Coastal Ecosystem Curriculum: Food Web

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Gulf of the Farallones
National Marine Sanctuary

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Introduction to the Coastal Ecosystem Curriculum

The Gulf of the Farallones is a dynamic coastal region with a very rich biological community. Many high school students living less than 20 miles from the Pacific coast are unaware of this complex and unique ecosystem located just outside of the Golden Gate. This Coastal Ecosystem Curriculum provides activities and a monitoring project to engage high school students in learning about the marine environment in their backyard.

This curriculum focuses on the coastal ecosystem in the Gulf of the Farallones. Birds, the sandy beach, and oceanographic currents are all connected in this ecosystem. One goal of this curriculum is to teach high school students about the natural connections in the ecosystem and how humans fit into the ecosystem. Sand crabs, the focus of the monitoring project, are prey for birds yet sometimes they carry parasites or domoic acid from plankton which can injure and kill birds. Oil spills can impact all organisms, and it is the oceanographic conditions that move oil and plankton. By understanding the connections in the Gulf of the Farallones, high school students can develop skills to become stewards of the ocean.

The water surrounding the Farallon Islands off the California coastline is protected and managed by the Gulf of the Farallones National Marine Sanctuary (NMS). Designated in 1981, the Sanctuary consists of offshore marine regions of the Gulf of the Farallones and the water up to the high tide line from Bodega Bay to Rocky Point. Of the thirteen National Marine Sanctuaries, San Francisco Bay residents are lucky to have three Sanctuaries protecting the coastal water so close to their homes. Cordell Bank NMS borders to the north and west of the Gulf of the Farallones NMS and Monterey Bay NMS protects the waters bordering the Gulf of the Farallones NMS south to Cambria.

The geological landscape under the water sets the scene for the Gulf and impacts the flow of the water. The Gulf of the Farallones is on the continental shelf, with the steep continental slope less than 30 miles from the shoreline. Seasonal winds drive currents and mixing, resulting in three oceanographic seasons. The life cycles of the animals living in the region are tied to the oceanographic conditions.

The upwelling season of spring and summer is driven by the northerly winds. In the activity entitled "Coastal Ocean Upwelling," students will examine real oceanographic data and observe how surface winds impact the Gulf of the Farallones. Cold, nutrient rich water is brought to the surface by the upwelling of deeper water. Phytoplankton use the upwelled nutrients along with the sunlight in photosynthesis and growth to form the base of the region's food web. From phytoplankton to zooplankton to fish, birds, and marine mammals, the energy is transferred from one trophic level to the next. There is great biological diversity and abundance – 36 species of marine mammals, more than 300,000 seabirds, and 30 endangered and threatened species – in the Gulf of the Farallones. In the Food Web unit, students learn about the connections between the trophic levels of the open waters of the Gulf of the Farallones, while in the Sandy Beach unit they examine coastal animals.

In the late summer and early fall, the winds die down and upwelling stops. This is called the relaxation period. Many marine mammals such as humpback and blue whales migrate to the region to feed on the abundant zooplankton krill during the summer and fall. The abundant seal population around the Farallon Islands attracts one of the largest concentration of white sharks in the world during the fall. Other animals, such as gelatinous zooplankton, also become very abundant during this season.

Beginning in November, winter storms dominate the region. The ocean water is well mixed, moving phytoplankton deeper, into darker water and reducing their growth. Sandy beaches change shape as the rough waters transport sand and sand crabs offshore. Students can measure the shape of beach slope as described in the Beach Profile Survey activity to see seasonal changes. The winter storm season lasts until about February when the strong northerly winds begin again and the cycle starts over with spring upwelling.

Students can make their own discoveries and become stewards of the marine environment through their involvement in the monitoring program. Included in this curriculum is a handbook for monitoring the sandy beach habitat. Pacific mole crabs (*Emerita analoga*), also called sand crabs, live in the swash zone of the sandy beaches along the Pacific coast. They are prey for fish, seabirds, shorebirds, and sea otters, and carry parasites that can affect these predators. Sand crabs feed on plankton, some of which produce the toxin domoic acid that can also affect these predators. In this project, students can use their understanding of the Gulf of the Farallones ecosystem and apply it to the sandy beach habitat. Students will monitor the abundance and distribution of sand crabs to establish a long-term baseline dataset to help access the health of the sandy beach habitat.

The Gulf of the Farallones is juxtaposed to the San Francisco Bay metropolitan area where 8 million people live. Waste and other pollution from cities are washed into the Gulf through the Sacramento and San Joaquin rivers and streams that drain into San Francisco Bay. Major shipping lanes run through the Gulf of the Farallones National Marine Sanctuary. Oil pollution is not just a threat but a reality. Small spills are common, and large spills are not rare. In 1984, 1.4 million gallons of oil were released into the Gulf of the Farallones by the Tanker Vessel *PUERTO RICAN*. In the Oil Spill unit, there are activities about this particular oil spill and how oil spills are cleaned up.

How to Use the Curriculum

This curriculum was designed for high school classrooms in the San Francisco Bay Area. These activities can be used in marine science, biology, and environmental science classes. Each classroom or science club is different, so by providing many activities and suggestions, we hope that each teacher uses the pieces of this curriculum that work for them and their students.

Section of the Coastal Ecosystem Curriculum
Gulf of the Farallones and Cordell Bank National Marine Sanctuaries
Oceanography of the Gulf of the Farallones
Food Web of the Gulf of the Farallones
Sandy Beaches of the Gulf of hte Farallones naitonal Marine Sanctuary
Oil Spills in the Gulf of the Farallones
Sandy Beach Monitoring Project: Teacher Handbook

For other units, go to www.farallones.org

It is recommended that all students are introduced to the Sanctuary, the seasons of the Gulf of the Farallones, the sandy beach habitat, and oil spills. One option is to present the Gulf of the Farallones NMS slide show followed by the Coastal Ocean Upwelling activity, then present the sandy beach slide show, map the T/V *PUERTO RICAN,* and conduct the Spilled Oil activity. If students participate in the monitoring project, it is important to introduce them to the Sanctuary and the sandy beach habitat during the project.

Organization of Curriculum and Activities

The background text at the beginning of each unit provides teachers with fundamental information. Each unit has several activities to choose from. The activities are linked to the California State Standards and include objectives, materials needed, and step-by-step procedures. The fact sheets and student worksheets are intended for teachers to reproduce for their students. Slide shows are available to rent from the Farallones Marine Sanctuary Association. Glossary words are italicized in the slide shows and background information.

Feedback and Evaluation

This is the first draft of the curriculum. We welcome all suggestions and comments – what worked, what didn't work, what is missing, and how to improve the curriculum for other teachers and students. Please fill out the Feedback and Evaluation Form at the end of this section or contact Jennifer Saltzman at jsaltzman@farallones.org or (415) 561-6625.

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Credits

This curriculum could not have been developed without the help of many people. Thank you to Sue Magdziarz, Maria Brown, and Jan Roletto who have read and critiqued every activity and slide, helping to make this a reality. Thanks also go to the rest of the Farallones Marine Sanctuary Association, Gulf of the Farallones NMS, and Cordell Bank NMS staff who contributed their knowledge, ideas, and love of the Sanctuary.

For the Oceanography Unit, Toby Garfield at San Francisco State University contributed to the Coastal Ocean Upwelling activity and Jerry Norton of the Pacific Fisheries Environmental Group contributed some of the graphs. Marlene Noble of the United States Geological Survey helped with stray questions about the geology of the region. Thanks to Ed Carpenter at San Francisco State for lending us slides. Thank you to all the photographers for their slides.

Thanks to all,

Jennifer Saltzman, Ph.D.
Education Coordinator
Farallones Marine Sanctuary Association

Feedback and Evaluation of the Coastal Ecosystem Curriculum

Name (optional) _____
School/Organization _____
Mail Address _____
Email Address _____
Grade/Subject _____

Thanks for your interest in the Coastal Ecosystem Curriculum. We would like your assistance in improving this curriculum. Your responses may be incorporated into future printings of this and other educational material. Please mail this form to: Education Coordinator, Farallones Marine Sanctuary Association, P.O. Box 29386, San Francisco, CA 94129.

What were your goals and objectives for using these materials?

Which activities did you use? How well did they work (rate 1-6, 6 is very well)? Do you have any suggestions for adaptations, extensions, or ways to improve the activities?

Evaluation continued on next page.

How useful was the background information?
not useful 1 2 3 4 5 6 very useful did not use

Did your students gain a better understanding about the coastal ecosystem? How did you evaluate your students?

Did you use the books and resources lists, website lists, or speaker lists? Were they useful? Please circle your response and comment.

books and resources lists:	not useful	1	2	3	4	5	6	very useful	did not use
website lists:	not useful	1	2	3	4	5	6	very useful	did not use
speaker list:	not useful	1	2	3	4	5	6	very useful	did not use

Do you plan to use this curriculum in the future? Why or why not?

Did this curriculum help you teach the California Standards? Which ones?
not useful 1 2 3 4 5 6 very useful does not apply

How can we further assist you? What type of supplemental information would you like? (please include your contact information)

Any other comments or suggestions

Food Web of the Gulf of the Farallones

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Standards Covered at High School Level from Science Content Standards for California Public Schools

The Food Web unit will help your students achieve the following educational standards. These standards are from the Science Content Standards and the History/Social Science Standards for California Public Schools. Performance standards, indicated by bullets after each content standard, are specific for each activity. We suggest using the fact sheets with the slide shows to emphasize key points and to provide students with written material for future reference.

Slide Show and Fact Sheet

Biology/Life Sciences

6. Ecology. Stability in an ecosystem is a balance between competing effects. Students will:
   e. Know a vital part of an ecosystem is the stability of its producers and decomposers.

- Students will describe a marine upwelling food web.
- Students will describe why the timing of breeding of wildlife is dependent on diatoms and upwelling.

Production/Grazing/Predation Game

Biology/Life Sciences

6. Ecology. Stability in an ecosystem is a balance between competing effects. Students will:

b. Know how to analyze changes in an ecosystem resulting from changes in population size.

- Students will be able to predict changes in population size due to increases and decreases in rates.

e. Know a vital part of an ecosystem is the stability of its producers and decomposers.

- Students will describe the upwelling food web and how the producers are very important to its stability.

Investigation and Experimentation

1. Scientific progress is made by asking meaningful questions and conducting careful investigations. Students will:

g. Recognize the usefulness and limitations of models as scientific representations of reality.

- Students will use the production rate and will be able to explain what the rate represents in reality.
- Students will be able to describe how to make the model more accurate.

How Much Does a Whale Really Eat? Worksheet

Biology/Life Sciences

6. Ecology. Stability in an ecosystem is a balance between competing effects. Students will:

f. Know at each link in a food web some energy is stored in newly made structures but much energy is dissipated into the environment as heat.

- Students will calculate the consumption rate of blue whales and compare it to their own consumption rates.

Wrestling for Resources

From History/ Social Science Content Standards for California Public Schools

Grade 12. Principles of Economics

12.1 Students understand common economic terms and concepts and economic reasoning.

1. Examine the causal relationship between scarcity and the need for choices.

- Students will discuss limited resources and cooperative behavior.

12.2 Students analyze the elements of America's market economy in a global setting.

2. Discuss the effects of changes in supply and/or demand on the relative scarcity, price, and quantity of particular products.

- Students will discuss the effect of common resources when managing a market.

Are there Algae in Your House? Activity

Biology/Life Sciences

6. Ecology. Stability in an ecosystem is a balance between competing effects. Students will:

e. Know a vital part of an ecosystem is the stability of its producers and decomposers.

- Students will make a list of marine primary producers that are found in human food products.

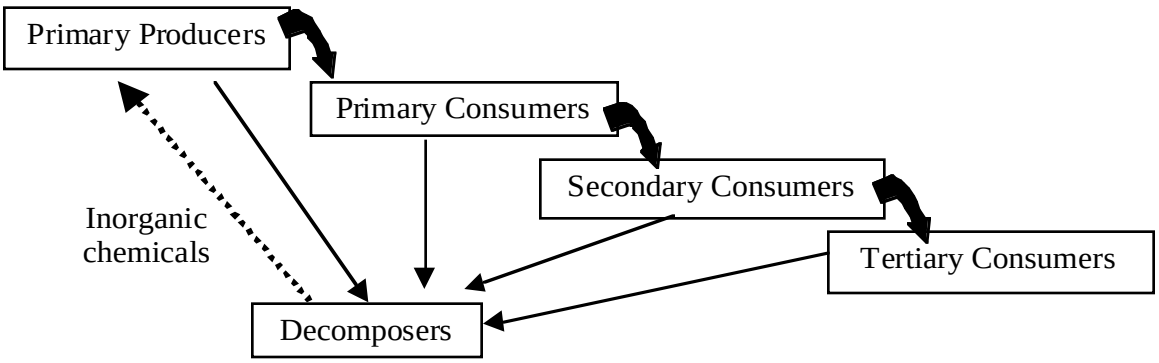
Food Web of the Gulf of the Farallones

In all habitats on Earth, individual organisms interact with other organisms and are influenced by their environment. The study of these processes is the science of ecology. In the marine environment, the ecology of the nearshore and coastal waters has been well studied because of their accessibility, while the deep sea and offshore regions are not as well understood. In this brief review, trophic dynamics, biochemical cycles, and population ecology will be discussed in reference to the Gulf of the Farallones.

Trophic Dynamics and Biochemical Cycles

In most ecosystems, primary producers use photosynthesis to capture energy for life. The energy is used for growth and maintenance and is passed on to other organisms. Primary producers, or autotrophs, combine inorganic chemicals with energy from sunlight to produce energy-rich organic compounds, such as sugar. Consumers, or heterotrophs, depend on primary producers for their nutritional and energetic requirements.

Organisms can be grouped into trophic levels, depending on where they get their energy. Primary consumers eat primary producers, secondary consumers eat primary consumers, and tertiary consumers eat secondary consumers. Both energy and matter are passed along from one trophic level to the next, but it is rarely a simple progression. Most predators feed at multiple trophic levels and take advantage of feeding opportunities when they arise. Most ecosystems, both terrestrial and marine, are quite complex, even the apparently simple ones. An important link in ecosystems that is often overlooked is the decomposers. They consume waste and dead organisms, recycling matter back into inorganic chemicals. This completes the cycle by providing the primary producers with the inorganic chemicals they require for growth.



In the marine environment, algae form the foundation to support growth at the higher trophic levels. Most of the single-celled algae are phytoplankton, freely floating in the surface layers of the water. Some single-celled algae live on the sediment and rocks. The next trophic level is the grazers which vary in different marine habitats. In the open water, zooplankton and filter-feeding fish graze on phytoplankton. On the rocky shores, snails and limpets graze on attached algae. Carnivorous zooplankton and sea stars are examples of secondary consumers. Baleen whales can also be classified as secondary consumers, because they eat the grazing zooplankton. Large fish and birds typically feed at higher trophic levels, yet are known to eat zooplankton also. In the ocean, there are bacteria which decompose the dead organisms.

There are usually complex interconnections between various trophic levels in an ecosystem. Consumers rarely eat only one food source. A good example of this is the blue rockfish (*Sebastes mystinus*), one of the most abundant nearshore rockfish in the Gulf of the Farallones. During most of the year, they feed on gelatinous zooplankton. In the spring when juvenile rockfish move into the nearshore habitat, adult blue rockfish feed on them. When food is scarce, the blue rockfish feed on the reproductive sori of the bull kelp, a large algae.

A food web is used to describe the relationships between species in an ecosystem. Upwelling regions such as the Gulf of the Farallones have shorter food webs in comparison to the open ocean ecosystems. There are fewer species at each level and fewer trophic levels in the upwelling food web, yet the upwelling region is much more productive. Diatoms are the dominant primary producers in the Gulf of the Farallones. Krill, more formally called euphausiids, are one of the most important primary consumers. Many species of fish, birds, and baleen whales migrate to the Gulf each summer to feed on the dense aggregations of krill. Salmon and other large fish eat the smaller herring and anchovies in addition to krill during some seasons. Party boat skippers look for feeding seabirds to help them find salmon feeding on the same krill. In addition to these in the pelagic habitat, organisms in the nearshore zones and on the sea floor are an important part of the Gulf of the Farallones ecosystem.

The transfer of energy is very inefficient between trophic levels. About 90% of the energy is lost to metabolic costs and heat at each level. By feeding at lower trophic levels, there is more energy available. The energy it takes to capture such small animals compared to the size of a whale could be considerable. Because krill are so abundant in the Gulf and can be found in large aggregations, this is a perfect feeding habitat for baleen whales. That helps explain why the largest animals are feeding on such small animals. The loss of energy between trophic levels creates a decrease in the number of organisms in each level. Phytoplankton are the most abundant, krill are less abundant, and the number of fish, whales, and birds that feed on krill is much less than the number of krill.

All ecosystems are limited by the amount of energy available from the Sun. Floating in the water, phytoplankton are mixed up and down, possibly into and out of the lighted zone. The amount of sunlight available in the water is less than in the air above. Water absorbs and reflects light, although in general, water is pretty transparent. In the big scheme of things, life would be very different if light was not able to pass through water.

The amount of available sunlight varies daily, seasonally, and with depth. Clouds and fog decrease the amount of sunlight reaching the surface. The Gulf of the Farallones is located at about 38° N. Because the Earth's axis is tilted from its orbit about the Sun, there are about 9.5 hours of sunlight during December and up to 14.75 hours during June. During the winter, the Sun is much lower in the sky. The sunlight travels through more of the Earth's atmosphere during the winter before reaching the ocean's surface, and there is a higher angle of reflection at the surface. These processes cause less light to penetrate into the ocean during the winter than during the summer. The amount of light decreases exponentially as light passes through water, because it is scattered and absorbed by the water molecules. Also, different wavelengths penetrate to different depths.

Phytoplankton need nutrients as well as sunlight. These are the inorganic chemicals required for growth and are the same natural chemicals used to fertilize agricultural fields and home gardens. Nitrogen in the form nitrate (NO_3^{-1}) and phosphorous in the form phosphate (PO_4^{-3}) are needed in the highest concentrations. Some phytoplankton, the diatoms, also require a form of silicon (silicate, SiO_4), because they have a "glass-like" shell. Many other nutrients, such as iron, are also required for growth but in smaller amounts. Phytoplankton absorb nutrients into their cells and incorporate them into their molecules. The availability of nutrients can limit the growth of phytoplankton. In the Gulf of the Farallones during the upwelling season, nutrients are constantly replenished from the deeper water. This nutrient supply is the driving force behind the very productive biological ecosystem.

Many kinds of invertebrates comprise the next trophic level of primary consumers. In the open water of the Gulf, krill and copepods are the dominant herbivores. Both are crustacean arthropods and spend their entire life as zooplankton. Copepods make up over 70% of the zooplankton in the open ocean, yet in upwelling regions the larger-sized krill increase in abundance. The krill are critically important to the productivity of upwelling regions, such as the Gulf of the Farallones and near Antarctica. They eat phytoplankton, copepods, and even fish larvae which means they are feeding at different trophic levels. *Thysanoessa spinifera* is the krill

species dominant over the continental shelf in the Gulf, and *Euphausia pacifica* lives in deeper water at the edge of the shelf and over the continental slope. *T. spinifera* forms daytime swarms at the surface during the upwelling season with up to 75,000 animals per cubic meter. The next trophic level has easy feeding when there are krill swarms at the surface. Krill are trapped at the ocean surface by predators like whales and salmon feeding from below.

At the microscopic level, there are more plankton than researchers originally imagined. By reducing the size of the holes of the mesh used to collect the plankton and using other techniques, very small plankton have been discovered and studied. These microorganisms are 1-10 mm (mm $=10^{-6}$ meters); some are photosynthetic and others, including bacteria, feed on the photosynthetic ones or on dissolved organic matter. Called the microbial loop, energy is cycled through the very small plankton, and some of the energy is transferred to the larger gelatinous zooplankton.

Bacteria are an often overlooked group at this trophic level of primary consumers. They consume organic matter that phytoplankton release or exude from their cells or that zooplankton lose when they are eating. Copepods are known as "messy eaters" because they spill lots of organic matter from the phytoplankton as they are eating. Think about the crumbs around your plate after eating crackers.

Near the shoreline, many invertebrates graze on bottom algae or feed by filtering the water for phytoplankton. In the rocky intertidal, snails and sea urchins are two examples of primary consumers that graze on the algae. The sandy beaches may look like nothing lives there, yet sand crabs and clams are there feeding on phytoplankton. Both of these nearshore habitats are closely linked to the open water, as food is transferred from one habitat to another.

Not all carnivores (the secondary consumers which feed on the primary consumers) are big, ferocious animals. Some are small, ferocious animals. Many single-celled protozoa eat bacteria. Chaetognaths, called arrow worms, are inch long lions of the planktonic world. These long, thin, transparent animals are arrow-shaped and can dart rapidly in the pursuit of other animals. Their mouth is fringed with spikes which grasp their prey (their Latin name means bristle jaw). During the fall relaxation period, gelatinous, carnivorous zooplankton, such as jellies, increase in abundance and eat smaller zooplankton and phytoplankton. The commercially important northern anchovies and Pacific herring also feed on plankton.

The largest of the secondary consumers are the baleen whales. Blue, humpback, fin, and minke whales feed on the schools of krill during the fall. It may seem strange that the largest creatures in the ocean eat some of the smallest. This disparity is true of terrestrial habitats as well. The largest land animals are not predators; they are grazing herbivores of grassy plains. Though the reasons for this are similar – food is readily available and it doesn't have to be chased – the size disparity in the ocean is the most striking. The blue whale may be a thousand times larger than the food it eats. An adult may eat several thousand pounds of food per day – up to 100 pounds per swallow. Rather than teeth, the mouth of the largest whale is equipped with many overlapping fringed plates of a modified hair-like structured called baleen. It is used as a filter or strainer to separate the plankton from the water.

Not all species feed at just one trophic level. Salmon and humpback whales feed on krill, a primary-secondary consumer, and anchovy, a primary consumer. As animals grow, they change prey and habitat. Fish begin feeding on small food particles as larvae and grow to eat larger zooplankton as juveniles. Rockfish are some of the most abundant bottom fish along the California coast. In their early life stage, they are zooplankton who eat smaller zooplankton. Adult rockfish settle to the bottom and eat crustaceans, squid, and small fish. White sharks in California feed on large fish until they are about 10-12 feet long, when they begin to eat pinnipeds (seals and sea lions). These changes make the description of the trophic structure of a specific ecosystem very complex. Here you have read about just a few of the species in the Gulf of the Farallones.

Last, but definitely not least, are the decomposers. There are many species of bacteria in the ocean, which are found at a density of 100 million bacteria in every liter of seawater. The many roles they play make bacteria very important to the health of an ecosystem. Energy is on a one-way path through the trophic levels, yet the material of life (carbon, hydrogen, and oxygen) is used over and over again. Bacteria and other decomposers break down waste and dead organic material back into inorganic compounds (carbon dioxide, nitrate, phosphate, etc.). The bacteria gain energy by breaking down the organic material while providing nutrients for the growth of phytoplankton. Bacteria have this important role and live in all habitats of the marine environment. The abundance, diversity, and other roles of bacteria are not well understood, although researchers are making new discoveries each year.

There are other animals that contribute to decomposition. Many filter feeders consume dead organic matter that is floating in the water. Worms, clams, mussels, and crabs depend on dead matter sinking to the sea floor.

Animals eat not only for energy but also for the chemical materials - the atoms of carbon, nitrogen, etc. They incorporate the chemicals of their food into their own tissues. A side effect may be metals, pesticides, and other toxic chemicals (both natural and man-made) that are passed from one trophic level to the next. Some of the chemicals are not harmful in low concentrations. Yet, at high concentrations those same chemicals are harmful and potentially lethal. One example of this is the chemical domoic acid which is produced by a phytoplankton species of diatom. In the nearshore zones, sand crabs and mussels filter the water, consume the diatoms, and accumulate the domoic acid in their bodies. The chemical does not harm these animals. When humans, fish, or sea lions eat the crabs, the domoic acid enters their brains and causes short-term memory loss. Domoic acid has led to the death of many marine birds and marine mammals. By knowing the connections within the food web, researchers can trace these chemicals and help prevent human illnesses.

Population Ecology

The food web is a fragile system, and the removal or extinction of one level, or even part of a population at one level, can impact the entire food web. The importance of understanding the food web is clear when looking at commercially harvested species and endangered species. A potential fishery along the California coast is the shortbelly rockfish, a small schooling fish, which eat krill and are eaten by salmon. If shortbellies are harvested, there may not be enough food for salmon, seabirds, or baleen whales.

Fisheries management has been the driving force in studying the population ecology of commercial species. Researchers create population models based on life history traits, such as feeding rate, growth rate, survival rate, number of eggs produced, and number of reproductive years. The models predict the population size in the future and are used as management tools to determine the proportion of the population that can be harvested and still sustain a healthy stock size. Many fisheries around the world have "crashed" because of overharvesting. There are many other factors, both natural and man-made, which influence population size such as habitat alteration and climate change. The National Oceanic and Atmospheric Administration's National Marine Fisheries Service works to create sustainable fisheries so that these natural resources will be here for generations to come.

The important commercial harvests from the Gulf of the Farallones National Marine Sanctuary, based on dollar value in 1987, are:

- Pacific herring (January-March)
- Salmon trolling (April-September)
- Rockfish (year-round)
- Bottom trawl fishery (sole, halibut, flounder) (year-round)
- Albacore tuna (August-October)
- Dungeness crab (November-June)

Population size is dependent on previous population size, number of individuals that reproduced previously, food availability, environmental conditions, and more. Populations fluctuate in size due to harvesting of the population, changes in the prey population size, or the predator population size. Environmental factors, such as land use practices and sea surface temperature, also impact the survival of larvae and juveniles. The impact may not be seen in the adult population until many years later. Also, there are natural trends of increases and decreases in population size. In the Production/Grazing/Predation Game of this curriculum, population size can be studied as one trophic level influences the population at another trophic level.

Every two to seven years, there is an El Niño event which is a disruption of the ocean-atmosphere system in the tropical Pacific having important consequences for weather around the globe. It causes major changes in the sea surface temperature, sea level, and fresh water runoff in the Pacific Ocean. These changes can affect the reproductive success of krill, anchovies, and many birds in the Gulf of the Farallones. The effects often ripple through the food web.

Research in the Gulf of the Farallones National Marine Sanctuary – Ecosystem Dynamics Study

Knowing the abundance and distribution of biological resources within the Sanctuary is critical management information. Just as critical is an understanding of the ocean conditions that influence abundance and distribution of these marine populations. Since 1995, biologists affiliated with the Gulf of the Farallones National Marine Sanctuary conduct research and monitoring cruises to investigate the abundance and distribution of marine organisms in the Sanctuary and to describe their oceanographic environment.

A grid of 15 sampling stations has been set up in the Gulf of the Farallones, from Pacifica to Bodega Bay. The sampling stations are located nearshore, in the middle of the continental shelf, and at the continental shelf break. At each station, plankton nets and oceanographic instruments are used to sample the zooplankton and ocean conditions. Net sampling is focused on two euphausiid species, *Euphausia pacifica* and *Thysanoessa spinifera*. Oceanographic conditions measured from the surface to bottom include temperature, salinity, chlorophyll, and currents.

Net sampling targets krill because they are a critical link in the Gulf of the Farallones food web. In fact, they are the reason that blue and humpback whales migrate to the Sanctuary each summer to feed. They are also an important food source for Pacific salmon, rockfish, and seabirds. Seabird and marine mammal observations are conducted during daytime transects between sampling stations. With this information, Sanctuary managers hope to understand what is affecting the distribution and abundance of krill and how that is tied to the presence of higher level predators such as marine mammals, fish, and seabirds.

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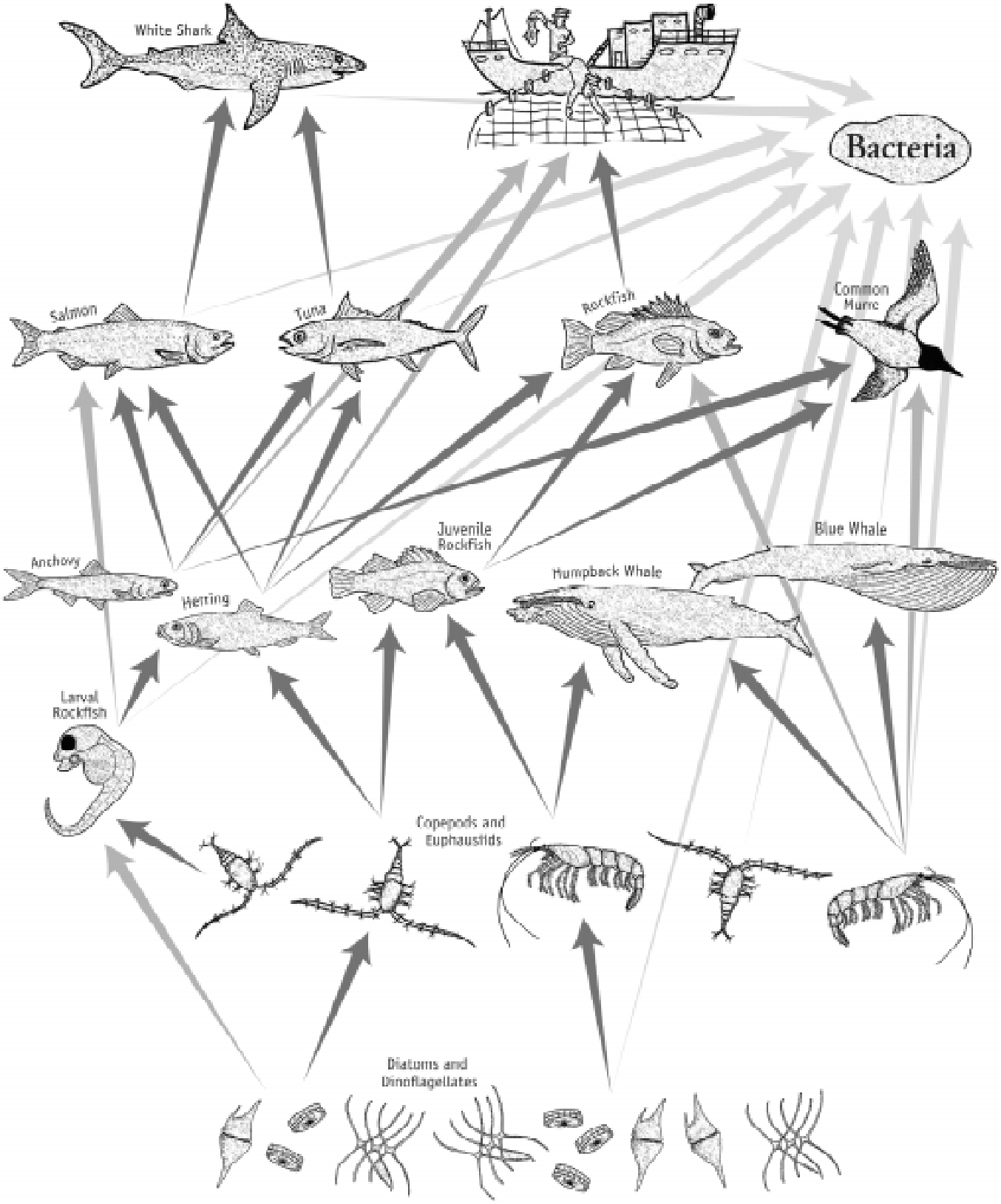


Food Web of the Gulf of the Farallones

Glossary of Terms
Food Web of the Gulf of the Farallones

Algae (singular-alga)	photosynthetic, aquatic or marine organisms that resemble plants but have no seeds or roots, ranging from one-celled diatoms to multicellular seaweeds.
Baleen	horny material that hangs in plates with a fringed edge, from the roof of the mouth of Mysticeti or baleen whales. Used to filter or strain zooplankton and small fish.
Benthic	associated with the sea floor or pertaining to organisms living in or on the sea floor.
Bloom	high concentration of phytoplankton, formed during times of high reproduction.
Community	a group of living organisms in a given area that interact with each other; the living component of an ecosystem.
Consumer	organism that feeds on plants or phytoplankton (primary consumers) or other organisms (secondary or tertiary consumers).
Decomposer	heterotrophic organism, breaks down nonliving organic matter for energy and releases nutrients.
Diatoms	microscopic, single-celled phytoplankton which have silica (glass-like) valves and are abundant in upwelling waters.
Dinoflagellates	microscopic, single-celled organisms. Both plant and animal traits. They have flagella which provides them some locomotion. Some species cause toxic red tides.
Ecosystem	a term used to describe the relationships between organisms and their environment.
Euphausiids	small, shrimp-like crustaceans (type of Arthropods) that feed on diatoms and are food for many large whales. Commonly called krill.
Filter feeder	an animal whose feeding strategy is to filter water for food. An example in the Gulf of the Farallones is a sand crab.
Food chain	sequence of organisms in which each is food for the next member in the sequence.
Food web	complex of interacting food chains, all feeding relationships in a community.
Herbivore	an organism whose diet consists largely or totally of algae or plant material, a primary consumer.
Invertebrate	an animal without a backbone or spinal column.
Krill	a common name of euphausiids that are shrimp-like crustaceans (a type of Arthropod). Food for birds, fish, and many baleen whales.

Larvae	immature pre-adult stages of an organism, which do not structurally resemble the adults. Often have different diets and habitats than the adults.
Nutrient	any organic or inorganic compound used in primary production. Required by algae and plants for normal growth. Nitrogen and phosphorous compounds are important examples.
Organic	matter that is produced by living organisms, a chemical compound with a backbone of carbon atoms.
Organism	a living entity; can be a plant, animal, protist, bacteria, or fungus.
Pelagic	associated with the open water habitat of the ocean, not associated with the sea floor.
Photosynthesis	the process by which plants and algae use the sun's energy to produce food. Carbon dioxide, water, and energy from light are combined into carbohydrates and oxygen.
Phytoplankton	drifting algae that have no control over the direction they travel. They use photosynthesis to produce food and are called primary producers.
Plankton	drifting algae and animals that have no control over the direction they travel; they are at the mercy of the currents.
Population ecology	branch of biology that deals with the number of a particular species that are found in an area and how and why those numbers change (or remain fixed) over time. Important in management of fisheries.
Primary producer	organism that creates new organic matter from non-living chemicals, uses photosynthesis or chemosynthesis.
Trophic level	position of an organism in the food chain or food web.
Upwelling	a process that occurs when strong winds blow surface water away from land, and deeper water comes up to the surface to replace it. This creates a highly productive biological community when the deeper water is nutrient rich.
Zooplankton	animals that float in the water and are at the mercy of the currents. Most are small crustaceans (1 mm-10 cm), although some are large jellyfish.

Food Web of the Gulf of the Farallones

To the west of the Golden Gate Bridge is a biologically rich ecosystem protected by the Gulf of the Farallones National Marine Sanctuary (NMS). The physical processes of the Gulf of the Farallones contribute to this ecosystem by upwelling nutrient-rich water to the surface during the spring and summer. Single-celled algae floating freely in the surface water use photosynthesis to capture energy which powers the entire web of life.

Upwelling regions are generally considered the most productive in the ocean due to the nutrient inputs from upwelling. The cold, nutrient-rich water is relatively sterile, but it provides the fertilizers that result in a very productive ecosystem. Diatoms are the dominant primary producers in the Gulf of the Farallones. Krill are the most important primary consumer here because so many species of fish, birds, and baleen whales eat them. Fish of all shapes and sizes are found in the next trophic levels. One well-known top predator in the Gulf is the white shark which feeds on seals.

Primary Producers

Floating in the water, single-celled algae, or phytoplankton, are mixed up and down through the lighted zone. They use photosynthesis to combine the energy of sunlight with carbon dioxide and other inorganic chemicals to produce high-energy carbohydrates and oxygen. Nutrients, the same chemicals used to fertilize agricultural fields and home gardens, are required by phytoplankton. Nitrogen in the form nitrate (NO_3^{-1}) and phosphorous in the form phosphate (PO_4^{-3}) are needed in the highest concentrations by phytoplankton. Phytoplankton absorb these nutrients into their cells and incorporate them into their molecules. In the Gulf of the Farallones during the upwelling season, nutrients are replenished from the deeper water. This nutrient supply is the driving force behind the rich biological community.

In the open water of the Gulf, krill and copepods are the abundant herbivores and spend their entire life as zooplankton feeding on phytoplankton. Copepods make up over 70% of the zooplankton in the open ocean, yet in upwelling regions the larger-sized krill increase in abundance. Krill form daytime swarms at the surface during the upwelling season.

A Pigeon Guillemot is part of the food web in the Gulf of the Farallones.

Upper Trophic Levels

Not all carnivores are big, ferocious animals. Some are small, ferocious animals. Many single-celled protozoa eat bacteria. Chaetognaths, called arrow worms, are inch long lions of the planktonic world. These long, thin, transparent animals dart rapidly in the pursuit of other animals. Their mouth is fringed with spikes which grasp their prey. During the fall, jellies come into the Gulf and eat smaller zooplankton and phytoplankton.

Commercial fishermen know the upper trophic levels well. Northern anchovies and Pacific herring feed on plankton. Salmon feed on krill, squid, anchovies, and herring. Scavenging food on the sea floor are the Dungeness crab. Blue, humpback, fin, and minke whales feed on the swarms of krill during the summer and fall. The Farallon Islands are home to the largest concentration of breeding seabirds in the continguous United States. Seabirds, such as the Common Murre, feed on krill, juvenile rockfish, herring, anchovies, smelt, and squid.

Not all species feed at just one trophic level. As animals grow, they change prey and habitat. Fish begin feeding on small food particles as larvae and grow to eat larger zooplankton as juveniles. Rockfish are some of the most abundant bottom fish along the California coast and are harvested commercially. In their early life stage, they are plankton and eat smaller zooplankton. Adult rockfish settle to the bottom and eat crustaceans, squid, and small fish. Young white sharks feed on large fish until they grow to 10-12 feet long when they begin to eat seals. These changes make the description of the trophic structure within a specific ecosystem more complex.

The transfer of energy is very inefficient between trophic levels. About 90% of the energy is lost to metabolic costs and heat at each level. By feeding at lower trophic levels, there is more energy available. The loss of energy between trophic levels creates a decrease in the number of organisms in each level. Phytoplankton are the most abundant, the krill are less abundant, while the number of fish, whales, and birds that feed on krill is much less than the number of krill. The energy it takes to capture such small animals compared to the size of a whale could be considerable. Because krill are so abundant in this region, it is a perfect feeding habitat for baleen whales. The blue whale may be one thousand times larger than the food it eats. An adult may eat several thousand pounds of food per day, up to 100 pounds per swallow. Rather than teeth, the mouth of the largest whale is equipped with many overlapping fringed plates of a modified hair-like structure called baleen. It filters the inch long krill from the water with its baleen.

Bacteria

Last, but definitely not least, are the bacteria which work as decomposers and consumers. Many species breakdown waste and dead organic matter into inorganic compounds (carbon dioxide, nitrate, phosphate, etc.) to gain energy. As a byproduct, they recycle nutrients for the growth of phytoplankton. Other species of bacteria consume organic matter that phytoplankton release or exude from their cells or that zooplankton lose when they are eating. Copepods are known as "messy eaters," because they spill lots of organic matter from the phytoplankton as they are eating. Bacteria play important roles in the food web and live in all habitats of the marine environment. The abundance, diversity, and other roles of bacteria are not well understood, although researchers are making new discoveries each year.

Krill form daytime swarms with up to 75,000 animals per cubic meter during the upwelling season in the Gulf of the Farallones.

Humans in the Gulf of the Farallones Food Web

In the Gulf of the Farallones, there are many important commercial species of fish and shellfish. The food web is a fragile system, and the removal or extinction of one level or even part of a population at one level can impact the entire food web. The importance of understanding the food web is clear when looking at the commercially harvested species. A potential fishery is the shortbelly rockfish, a small, schooling fish which eat krill and are eaten by salmon. If shortbellies are harvested, there may not be enough food for salmon.

Important commercial harvests of the Sanctuary

- Pacific herring (January-March)
- Salmon trolling (April-September)
- Rockfish (year-round)
- Bottom trawl fishery (sole, halibut, flounder) (year-round)
- Albacore tuna (August-October)
- Dungeness crab (November-June)
- Sea Urchins

Gulf of the Farallones National Marine Sanctuary Research

Knowing the abundance and distribution of biological resources along with the ocean conditions within the Sanctuary is critical management information. Since 1995, biologists affiliated with the Gulf of the Farallones NMS have investigated the abundance and distribution of marine organisms in the Sanctuary and described the oceanographic environment.

At 15 sampling stations, plankton nets and oceanographic instruments are used to sample the zooplankton and ocean conditions. Oceanographic conditions measured from the surface to sea floor include temperature, salinity, chlorophyll, and currents. Seabird and marine mammal observations are conducted during daytime transects between sampling stations.

Sanctuary managers hope to understand what is affecting the distribution and abundance of krill and how that is tied to the presence of higher level predators such as marine mammals, fish, and seabirds.

Food Web Activities

Production/Grazing/Predation Game

Objective

Students will be able to describe the dynamics of a simple food chain with three trophic levels. They will learn that the population size depends on the abundance of lower trophic levels and the rate of growth and predation.

Materials and Supplies

For each group: 6 game boards (page with nutrients)
6 pages of each trophic level, copied onto colored paper
(diatoms on green paper, krill on yellow paper, whale on purple paper)
stop watch
scissors

Background

In a simple food chain with three trophic levels, there are primary producers, grazers, and predators. The population size of each level depends on the abundance of nutrients or prey, and growth, feeding, and reproduction rates. In this activity, the trophic levels are from an upwelling ecosystem such as the Gulf of the Farallones with phytoplankton (diatoms), zooplankton (krill), and whales. For simplicity, the production rate is the combination of the growth, feeding, and reproduction rates. Students should play at least two rounds of the game with different production rates. The first round is a steady state system where all three tropic levels continue to grow. In the other rounds, one tropic level will go extinct (crash) due to lack of food and then the other tropic levels will slowly crash.

Fishery management depends on population dynamics models. In this very simple model, there is only one production rate. In fishery models, growth, feeding, and reproduction rates are included separately. As a fish grows, it feeds on different sized food and is prey to different predators. Also, the rates are different at different life stages and are important in determining population size. Population dynamics models are very complex when they account for the changes in a population at different life stages.

Students will learn that the trophic levels depend on each other. When one trophic level decreases, it will affect the abundance of organisms at other trophic levels.

Activity

1. Discuss population dynamics. Students should know that diatoms are the primary producers, krill (grazers) eat diatoms, and whales (predators) eat krill. This is a game to see how trophic levels are dependent on each other. Ecosystems are controlled by the production rate of each trophic level and the nutrient supply. In this game, a steady state system is when all trophic levels are growing and none are limited.

2. Divide students into groups of 4. Pass out all supplies to each group.

3. Assign each person to a trophic level, and one person should be in charge of the stopwatch.
   Nutrients (NO_3^{-1} = Nitrate, PO_4^{-3} = Phosphate) - required for photosynthesis by diatoms
   Primary Producers - diatoms - green
   Primary Consumers/Grazers - krill - yellow
   Secondary Consumers/Predators - whales - purple

4. The page with the nutrients is the game board. The other pages should be cut into squares. Each card represents an abundance of organisms that consumes the abundance of one card of their prey (the lower trophic level). For example, one card of krill represents enough krill to feed one whale. Each group should play at least 2 rounds (Round 1 and a round of 2a, 2b, or 2c).

5. Rules:

- Each round lasts exactly 5 minutes.
- To begin, lay down the 6 nutrient sheets on a desk.
- Use the start time and production rate for each trophic level from the chart below.
- The **start time** is the time at which a trophic level begins growing (start laying down cards).
- The **production rate** is the combination of the feeding, growing, and reproduction rates. It is the time interval between laying cards down.
- For example in Round 1, primary producers lay down one card at the beginning (t=0) and lay down 1 card every 5 seconds for the entire 5 minutes. Krill (grazers) start after 10 seconds (t=10), and lay down 1 card every 10 seconds. When adding more cards to the board, the population is reproducing and growing.
- Place cards only over their prey (lower trophic level). Do not overlap cards of the same color. Diatoms (green) lay down their cards on the nutrient sheet. Krill (yellow) may only lay down their card (feed) on top of diatoms (green), and whales may only lay down their card (feed) on top of krill (yellow).

		Round 1		Round 2A		Round 2B		Round 2C	
Trophic Level	Card Color	start time	production rate	start time	production rate	start time	production rate	start time	production rate
Diatoms	green	0	5	0	5	0	5	0	2
Krill	yellow	10	10	20	3	10	15	10	5
Whales	purple	20	30	25	20	20	10	20	10

Going extinct/crashing of a trophic level

This can be confusing, so it is best to be flexible when students say a trophic level has crashed.

- When a card is showing, those organisms are alive, feeding, and reproducing. Once a card has been covered up, the organisms have been eaten and are dead.
- If all the cards of a trophic level are covered up (they have all been eaten), they cannot reproduce or feed. That trophic level has gone extinct or crashed.
- If a trophic level cannot feed (lay down any more cards), because there are no more cards of their prey (lower trophic level) uncovered (there is no more food left), then that trophic level has crashed.
- When a trophic level has crashed, record the time and number of cards uncovered for the crashed trophic level.

End of Round

- At the end of 5 minutes, record for each trophic level the number of cards remaining uncovered (still alive and feeding) and/or when the trophic level crashed.

When students are done, they should write their results on the blackboard to compare them with other students' results and to complete the results table. They should answer the questions about all 4 rounds, rather than just the rounds that they played.

		Round 1		Round 2A		Round 2B		Round 2C	
Trophic Level	Card Color	Crash Time	Number of Cards	Crash Time	Number of Cards	Crash Time	Number of Cards	Crash Time	Number of Cards
Diatoms	green								
Krill	yellow								
Whales	purple								

Remember that this game is just a simplified version of real life. It is modeled after how real populations can affect each other. The rate of laying down cards is the feeding, growing, and reproduction rate.

The following results table has the answers that you should expect. Students will probably get close, but not exactly these answers, depending on how well they followed the rules.

		Round 1		Round 2A		Round 2B		Round 2C	
Trophic Level	Card Color	Crash Time	Number of Cards	Crash Time	Number of Cards	Crash Time	Number of Cards	Crash Time	Number of Cards
Diatoms	green	-	31	0:44	0	-	60	2:23	45
Krill	yellow	-	20	0:45	8	0:20	0	-	30
Whales	purple	-	10	3:05	9	0:30	1	-	29

Answers to student worksheet questions, with more information for the teacher.

1. Round 1 is a steady state system. All levels are producing at a rate slower than the trophic level below them. The diatoms have the highest (fastest) rate at 1 card every 5 seconds, the krill are the middle with a rate of 1 card every 10 seconds, and the whales are the lowest (slowest) at a rate of 1 card every 30 seconds.

Round 2A is a primary producer limited system. The krill are producing at a faster rate than the diatoms, so the diatoms go extinct first and then the other levels crash afterwards.

Round 2B is limited by the whales. The whales begin producing before the krill have had time to get going. The diatoms continue to grow through the whole round.

Round 2C is limited by nutrients. The diatoms use up the nutrients before the round is over. The krill and whales continue to feed, but the diatoms do not reproduce anymore.

2. The production rate in Round 1 is increased from one trophic level to the next. If this round continued, the diatoms would crash first because they would run out of nutrients.

3. Diatoms were eaten, so they could not reproduce (lay another card down), then the krill ran out of food, then the whales. The whales survived longer because their production rate was so much slower than the other levels. Krill were eating at a faster rate than the diatoms were photosynthesizing and growing.

4. Steady state could be restored in Round 2A by increasing the rate of the diatom production (lowering the rate to below one card per 3 seconds to one card per 2 seconds) or by decreasing the rate of krill production (making the production rate at one card every 6 seconds).

5. Diatom abundance is controlled by . . .

   Round 1. diatom production rate and krill production rate
   Round 2A. krill production rate
   Round 2B. diatom production rate.

6. The growth rate of diatoms in Round 2C is limited by nutrients. If this game were to last longer, the krill and whales would go extinct because they would run out of food.

7. For this model, it is assumed that the feeding rate, reproduction rate, and growth rate are all one rate. In reality, this is not true. The assumptions surrounding when a tropic level crashes are not realistic. This model is limited in predicting the relationships between feeding rates and reproductive rates of different trophic levels. This model is emphasizes the relationship between trophic levels.

Population Dynamics Game Student Worksheet

		Round 1		Round 2A		Round 2B		Round 2C	
Trophic Level	Card Color	start time	production rate	start time	production rate	start time	production rate	start time	production rate
Diatoms	green	0	5	0	5	0	5	0	2
Krill	yellow	10	10	20	3	10	15	10	5
Whales	purple	20	30	25	20	20	10	20	10

Results		Round 1		Round 2A		Round 2B		Round 2C	
Trophic Level	Card Color	Crash Time	Number of Cards	Crash Time	Number of Cards	Crash Time	Number of Cards	Crash Time	Number of Cards
Diatoms	green								
Krill	yellow								
Whales	purple								

1. What is the abundance of each tropic level at the end of the game for all four rounds? Which levels are growing at the end of the game for all four rounds?

2. Round 1 is a steady state system. Compare the production rates of the trophic levels. Predict what would happen to the diatoms and whales if this game were to run another 5 minutes?

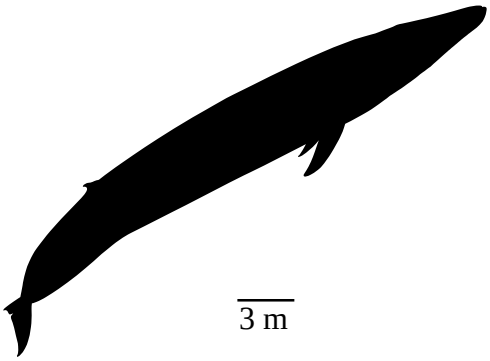
3. Why did all the trophic levels crash in Round 2A?

4. Name two ways a steady state could be restored for Round 2A?

5. Compare the abundance of diatoms alive at the end of Rounds 1, 2A, and 2B. What controls the abundance of diatoms in each round?

6. What limits the growth of the diatoms in Round 2C? Predict what would happen to the diatoms and whales if this game were to run another 5 minutes?

7. What are some of the assumptions and limitations of this model?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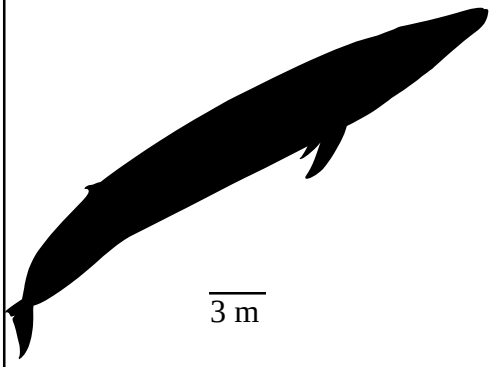
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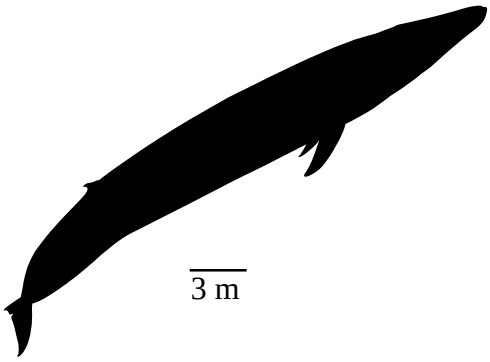
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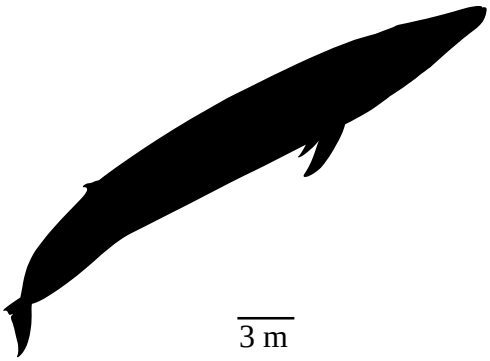
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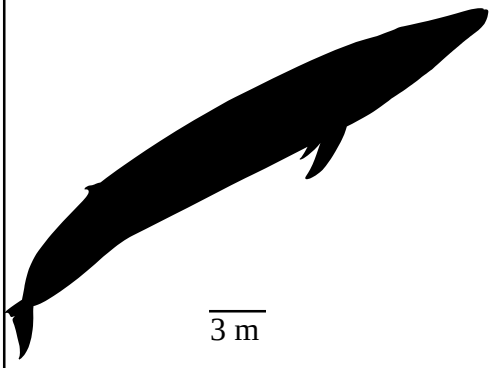
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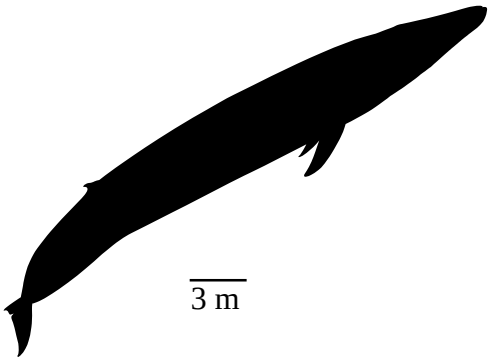
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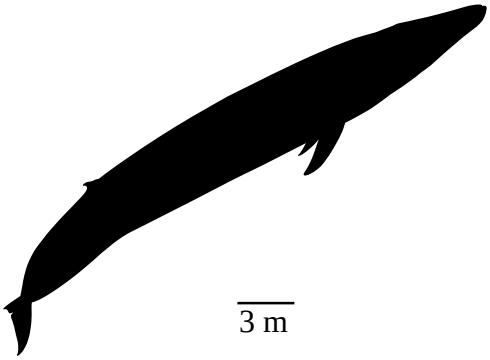
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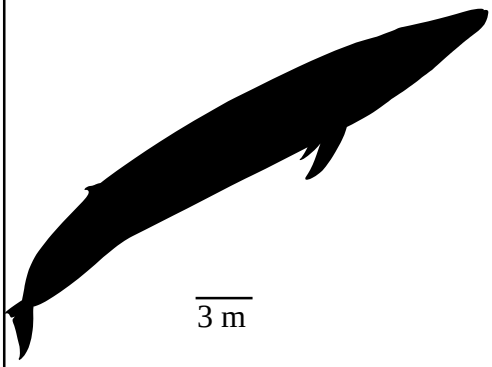
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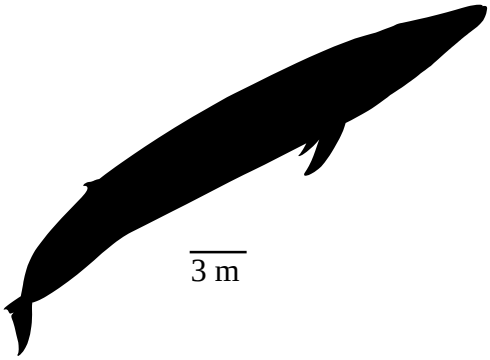
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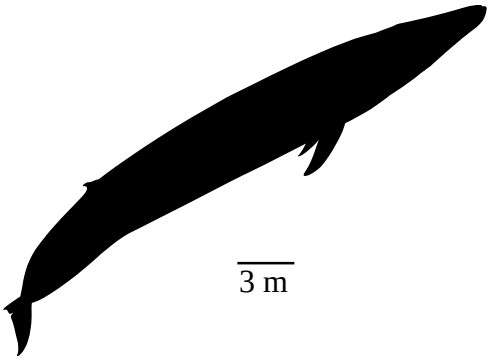
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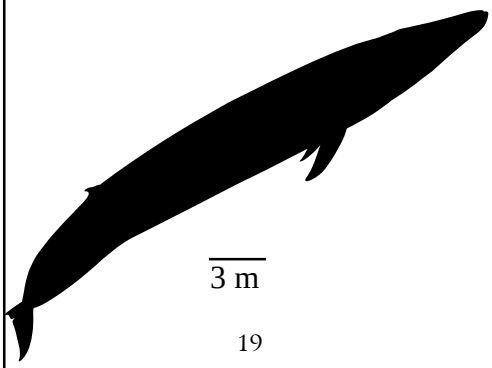
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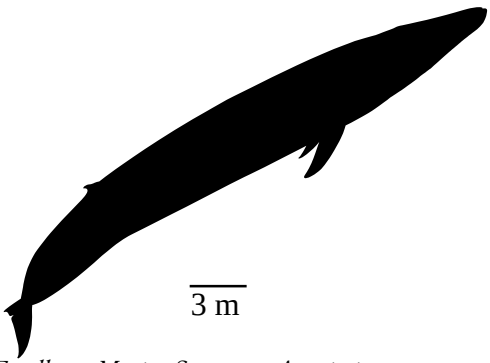
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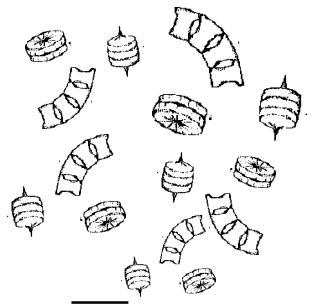

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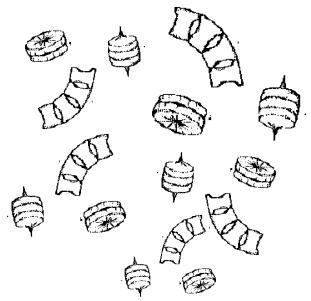

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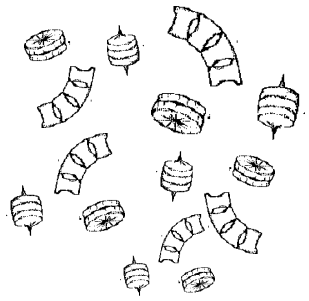

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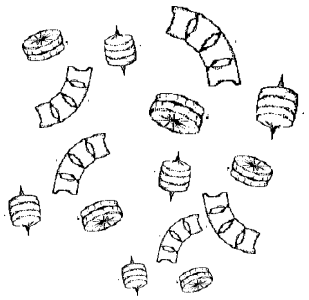

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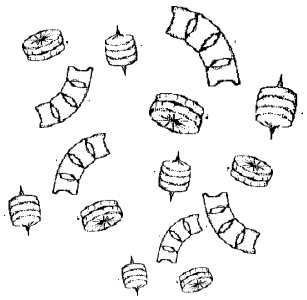

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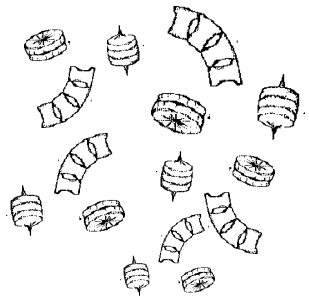

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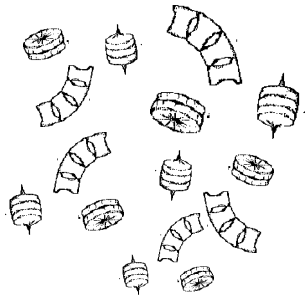

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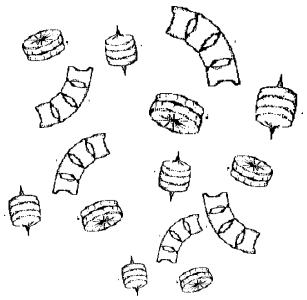

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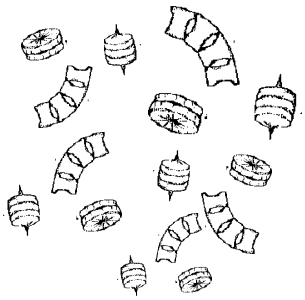

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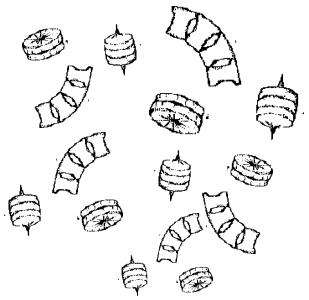

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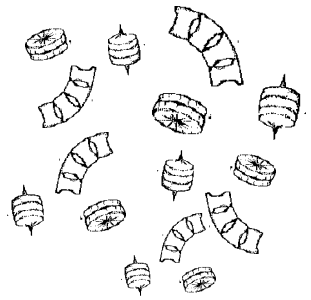

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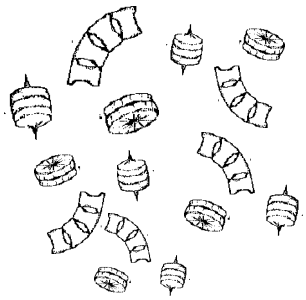

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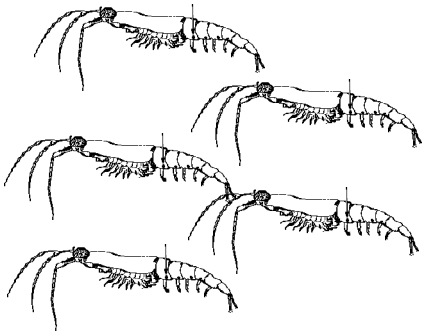

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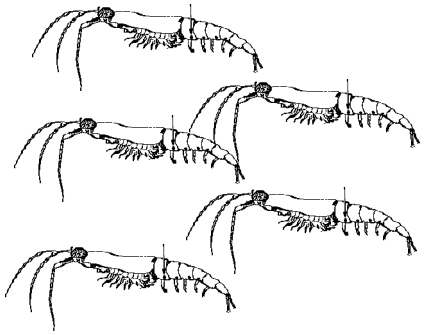

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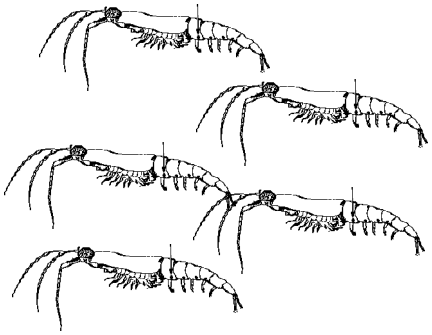

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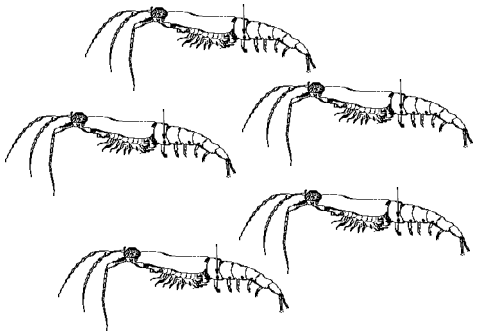

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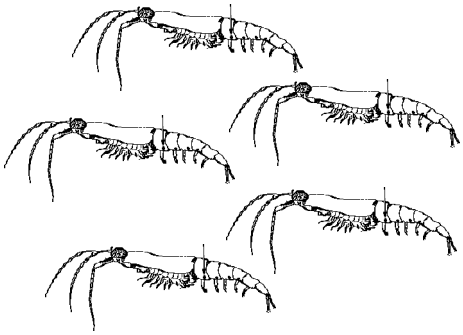

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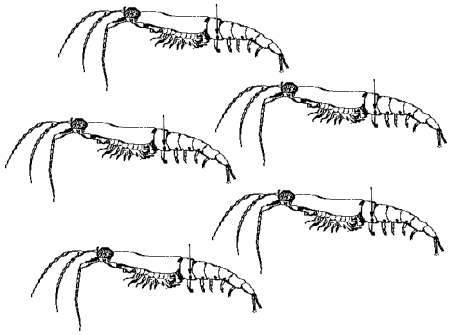

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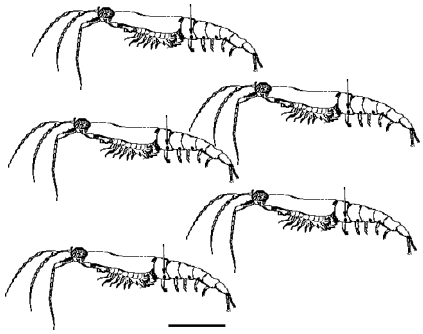

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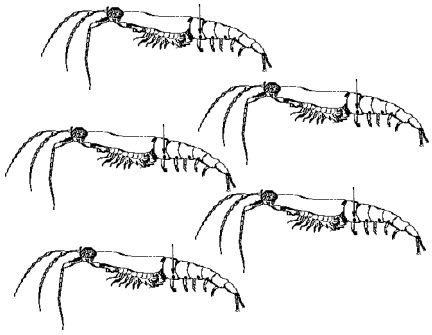

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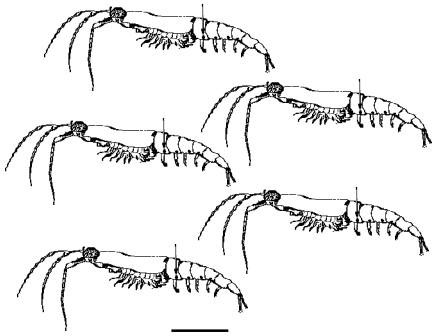

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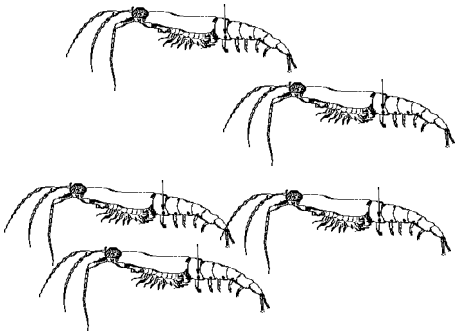

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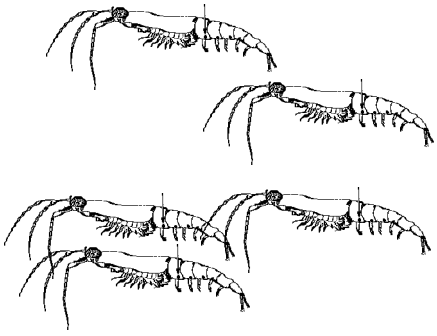

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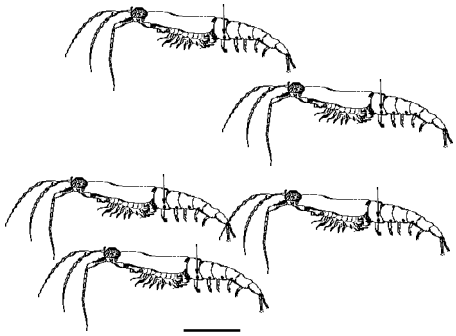

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How Much Does a Whale Really Eat?

Objective

Students will calculate feeding rates of whales and compare them to feeding rates in humans. This is a math-intensive exercise.

Materials and Supplies

Worksheet for students

Background

Whales are very large animals, and sometimes it is hard to believe how much they have to eat. The largest whales are the blue whales (*Balaenoptera musculus*) which can grow to 100 feet and 100 tons while eating krill which are only 2 cm long and weigh next to nothing. How do blue whales survive? Krill in upwelling regions such as the Gulf of the Farallones are very abundant, energy rich, and very easy to catch. Baleen whales feed during the summer in areas with very high concentrations of plankton and small fish.

Students will calculate how much a whale eats and compare it to how much they eat. A typical human weighs 150 lbs and consumes 2,000 calories per day. A typical whale weighs 50 tons and needs nearly 400,000 calories per day. A whale may spend 15 hours per day feeding during the summer season.

Activity

Questions and answers.

1. A blue whale is about 90,000 kg (198,000 lbs) and it eats about 4% of its body weight per day during the feeding season. How much does it eat per day?

   90000 kg X 4% = 3600 kg

2. A blue whale can fill its stomach to about 1,000 kg (2,200 lbs). How many times does a blue whale fill up its stomach each day?

   3600 kg / 1000 kg = 3.6

3. Blue whales feed for about 120 days during the feeding season each year. How much does a blue whale eat each year?

   3600 kg/day X 120 days/year = 432,000 kg/year

4. Krill have a caloric value of about 6 calories per gram. How many calories does a blue whale eat each year?

   432,000 kg/year X 6 calories/g X 1000 g/kg = 2,592,000,000 calories per year.

   A whale spends about 15 hours per day feeding during the summer season. How many calories does it consume per minute during feeding?

   $\frac{\text{3600 kg/day X 6 calories/g X 1000 g/kg}}{\text{(15 hours/day X 60 minutes/hour)}}$ = 24,000 calories per minute

5. Investigate your own consumption rates.

- How many minutes do you spend feeding per day?
  60 minutes
- How many calories do you eat per day?
  2000 calories
- Calculate the number of calories you consume per minute during feeding?
  2000 calories / 60 minutes = 33.3 calories per minute
- Calculate the number of calories you consume per year?
  2000 calories/day X 365 day/year = 730,000 calories per year
- If you eat food with a caloric value of 0.25 g per calorie, how many grams of food do you eat each day?
  0.25 g/calorie X 2000 calories/day = 500 g/day

6. Compare your caloric intake with that of a whale. What factors account for the difference in caloric intake? How does food availability differ for humans and whales?

<u>Credits</u>

The idea for this activity came from Neptune's Web (pao.cnmoc.navy.mil/educate/neptune).

Evans, P. G. H. 1987. The Natural History of Whales & Dolphins. Facts on File Publications. New York.

How Much Does a Whale Really Eat? Student Worksheet

1. A blue whale is about 90,000 kg (198,000 lbs) and it eats about 4% of its body weight per day during the feeding season. How much does it eat per day?

2. A blue whale can fill its stomach to about 1,000 kg (2,200 lbs). How many times does a blue whale fill up its stomach each day?

3. Blue whales feed for about 120 days during the feeding season each year. How much does a blue whale eat each year?

4. Krill have a caloric value of about 6 calories per gram. How many calories does a blue whale eat each year?

5. A whale spends about 15 hours per day feeding during the summer season. How many calories does it consume per minute during feeding?

6. Investigate your own consumption rates.

- How many minutes a day do you spending feeding?
- How many calories do you eat per day?
- Calculate the number of calories you consume per minute during feeding?
- Calculate the number of calories you consume per year?
- If you eat food with a caloric value of 0.25 g per calorie, how many grams of food do you eat each day?

7. Compare your caloric intake with that of a whale. What factors account for the difference in caloric intake? How does food availability differ for humans and whales?

Wrestling for Resources

Objective

Students will be introduced the concept of sustainable development with a simple classroom activity that illustrates how "cooperative behavior" between people competing for a limited resource can benefit all involved.

Materials and Supplies

M&M candies or other small prizes, enough to award 15 to each student

Background

Pairs of students will thumb wrestle to represent competing for a limited resource. For each time one person traps the other person's thumb, the "thumb trapper" earns one point. The goal for each pair is to score the most number of points. Be aware that calling the pair of students either partners or opponents when introducing the activity may influence the outcome. Some students will fight to get the most points and neither in the pair will get many. Other students will figure out if they work together, they both can easily earn lots of points. By working together, student pairs are cooperating and both benefit. This cooperative behavior is important in sustainable development.

Activity

1. Tell your students that they are going to thumb wrestle for M&M's.
2. Pair the students up and tell them they have 30 seconds to play and to count the number of thumb trappings by each student. For each thumb trapping, each individual earns one M&M.
3. Say go and 30 seconds later say stop.
4. Pass out one M&M for each point.
5. Discuss the strategies that each pair developed. Some pairs will get 5-7 and other will figure out that they can get 20 or more. How much time does it take to earn one point?
6. Have students think about how people in the fishing industry compete for a single resource such as a local population of fish and how they can work together. The students with larger hands might be compared with factory ships that can sweep the ocean with nets miles long, leaving less for the small fishing boats. Students who work together and trade off winning are like those who share the common resources. If resources are shared through policies like quotas, everyone can benefit with more employment, controls on catch sizes, and higher market price. Even the fish can benefit.

Extension

Have your students find newspaper articles on declining fisheries and the solutions proposed. Review the results of quota that have been imposed elsewhere (See California Sea Grant's Cooperative Extension Newsletter from November-December 1994 on the British Columbia halibut fishery quotas).

Credit

This activity is based on:

Haddow, A. 1998. Wrestling for Resources. Current, the Journal of Marine Education 15(1) 44.

Are there Algae in Your House?

Objective

Students will understand that algae are a part of the resources that oceans provide to humans. By investigating household products, students will discover that the human senses are not enough to detect the presence of algae in food.

Materials and Supplies

Various food products (or just the containers)

Brownie mix, cheese, chocolate milk, coffee creamer, cottage cheese, egg substitute, evaporated milk, frozen foods and desserts, frozen yogurt, ice cream, infant formula, margarine, mayonnaise, multiple vitamins, pet food, pudding, relishes, salad dressing, sauces and gravies, sour cream, toothpaste, whipped topping, whipping cream, yogurt

Samples of brown, red, and green seaweed (from health or ethnic food stores) (optional)

Background

Although fish and other seafood products make delicious and healthy meals for people around the world, many American children would not object if they never had to eat another tuna casserole again. But would they object if there were no more cheese, chocolate milk, peanut butter, pudding, frozen desserts, or fruit drinks? What do these different types of food have in common? They are just a few of the foods that contain seaweed.

Many kinds of seaweed are eaten, because they are full of vitamins and iodine. Asian cultures use seaweed like Americans use green beans and carrots. Since Americans have not developed the same taste for seaweed, manufacturers use only derivatives from the seaweed. Alginate, carrageenan, and beta-carotene act as stabilizers, thickeners, and colorants in the many American foods.

Seaweeds are not really weeds, but are large marine algae that grow in coastal waters. Algae include thousands of species from microscopic phytoplankton to huge floating or anchored "plants" seen washed up on shore. The three main groups of algae are the brown, red, and green algae. They all provide important ingredients for manufactured foods.

- Carrageenan is a generic term for compounds extracted from a species of red algae used in stabilizing and gelling foods, cosmetics, pharmaceuticals, and industrial products.
- Alginates are extracted from brown algae and are used to make water-based products thicker, creamier, and more stable over extreme temperatures and time, making the food last longer.
- From green algae, the natural pigment beta-carotene is removed and used as a yellow-orange food coloring. It is currently believed to help prevent certain forms of cancer.

The seaweed derivatives are only a portion of the many products derived from ocean algae, animals, minerals, and seawater. Seaweeds and other marine organisms are also a source of unique molecules for marine-derived medicine. Together they provide many good reasons to protect Earth's oceans.

Activity

This activity could be done in class with students or the teacher bringing in items or at home by students looking around their own home. Students should turn in a page showing what they find.

1. Show the class a few items with the algae derivatives, without mentioning that they come at least partially from the ocean. Ask students to guess what the foods have in common.
2. Explain that each product contains algae, which is used in many everyday foods and household items. Point out the nutrition label on the packaging. Show the students pictures or samples of brown, red, and green algae. Explain that the alginate, carrageenan, and beta-carotene are derived from the algae.
3. Ask students if they would ever eat seaweed or algae.
4. With the food items in hand, let the students hypothesize why they think the products contain algae. Have students fill out the worksheet.
5. Ask students to smell and taste the algae samples if possible.
6. Ask students why they think other cultures eat more algae than Americans do.

Credits

This activity is based on lesson plans from the following two websites:
Neptune's Web lesson plans for social studies (http://pao.cnmoc.navy.mil/educate/neptune).

Smithsonian's Ocean Planet There are Algae in your House! By B. Nalker and D. Casey. (http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/education_lesson1.html).

Resources

Maine Coast Sea Vegetables . . . http://www.seaveg.com/

Food Products Student Worksheet

Product	Carrageenan	Alginates	Beta Carotene	No Algae
brownie mix				
butter				
cheese				
chocolate milk				
coffee creamer				
cottage cheese				
egg substitute				
evaporated milk				
frozen foods/desserts				
frozen yogurt				
ice cream				
infant formula				
margarine				
mayonnaise				
multiple vitamins				
peanut butter				
pet food				
pudding				
relishes				
salad dressing				
sauces and gravies				
sour cream				
soup, canned				
toothpaste				
whipped topping				
whipping cream				
yogurt				

Additions to Activities Already a Part of Your Biology Curriculum

- Animal Dissections. Look in the stomach of a fish, shark, or mussel. What did it have for its last meal? Was the animal living in the wild or was it from a farm? Try to identify any remains. Analyzing gut contents is used to understand the food web. For many fish species, it is nearly impossible to see them feed in the wild, yet their gut contents tell us what they eat and the percentages of each species eaten.

- Microscopic Organisms. When studying microscopic organisms, take a look at marine phytoplankton. Take a sample of water from the sea. It is best to use a net with a small mesh size to catch the small phytoplankton. Use keys to identify the plankton. If purchasing pre-made slides, buy a set of marine phytoplankton. Compare the size of diatoms to dinoflagellates or other phytoplankton. Diatoms are the dominant phytoplankton in the upwelling regions such as the Gulf of the Farallones. Dinoflagellates are the food of choice for sand crabs.

- Photosynthesis and Respiration. Measure the change in the oxygen concentration of water in a light and dark bottle. This was the original way to measure photosynthesis in the ocean. In the dark bottle (cover a flask with tape), only respiration can happen. In the light bottle, both photosynthesis and respiration occur. First measure the oxygen concentration of water from the ocean, the bay, or a lake. Then fill the dark and light bottles with water from the ocean, the bay, or a lake. Let sit for 24 hours. Measure the oxygen concentration of the water in both the dark and light bottles. The light bottle should have an increase in oxygen if there were phytoplankton present.

- Chlorophyll a and Other Photosynthetic Pigments. Using a simple chromatography procedure include marine algae in your list of samples to analyze. You can collect algae at the shore (be sure you have a permit if needed, check with the beach manager). A description of this activity can be found in S.E.A. Lab: Marine Science for High School Students in Chemistry, Biology and Physics. UNC Sea Grant Publication Unc-SF-90-01.

- Food Web Connections. Students can make mobiles or drawings to represent the food web. They should connect the organisms using arrows to show the feeding relationships in an ecosystem. Different groups of students can work on different habitats (open waters of the coastal Gulf of the Farallones, the open ocean water, the sandy beach, and the rocky intertidal zone).

Food Web of the Gulf of the Farallones Slide Show

#	Topic (photographer)	**Script** *(italicized words in glossary)*
1	Title Slide	Welcome to a slide show sponsored by the Gulf of the Farallones National Marine Sanctuary and the Farallones Marine Sanctuary Association. Today's topic is the *food web* of the Gulf of the Farallones.
2	Farallones (K. Evans)	Located just outside of the San Francisco Bay, to the west of your school, is the Gulf of the Farallones. This special marine environment harbors a fascinating array of plants and animals, from huge whales to single-celled *algae*.
3	Birds on Island	The water surrounding the Farallon Islands and the nearshore coast is home to a rich biological *community*. The largest and most diverse eastern Pacific populations of seabirds, seals, and sea lions, south of Alaska, are found here. The Farallon Islands are home to the largest concentration of breeding seabirds in the contiguous United States. Food is plentiful in the Gulf waters and the islands provide a habitat for breeding. Where does this food come from? Who eats whom? How does the energy flow through the system? The answers to these questions are the focus of today's presentation.
4	Humpbacks feeding (D. Shapiro)	The ocean is a dynamic place, influenced by the changes in the weather throughout the year. We see three seasons in the Gulf of the Farallones, each with a different face and impact on the *ecosystem*. Strong spring winds bring *nutrient*-rich water to the surface, which drives the biological community. The *primary producers* use the nutrients and provide energy for the community, from small *zooplankton* all the way up to the humpback whales. The other seasons of the region are important in maintaining the ecosystem.
5	3 Seasons Figures	A brief review of the seasons of the Gulf is necessary since the cycles of the *organisms* are tied closely with the seasons. During an average year in the Gulf of the Farallones, *upwelling* begins in late February and runs through the summer. Cold, nutrient-rich water is brought to the surface, and *phytoplankton* become abundant. Relaxation follows during late summer and early fall when the phytoplankton become limited by the supply of nutrients and grazing pressure. The population of phytoplankton decreases in abundance during the relaxation period which is the growing season for many animals. In November, winter storms mix up the water. Nutrient concentrations increase because the deeper water is mixed into the surface water. Yet

		phytoplankton do not get enough sunlight to grow rapidly until spring. The winds start blowing consistently from the north to begin the upwelling season during the spring.
6	Sanctuary map	We will focus on the waters of the Gulf which are protected and managed by the Gulf of the Farallones National Marine Sanctuary. This federally designated area encompasses nearly 1000 square miles (3251 km^2). The goal of the Sanctuary is to protect the resources of the marine environment.
7	Open water with fish	There are many habitats in the Gulf of the Farallones National Marine Sanctuary. The open water of the Gulf, . . .
8	Sandy shore	. . . the sandy shores of Tomales Bay and . . .
9	Rocky bottom	. . . the rocky bottom near the Farallon Islands are just a few examples.
10	Food Web	Let's examine the open water in the coastal region. This is a fairly simple model of a food web in the Gulf of the Farallones. It shows the feeding interactions between groups of organisms. We are going to build a more complete food web today. The base of the food web is the phytoplankton. They are the primary producers or the first *trophic leve*l. Phytoplankton are eaten by the zooplankton. Zooplankton are eaten by the next trophic level of *consumers* – little fish and whales. Fish are eaten by other fish, humans, and birds which are the top of the food web. Bacteria eat phytoplankton, waste, and dead material from all levels. Energy enters the system through the phytoplankton and is transferred and used at each level. The chemicals that makes up the bodies and tissues are passed from trophic level to trophic level and are recycled into reusable forms by the bacteria.
11	Sun on water	Throughout this slide show, you will learn about a few specific species and groups living in the Gulf of the Farallones. The food web is a very complex set of interactions. Many are still unknown. We are going to follow the energy and where does that begin? With the Sun!
12	Two Diatoms	Primary producers use *photosynthesis* to convert the carbon dioxide into a high-energy sugar with energy from sunlight. In the open water, *diatoms,* seen here, are the dominant single-celled phytoplankton. They use this energy plus other chemicals called nutrients to maintain their cell, grow, and reproduce. Nutrients, which are the same as fertilizers for plants, are required by all living things. We will follow the energy through the ecosystem.
13	Diatoms	In comparison with other types of phytoplankton, diatoms are fast growing, but they can not propel or move themselves. They have cell walls made of silica which is the same material as in glass. Diatoms

reproduce by simple cell division, and their growth rate is dependent on the amount of sunlight and nutrients available. Because diatoms have glass cell walls, what nutrients or chemicals do you think they need in order to divide? (They need the nutrient silica.)

During the springtime with the increase in sunlight and upwelling of nutrients, they reproduce at very fast rates, at several divisions per day. There are many species of diatoms living in the Gulf of the Farallones.

14	Diatoms with long spines	Some grow in chains as you see here. Does anyone have an idea why a chain would be advantageous to a single-celled organism in water? (Chains of cells have more surface area and that helps them float.) Long spines aid in flotation as well as make it more difficult for predators to eat them. Diatoms must stay in the lighted surface water to gather enough energy for growth. They range in size from one thousandth of a millimeter to one tenth of a millimeter. Phytoplankton are the base of the food web and the energy flow begins here.
15	Kelp	In shallow waters near the shore and around the Islands, *benthic* algae are an important part of the lowest trophic level. They photosynthesize and require sunlight and nutrients just like the diatoms.
16	Krill (S. Leatherwood)	The next level in the food web is the zooplankton. Does anyone know the name of this important zooplankton found in the Gulf of the Farallones? More formally called *euphausiids*, *krill* are small crustaceans that spend their entire lives as zooplankton. As young *larvae*, they eat small phytoplankton and protozoa. As they grow, they eat the larger diatoms. One abundant species lives over the continental shelf, while the other abundant species lives in deeper water at the edge of the shelf and over the continental slope.
17	Krill with thumb (S. Leatherwood)	These are adult krill. How big is one krill based on the size of this finger? About 1 cm in length. One species form swarms during the upwelling season with up to 75,000 animals per cubic meter. The next trophic level has easy feeding when there are krill swarms. Animals eat to get the chemical energy of the their prey's molecules as well as building materials from which they construct their own tissues. The most important thing to remember about energy flow in an ecosystem is that it is linear, or one-way. That is, energy moves along the food web from one organism to the next as long as it is not used. Once energy has been used (to move, digest food, or reproduce), it is lost and is unavailable for other organisms.

18	Blue Rockfish	Next in the food web, fish and *baleen* whales eat the lower trophic level of zooplankton. We are going to focus on the commercially important rockfish. There are many species in this group, each with a different life history. Blue rockfish are a classic nearshore species and the most abundant nearshore rockfish along our coast. Here is a simplified story of rockfish and how they fit into the Gulf of the Farallones food web. The adults spawn from December through February, which as you may recall is the winter storm season. This is a dicey strategy: to have young when the water is being mixed every which way.
19	Larval *Sebastes* sp.	The larvae are *pelagic*, which mean they live in the open water. The larvae get pushed up and down, out-to-sea, and to the beach. Is there food for them? Maybe not. Will they get eaten? Probably. Why do they reproduce in the winter? There must be a big payoff when they get it right – just enough food to make it to the spring upwelling season, and they are able avoid predators. When the upwelling cycle begins in late February, the food web begins to develop which provides lots of food for these larval fish.
20	Juvenile blue rockfish	In April, the rockfish larvae undergo metamorphosis into pelagic juveniles. There is plenty of zooplankton for them to eat. Yet at this life stage, they are food for salmon and seabirds. In May and June, the pelagic juveniles such as these blue rockfish settle into benthic, or bottom, habitats nearshore.
21	Lingcod	Now in a different habitat, the predators of the rockfish change. It is lingcod seen here, greenlings, and even other rockfish which feed on the juvenile rockfish on the bottom. One researcher found 53 juvenile rockfish in the gut of one lingcod! The food web becomes more complex because one life stage, the juvenile, is the prey for another life stage, the adult. The trophic levels are not as simple as they may have seemed initially. Blue rockfish stay nearshore as adults while …
22	Yellowtail rockfish	… the yellowtail rockfish seen here change their habitat one more time. They use the nearshore area as a nursery area during their first year then move to deeper offshore habitat as adults.
23	Barnacles	In a similar way, these barnacles and other animals spend part of their life floating and part of their life on the sea floor. At both stages, the barnacles are eating plankton, although the size of plankton changes as the barnacle grows.

24	Common Murres on water (D. Howard)	Moving above the water, we find the abundant Common Murre. These seabirds live, feed, and breed in the Gulf of the Farallones region. Actually these birds spend a lot of time under water. They can dive for over one minute, often down to about 100 feet. Some have been recorded diving to 300 feet! Murres feed on mid-water schooling animals, especially juvenile rockfish, krill, anchovies, smelt, and squid.
25	Murre egg	Common Murres nest in dense colonies on cliffs where there is competition for nest space. Beginning in late October, pairs arrive at their territories and maintain them throughout the winter. In April and May, Murres lay their eggs. By analyzing the eggs, researchers know that the Murres eat krill during this time.
26	Seabird Chick	Most chicks hatch in June. The adults feed their chicks juvenile rockfish and northern anchovy. Remember, the juvenile rockfish are abundant during this same period. This sequence sets the young Murres ready to fledge in July and swim toward the coast when the food is plentiful.
27	Colony of Murres	During the warm water years of El Niño, juvenile rockfish are not as abundant, and Common Murres rely on northern anchovies much more than usual. This complicates the food web in ways that you may not have originally imagined. Not only do we need to include the prey of different life stages, different seasons, and now different years to represent the complexity in the food web.
28	Plankton	Here in the Gulf of the Farallones, what are the trophic levels that we have looked at so far? First are the diatoms who use photosynthesis to trap energy into a usable form. Next are the zooplankton which include krill. We must not forget that the larval rockfish are also zooplankton.
29	Schooling Fish & Murres	The third trophic level are the adult rockfish and the Common Murres. We need to include the other prey of these birds such as smelt, anchovies, and squid in the food web. There is another major group of organisms in this food web. Remember this is the path of energy. It travels from one individual to another. Some individuals die before they are eaten. What happens to them? Crabs and other *decomposers* eat the dead animals.
30	Bacteria	Moving back down in size we must include the bacteria in the food web. They are an important link in the system. The more and more researchers study marine bacteria, they discover more ways that the bacteria help drive an ecosystem. Bacteria are one of the decomposers of the sea. They essentially eat dead organisms and waste material. While they gain energy for their own growth, they break down the material back into nutrients which are then available to the phytoplankton.

In the open water, most life live in the sun-lit surface water. As organisms die, they slowly sink or get washed to shore. The bacteria breakdown this material and most of the nutrients end up in the deeper, darker water. The diatoms cannot survive without light and do not live in the dark water where the nutrients are. Upwelling and coastal runoff provide nutrients to the diatoms and other phytoplankton in the surface waters. It is the bacteria that recycle the nutrients and make them available to the phytoplankton.

31 Pigeon Guillemot eating fish

How do we know all of this? How do researchers figure out what the animals eat? One way to study fish is to examine their gut contents. For birds, fecal pellets, regurgitation material, and behavior provide lots of information on where they fit in the food web.

32 Herring Fishing in Tomales Bay (R. Allen)

The Gulf of the Farallones has the largest concentration of fishing vessels in California, Oregon, and Washington which depend on this food web. Removing fish from the ocean impacts the other organisms in the ecosystem. Managing fisheries, which essentially sets limits on the amount of fish caught, is a very hard thing to do for several reasons. Fishery managers must try to predict how the biological community will respond to removing a certain amount of fish. Yet, the biological system is both complex and naturally variable, which means it is hard to make predictions. The fishing industry is very important economically to the region which adds one more challenge to fisheries management.

33 Research (J. Hall)

Since 1995, biologists affiliated with the Gulf of the Farallones National Marine Sanctuary have been conducting research and monitoring cruises to investigate the abundance and distribution of marine organisms in the Sanctuary. Net sampling targets krill because they are a critical link in the Gulf of the Farallones food web. In fact, they are the reason that blue and humpback whales migrate to the Sanctuary each summer to feed, and they are an important food source for Pacific salmon, rockfish, and seabirds. Seabird and marine mammal observations are conducted during daytime transects between sampling stations. With this information, Sanctuary managers hope to understand what is affecting the distribution and abundance of krill and how that is tied to the presence of higher level predators such as marine mammals, fishes, and seabirds.

34 Blue rockfish

Remember what Common Murres eat? They eat many of the same fish that are commercially fished (i.e. rockfish, anchovies, smelt, and squid). The regulations for fishing rockfish need to be based on models which include the needs of the Common Murres.

Focusing just on Common Murres, what other ways do you think humans may impact them?

35 Oiled Common Murre

Oil spills are detrimental to Common Murres because they often sit on the surface water where some of the oil is. This bird has oil on its chest. As they clean their feathers, they consume some of the toxic oil. They also get hypothermia. In 1984, over 1,800 Common Murres were killed when the T/V *PUERTO RICAN* spilled over 1.4 million gallons of oil.

36	Murre in net with fisher folks	Fishing gear can also kill birds. They drown in nets,
37	Murre with 6-pack plastic ring	or they become entangled in plastic such as this 6-pack ring.
38	Sea lions on channel marker	Today, we have only examined a few species of a few groups of organisms living in the Gulf of the Farallones. There are many kinds of phytoplankton, more zooplankton such as the copepods, more fish such as the commercially important salmon, herring, anchovies, and the ugly lingcod. And how could we not even mention the sea lions or other marine mammals?
39	Kelp Harvest	You are part of the food web. We no longer hunt for marine mammals in the Gulf of the Farallones or collect Common Murre eggs on the Farallon Islands as humans used to. Now algae and krill are harvested for food such as ice cream and pet food.
40	Complex food web	The food web is much more complicated than the original drawing, and is still incomplete. There are complex relationships between the trophic levels. Each trophic level depends on the one below it for its energy. Energy is used at each level for growth and reproduction, and lost as heat. Only about 10% of the energy is available from one level to the next. The arrows represent the transfer of energy. It does not show the recycling of the nutrients. Are there any other groups that we have missed? Most definitely. We have examined only a few species that feed in the open water/pelagic habitat. We are missing the bottom community that decomposes the dead tissue that reaches the sea floor.
41	Sanderling at Alameda mud (K. Evans)	The nearshore sandy beaches, rocky intertidal zone, and benthic area all are important components to the Gulf of the Farallones ecosystem which you can learn about in other slide shows.
42	Southeast Farallon Island (K. Evans)	How do our needs as people affect the ocean as a home for the organisms that live there? That is a question for you to help decide. The food web of the Gulf of the Farallones represents the biological community of the region. We hope that by understanding the ecological connections of the marine community you will appreciate the special environment outside of the Golden Gate.

Books and Resources
Food Web of the Gulf of the Farallones

Activities

Penn, G. 1997. Coastal Awareness: A Resource Guide for Teachers. US Department of Commerce, NOAA, Office of Public and Constituent Affairs/ Outreach Unit. Write to: 1305 East-West Highway, Station 1W204, Silver Spring, MD 20910.

S.E.A. Lab: Marine Science for High School Students in Chemistry, Biology and Physics. UNC Sea Grant Publication Unc-SF-90-01.

Regional Descriptions

LeBoef, B.J. and S. Kaza, 1985. Natural History of Año Nuevo. Boxwood Press, Pacific Grove, CA.

Monterey Bay Aquarium, 1997. Natural History of the Monterey Bay National Marine Sanctuary. ISBN 9-781878-244116. (Monterey Bay is just to the south of the Gulf of the Farallones.)

Schmieder, R.W., 1991. Ecology of an Underwater Island. Cordell Expeditions, Walnut Creek, CA. (Cordell Bank is just north of the Gulf of the Farallones.)

Textbooks

Castro, P. and M.E. Huber, 1997. Marine Biology. McGraw-Hill Companies. ISBN 0-697-24360-5.

Levinton, J.S. 1982. Marine Ecology. Prentice-Hall, Inc. New York.

Milne, D. 1995. Marine Life and the Sea. Wadsworth Publishing Co. ISBN 0-534-16314-9.

Sumich, J.L., 1996. Biology of Marine Life. WCB/McGraw-Hill Companies. ISBN 0-697-15989-2.

Selected Web Sites
Food Web of the Gulf of the Farallones

Marine Biology and Ecology

- Marine Biology Glossary . . . http://life.bio.sunysb.edu/marinebio/glossary.html
- Ocean Discovery Center Sea Life . . . http://www.odc.ucla.edu/html/body_odsea_life.html
- Marine Biology Learning Center . . . http://www.marinebiology.org/science.htm
- Pacific Biological Communities . . . http://bonita.mbnms.nos.noaa.gov/sitechar/bio.html

Food Web

- Ocean Link's Food Web . . . http://oceanlink.island.net/oinfo/foodweb/foodweb.html
- Krill Fishery . . . http://csf.colorado.edu/forums/deep-ecology/2000/msg00155.html
- Food Web Game . . . http://www.mastep.sjsu.edu/lessons/webgame/home.html
- Food Web of Chesapeake Bay . . . http://www.chesapeakebay.net/info/ecointr6.cfm

Organisms

- Phytoplankton Ecology . . . http://www.mote.org/~pederson/phyto_ecol.phtml
- Introduction to Marine Botany . . . http://www.mbari.org/~conn/botany/
- Plankton Net . . . http://www.uoguelph.ca/zoology/ocean/index.htm
- Animal Sounds on the Net . . . http://members.tripod.com/Thryomanes/AnimalSounds.html
- Museum of Paleontology Marine Organisms... http://www.ucmp.berkeley.edu/help/topic/marinebio.html
- Seabird and Fish Research... http://www.absc.usgs.gov/research/seabird&foragefish/index.html
- Shorebirds ... http://migratorybirds.fws.gov/shrbird/shrbird.html
- Fish and Wildlife Endangered Species Resource . . . http://endangered.fws.gov/kids/index.html
- Modeling Crab Behavior ... http://tbone.biol.sc.edu/~dean/model/model.cgi

Marine Mammals

- The Whale Net... http://whale.wheelock.edu/welcome.html
- Elephant Seals at Año Nuevo . . . http://parks.ca.gov/central/bayarea/ansr228.htm
- The Marine Mammal Center . . . http://www.tmmc.org/
- A Curriculum Unit on Whales on the Web . . . http://curry.edschool.virginia.edu/go/Whales/

Other Issues

- El Niño Watch in California . . . http://cwatchwc.ucsd.edu/cgi-bin/elnino.cgi
- Harmful Algal Blooms... http://www.redtide.whoi.edu/hab/default.html