diet:			
Prey Species:			
Percentage of Diet:			

[9]   You now have enough information to construct a food web diagram from your findings. Consider the hypothetical example below. In a forest, both deer and rabbits eat the plants. Wolves, the predators in the system, eat both deer and rabbits. We can draw these feeding relationships like this, with arrows pointing **to** the consumer:
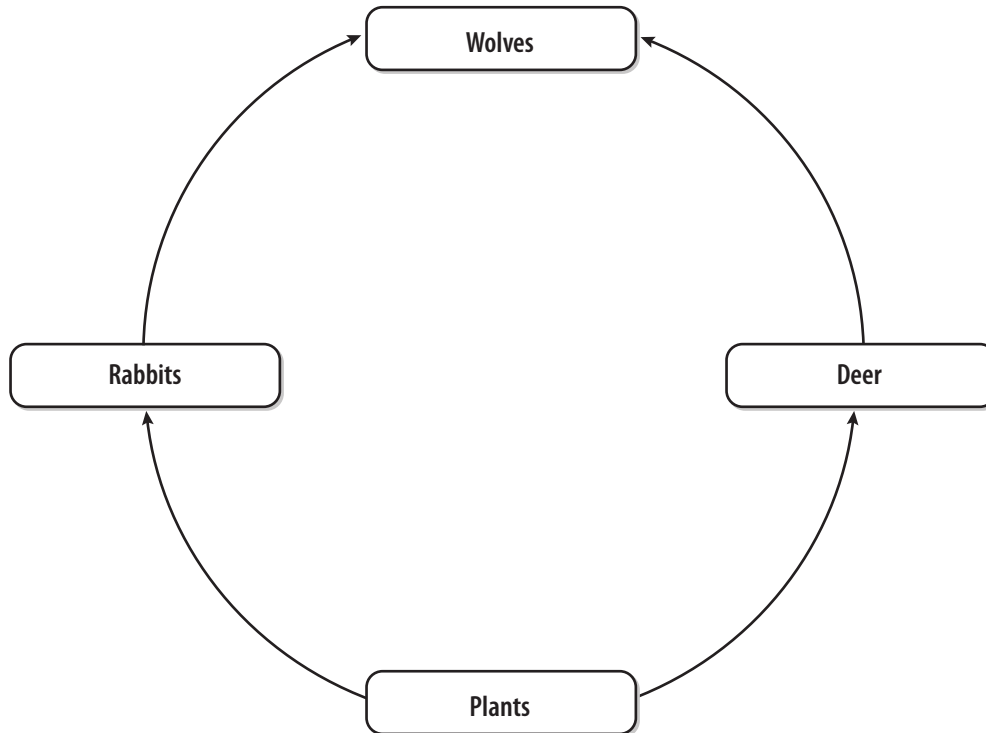
[9.1]   Use your data on feeding relationships to construct a food web diagram for the organisms that live in the simulated intertidal zone. Link the species names below with arrows that point from prey to consumer. (Unlike the simple four-species example on the previous page, your nine-species diagram will look more complicated, with many crossing lines.)

| Starfish | Whelk | Chiton |

| Acorn Barnacle | Mussel | Goose Neck Barnacle |

| Nori Seaweed | Coral Weed | Black Pine |

[10]   Click the **TEST YOUR UNDERSTANDING** buttonand answer the question in the pop-up window.

Experiment 3: Who Rules the Rock?

Based on your studies so far, you know important details about the competitive and feeding relationships among the species in your simulated intertidal community, and these relationships, when integrated, define the role played by each. One way to more fully elucidate the importance of a species to its community structure is to remove it from the environment and observe what happens. In this exercise, you will experimentally determine how removing each of the highest trophic level species (the mobile consumers) affects the rocky intertidal community structure.

[1]   Before you start your experiments, first make some predictions. Refer back to your data to inform your answers. [NOTE: only one species will be removed in each experiment.]

[1.1]   **In the spaces provided below, predict which other species in the community will be impacted the most by each removal and explain your reasoning.**

Predicted impact of removing Whelk and explanation:

Predicted impact of removing Chiton and explanation:

Predicted impact of removing Starfish and explanation:

[1.2]   **One removal experiment will have a more dramatic impact than the other two. Write down which one you predict this will be, and why:**

[2]   Select **"Who Rules the Rock?"** from the **Select an Exercise** menu.

[3]   Your first step is to record population sizes BEFORE REMOVALS. To make sure the simulation is initialized correctly, click the **RESET** button. A data table is provided on the next page for recording your results.

> ★ *HELFUL HINT: if you click on the colored bars in* **the Population Size** *graph, the numbers (population sizes) that the bars represent will pop up!*

> [3.1]   **In the table on the next page, record the population size of each species at 'Time Elapsed = 0 Weeks' in the BEFORE REMOVALS column.**

[4]   After recording data BEFORE REMOVALS, you are ready to remove mobile consumers. Find the **REMOVE WHELK** button (which depicts a Whelk with a slash through it) in the **TOOLS PANEL**. When you click this button, all Whelk will vanish from the Intertidal Zone.

[5]   For each removal experiment, you will run the simulation for 200 weeks (in model time, not real time!). To do this, first make sure that the Time Elapsed = 0 weeks (RESET if not), and then click the **STEP 200** button in the **CONTROL PANEL**..

> ★ *HELPFUL HINT: If your computer is a little slow, you can speed things up using the Speed Slider to the right of the* **CONTROL PANEL**

[6]   Confirm that the simulation stopped at (or near) 200 weeks. If so, click the bars in the Population Size graph and record the abundance of each species.

> [6.1]   **In the data table, record the population size of each species in the AFTER WHELK REMOVAL column.**

[7]   **RESET** the simulation and confirm that Time Elapsed = 0 weeks. Then click the **REMOVE CHITON** button to remove all Chiton from the Intertidal Zone.

[8]   Click the **STEP 200** button to run the simulation for 200 weeks.

> [8.1]   **When Time Elapsed = 200 weeks, record the population size of each species in the AFTER CHITON REMOVAL column.**

[9]   Finally, **RESET** the simulation and use the **REMOVE STARFISH** tool and the **STEP 200** button to repeat the experiment for Starfish.

> [9.1]   **In the data table, record the population size of each species in the AFTER STARFISH REMOVAL column.**

Abundance Data for Removal Experiments

SPECIES	BEFORE REMOVALS	AFTER WHELK REMOVAL	AFTER CHITON REMOVAL	AFTER STARFISH REMOVAL
Nori				
Black Pine				
Coral Weed				
Mussel				
Acorn Barnacle				
Goose Neck Barnacle				
Whelk		0		
Chiton			0	
Starfish				0

[10]   When your data table is complete, answer the following questions. Try to be as quantitative as possible with your answers, indicating by approximately how much each species increased or decreased in size (e.g., "The Starfish population more than doubled"; "The population of Coral Weed decreased to about half its original size.").

[10.1]   **What were the most dramatic changes to the community after Whelk were removed?**

[10.2]   **What were the most dramatic changes to the community after Chiton were removed?**

[10.3]   **What were the most dramatic changes to the community after Starfish were removed?**

[10.4]   **Which removal had the greatest impact upon the rest of the community?**

[10.5] **Referring back to your competitive dominance hierarchy and food web diagrams, try to explain what happened in the removal experiment that had the greatest impact on community structure. Why was the effect so pronounced?**

[10.6] **Look back at what you predicted would happen when you removed each of the three mobile consumer species in Step 1 above. Were you correct for all three? If not, describe what you think you missed in each case.**

[11] Click the **TEST YOUR UNDERSTANDING** button and answer the question in the pop-up window.

The Keystone Species Concept

As described in the Introduction, a "keystone" is the stone in the middle of the top of an arch that supports all the other stones. If you remove the keystone, the whole arch falls down. In many ecological communities, one species can play a particularly important role in determining and supporting community structure. Remove this species and the community structure changes radically. When you removed one mobile consumer from the intertidal simulation, it had a much larger impact on the rest of the community compared to the removal of the other two mobile consumers. This species is an example of a **Keystone Species**, which has a disproportionately large impact on its ecological community compared to its relatively low abundance.

The keystone predator in the intertidal zone you studied occupies a position at the top of the food chain, which is common for keystone species. They also tend to be susceptible to both natural and human disturbance. Other examples of the dramatic effects of keystone species removals in the real world include deer populations rapidly increasing with the local extinction of predatory wolves, kangaroo rats dominating rodent communities with the removal of coyotes, and sea urchins decimating kelp forests when predatory sea otters go into decline.

Optional: Species Reintroduction

[12]   Conservationists sometimes advocate reintroducing native species that have gone extinct locally. A well-known recent example is the reintroduction of wolves into Yellowstone National Park.

> [12.1]   **If you were to reintroduce Starfish into the Intertidal Zone, what do you think would happen to the intertidal community? Write your prediction in the space provided below:**

[13]   **RESET** the simulation, **REMOVE STARFISH**, and **STEP 200** weeks forward (this returns the simulation to its state at the end of the previous exercise). Click the **ADD MOBILE CONSUMER** tool and select Starfish.

[14]   Move your mouse into the Intertidal Zone and click six or seven times to add some Starfish back into the community.

[15]   Use the **STEP 200** button to advance the simulation another 200 weeks and watch what happens to the population sizes of the different species.

[15.1]   **Briefly describe the changes you observed in abundance of different species.**

[15.2]   **Look at the population sizes and describe how they compare to your BEFORE REMOVAL population data — when you first ran the simulation before removing any of the mobile consumers.**

Extension Experiment: Invasion!

In this exercise, your pristine intertidal area will be invaded by the European green crab, *Carcinus maenas*. As its name suggests, this crab is not native to North America. The green crab is an exotic ("alien") species from Europe that has aggressively invaded large areas of coastline on both the east and west coasts of the United States. As with many invasive predators, the green crab can gain competitive advantage over native species, resulting in significant change in the communities it invades. Marine biologists in the state of Washington are concerned about how the crab may be affecting native species.

In this final, more open-ended exercise, the Washington Department of Fish and Wildlife has hired you as a consultant. They want you to determine: (1) how alien green crabs interact with native species; and (2) how invasive green crabs impact the intertidal community as a whole.

[1]   Select **"Invasion!"** from the Exercise Menu in the upper left-hand corner of the screen to load the experiment.

Initially, the system should look the same as in previous exercises. You have access to the same tools; however, you now have some new tools as well. If you select the **ADD A MOBILE CONSUMER** button in the Tools Panel and click on the arrow next to it you will see a new option for adding Green Crabs. You also have a new **CRAB REMOVAL** button that will allow you to eliminate green crabs. You can also now **ADD ALGAE**, in addition to sessile and mobile consumers.

[2]   To observe the crab invasion, run the model by clicking the **GO** button and watch the action for approximately 200 weeks. (You can also use the **STEP 200** button to run it exactly 200 weeks.) The crabs are cryptically colored, so watch carefully!

For your report, you should determine the impacts of the green crab invasion using the techniques you used previously in this lab: species transplants, removals, and gut content analysis. Your report should address how the crabs interact with native species and how they impact the intertidal community in general.

[2.1]   **Once you have gathered data and made observations, write a one-to-two page report to the Washington Department of Fish and Wildlife. Briefly describe: (1) your questions and experimental approaches; (2) your discoveries about the relationships between the green crab and other intertidal species; and (3) a sketch of how the green crab fits in to the existing food web.**

Optional: Biocontrol

Organisms that are introduced to eliminate or otherwise limit population growth for unwanted pest species are known as **"biocontrol agents".** Biocontrol agents are often parasites, predators, or pathogens. Ideally, when biocontrol agents are introduced into an ecological community, the unwanted species will be controlled without further intervention and the system will be self-sustaining. Use of biocontrol agents is not without risk however, and biologists must be very careful that the introduced biocontrol organism will not further negatively impact the native species and become a pest itself. There are plenty of nightmare examples from our past where introduced biocontrol agents have become a bigger problem than the species they were introduced to control. Famous examples include the mongoose in Hawaii, which was introduced to eat rats but preferred eating the native bird fauna; and cane toads in Australia, which were introduced to control a sugar cane beetle, but instead had devastating impacts on indigenous amphibian and reptile communities and did almost nothing to control the insect pests.

There is a parasitic barnacle, *Sacculina*, which research has suggested might be useful as a biocontrol agent for invasive European green crabs. The larvae of *Sacculina* settle on crabs, piercing the exoskeleton. This type of infestation slows down the crabs' ability to reproduce and therefore, over time should lead to a decrease in the crab population size.

[2.2]   **Having investigated the impacts of the European Green Crab on the intertidal zone community, the Department of Fish and Wildlife is considering using parasitic barnacles** *(Sacculina)* **to control the crab. Given what you know about the importance of species interactions to community structure, what would you suggest should be learned about this parasitic barnacle species before it is introduced into the intertidal community you have been studying?**

Key Publications

This laboratory was inspired by the following classic papers by R.T. Paine, whose work on intertidal communities originated the idea of keystone predation:

Paine, R.T. 1966. **Food Web Complexity and Species Diversity.** *The American Naturalist* 100: 65-75

Paine, R.T. 1969. **The Pisaster-Tegula Interaction: Prey Patches, Predator Food Preference, and Intertidal Community Structure.** *Ecology* 50: 950-961.

The following review article addresses the idea of keystone species from a more modern perspective:

Power, M.E., D. Tilman, J.A. Estes, B.A. Menge, W.J. Bond, L.S. Mills, G. Daily, J.C. Castilla, J. Lubchenco, R.T. Paine. 1996. **Challenges in the Quest For Keystones: Identifying Keystone Species is Difficult — But Essential To Understanding How Loss of Species Will Affect Ecosystems.** *BioScience* 46: 609-620.