

COASTAL ECOSYSTEM CURRICULUM: OCEANOGRAPHY



FARALLONES MARINE SANCTUARY ASSOCIATION

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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 assess 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 the Farallones National 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.

Funding

The Coastal Ecosystem Curriculum and Coastal Ecosystem Teacher workshop are funded in part by the T/V *PUERTO RICANO* Oil Spill Restoration Fund through the Gulf of the Farallones National Marine Sanctuary.

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?

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

Oceanography 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 Coastal Ecosystem Curriculum 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 relate the abundance of wildlife in the Gulf of the Farallones to seasonal upwelling of nutrients.

Earth Sciences

5. Heating of Earth's surface and atmosphere by the Sun drives convection within the atmosphere and oceans, producing winds and ocean currents. Students will:

d. Know properties of ocean water, such as temperature and salinity, can be used to explain the layered structure of the oceans and the generation of vertical ocean currents.

- Students will describe how sea surface temperature indicates when cold water is upwelled to the surface.

Investigation and Experimentation

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

k. Recognize the cumulative nature of scientific evidence.

- Students will be able to describe the seasonal cycle of the ocean using different parameters.

Coriolis Effect Activity

Earth Sciences

5. Heating of Earth's surface and atmosphere by the Sun drives convection within the atmosphere and oceans, producing winds and ocean currents. As a basis for understanding this concept, students will:

b. Know the relationship between the rotation of Earth and the circular motions of ocean currents.

- Students will be able to relate the deflection on the spinning cardboard to the spinning Earth.

Water Density Activity

Earth Sciences

5. Heating of Earth's surface and atmosphere by the Sun drives convection within the atmosphere and oceans, producing winds and ocean currents. As a basis for understanding this concept, students will:

d. Know properties of ocean water, such as temperature and salinity, can be used to explain the layered structure of the oceans and the generation of vertical ocean currents.

- Students will be able to predict the relative density and depth of a water sample based on temperature and salinity.

Investigation and Experimentation

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

a. Use appropriate tools and technology to collect data, analyze relationships, and display data.

- Students will use scales and graduated cylinders to make known-density salt-water solutions.

d. Formulate explanations by using logic and evidence.

- Students will be able to support their predictions with evidence from their observations.

l. Analyze situations and solve problems that require combining and applying concepts from more than one area of science

- Students will discuss density in terms of both physics and chemistry.

Coastal Ocean Upwelling Activity

Earth Sciences

5. Heating of Earth's surface and atmosphere by the Sun drives convection within the atmosphere and oceans, producing winds and ocean currents. As a basis for understanding this concept, students will:

b. Know the relationship between the rotation of Earth and the circular motions of ocean currents.

- Students will describe the impact of the Coriolis effect and coastal upwelling.

d. Know properties of ocean water, such as temperature and salinity, can be used to explain the layered structure of the oceans and the generation of vertical ocean currents.

- Students will relate sea surface temperature to wind speed to explain why sea surface temperature is cold during the summer.

Investigation and Experimentation

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

i. Analyze the locations, sequences, or time intervals that are characteristic of natural phenomena.

- Students will analyze multiple graphs to learn about the seasons of oceanographic conditions.

Oceanography of the Gulf of the Farallones

The Gulf of the Farallones is a unique oceanographic area. Just outside of San Francisco Bay, strong spring winds bring nutrient-rich water to the surface and create a rich biological community. The geological landscape under the water sets the scene and impacts the flow of the water. Waves and surface *currents* are primarily wind-driven and result in three oceanographic seasons over this interesting region: winter storms, *upwelling*, and relaxation.

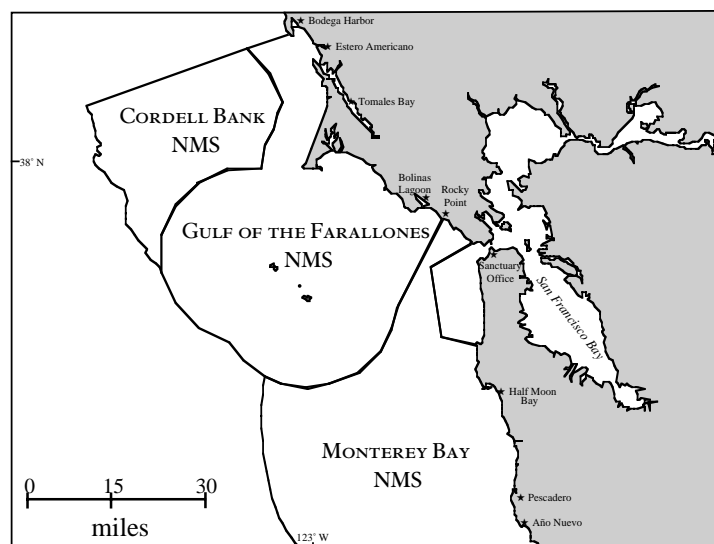
The Gulf of the Farallones National Marine Sanctuary encompasses 948 square nautical miles (3,251 km²), including the Gulf of the Farallones. Also included in the Sanctuary are the many habitats of the nearshore area, such as rocky intertidal, sandy beaches, mudflats, and estuaries (also known as esteros). This unit focuses on the open water in the nearshore zone and the basic principles of the oceanography in that region.

Geology of the Gulf of the Farallones

Located just west of the Golden Gate Bridge, the Gulf of the Farallones covers the *continental shelf* and *slope*. From the shoreline to about 100-150 m deep, the continental shelf forms a broad submarine plain, with rocky outcrops, gravel, sand, clay, and deposits of broken shells. Sand and silt cover much of the continental shelf. It is one of the widest areas of continental shelf along the Oregon and Northern California coast. About 25 miles from the coast, the seafloor drops off with a grade of about 3°, from 100-150 m to about 3200 m. This is called the continental slope and is covered with a more uniform sandy sediment. Near the shelf edge, a discontinuous ridge of granite, the Farallon Ridge, runs in a northwesterly direction closely paralleling the coast. The high points of this ridge rise above the ocean surface and are the Farallon Islands, after which the Gulf is named. The Farallon Islands, located a few miles east of the slope, rise up from the continental shelf to above the sea surface.

Ocean Water

To understand the dynamics of the ocean water, it is necessary to understand the physical and chemical properties of water itself. Water is a unique liquid. It is the only substance on Earth that naturally occurs in all three states (gas, liquid, and solid) at temperatures that are experienced by living organisms. Its physical properties set it apart from all other liquids and makes it an ideal medium for life.



Water is a fluid with low viscosity – it flows easily. It readily drains across the land into basins, waves form easily on the surface, and fish and ships pass through it without using much energy.

Water has a relatively high density among liquids. As a consequence, it builds up great pressures with depth. The pressure on an animal or submarine is twice as great at a depth of 10 meters as it is for terrestrial animals at sea level. But high density also means great buoyancy. Aquatic animals do not need extensive skeletons because the water supports them. Sound travels through water more quickly and farther than in air because of its density. Many animals, including humans, produce sounds to help in navigation and communication.

Density of water is dependent on temperature, *salinity*, and pressure. The simplest comparison is that fresh river water or rainwater is much less dense than salty seawater. Density increases as the amount of salt in the seawater (salinity) increases. Density also increases as water gets colder (temperature decreases, until 4°C). These two properties, along with pressure, separate water masses in the ocean on the basis of their densities. Cold, salty water descends to the bottom of the ocean while warmer, less salty water overrides it at the surface.

Water is transparent. Sunlight to drive photosynthesis penetrates 100 meters in the open ocean. In nearshore areas, marine plants in California may not have sufficient light below 10-15 meters; however, marine plants can photosynthesize as deep as 100 meters in clear tropical seas. Sunlight is a rainbow of colors that penetrate to different depths – reds and oranges are absorbed in the first few feet while greens and blues penetrate the deepest. Paradoxically, bright red animals are often found living at depths where the absence of red light makes them nearly invisible.

Water has a high heat capacity. It takes a greater exchange of heat to raise or lower its temperature than for any other substance on Earth (except for ammonia). For this reason, water temperatures are very stable. There are no great daily or seasonal swings of temperature in the ocean like those that occur on land. At any one place, the annual ocean temperature range is usually less than 10°F (5.5 °C), the daily range is not more than 1° F (< 1°C). Compare this with inland cities where the difference from noon to midnight may average 20-30°F (10-15°C). The high heat capacity of water also means that it can give off or absorb a great deal of heat without changing temperature very much. The ocean exchanges heat with the air or land. Consequently, the air temperature in the San Francisco Bay area, which is near the ocean, is more moderate than areas in the middle of the continent. For example, the average temperate range in Kansas City, Kansas (39.1°N 94.7°W) is 16-90°F (-9-32°C) while at nearly the same latitude in San Francisco (37.8°N 122.4°W) the average temperature range is 45-68°F (7-20°C).

The surface of the ocean is warmed by the Sun. Waves churn and mix the surface water, down to 100 meters during large storms. As a result, temperatures near the surface are very uniform. There is often a zone where the temperature decreases rapidly called the thermocline. In the open ocean away from the shore, the thermocline depth will be deeper (approximately 100 m) than in the nearshore waters of the Gulf of the Farallones (10-20 m). The water below the thermocline is much colder than the surface water.

Water is the best known solvent. More substances dissolve in water than any other liquid. As a consequence, given the 4 billion years that water has flowed across the land into the ocean basins, nearly every element found in Earth's rocky crust is now in seawater. These elements are what make the ocean salty. The total amount of salts in seawater is called salinity. It is measured in grams of salt per 1000 grams of seawater. The average salinity for all oceans is about 35 ppt (parts per thousand) (this is equal to 3.5%).

General Ocean Currents

Air and water are both fluids (though of very different densities). The warming by the Sun causes convection currents in the atmosphere and the oceans. The interaction between the atmosphere and the ocean is a very complex, dynamic, and important phenomenon. The atmosphere, being less dense, moves more easily in

response to warming by the Sun. Convection cells form the trade winds and westerlies at sea level and jet streams at high altitudes. These winds are the primary forces driving ocean currents. The frictional effect of wind blowing across the sea surface sets the water in motion, but, due to the much greater density of water, its speed is only 2% of the speed of the wind. Ocean currents tend to be much more stable and discrete than winds and affect the distribution of marine life.

The general pattern of ocean circulation is the same in the Atlantic and Pacific Oceans, and slightly different in the Indian Ocean. Trade winds just north and south of the equator drive the ocean water to the west. In the middle latitudes, the westerlies drive the surface water in the opposite direction, to the east. The result is a current system in each ocean that is dominated by an oval gyre. The gyres rotate in a clockwise direction in the Northern Hemisphere and a counterclockwise direction in the Southern Hemisphere, with their center at about 30° N/S. Because of the Earth's rotation, the gyres are not symmetric. The center of rotation is pushed towards the western side of the gyre. Western boundary currents (e.g. Gulf Stream in the western part of the Atlantic Ocean) are warm currents which carry tropical water poleward and are very fast (100 km/day), narrow (< 100 km), and deep (1-2 km). Eastern boundary currents (e.g. California Current in the eastern side of the Pacific Ocean) are cold, carrying water from the high latitudes, slower (10 km/day), wider (>1000 km), and shallower (<500 m) than western boundary currents.

Because of the Earth's rotation, the *Coriolis effect* deflects water and air currents. In the Northern Hemisphere currents are deflected to the right, and in the Southern Hemisphere currents are deflected to the left. This phenomenon can be explained with complex mathematics or with a few simple models. Imagine you are sitting near the center on a spinning merry-go-round with your friend on the edge. As you toss the ball to her, it looks like the ball curved, and your friend was not able to catch it. Why? Your friend was moving away while the ball was in the air, and the merry-go-round moving below the ball did not influence the ball's movement. If another friend were in a tree above the merry-go-round, he would see that the ball actually went straight. If you compare the distance that you travel near the center to the distance that your friend travels at the edge of the merry-go-round, she goes much further and at a faster rate than you. On Earth, something similar is happening. At the equator, Earth is spinning faster than at the poles. Air currents and water currents are influenced by the rotating Earth and are deflected from their initial direction. Moving objects are deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, relative to the ground. The amount of deflection is dependent on the speed of the moving object and its location on Earth.

Currents move not only across the surface but from the surface to depth as well. The density of seawater is not constant, and that is what drives the vertical currents. When masses of waters meet, they do not mix immediately. The more dense water sinks under the less dense water. The densest water on Earth is both the coldest and the saltiest, and it is found in the deepest ocean basins. This water was formed near the surface during ice formation. The formation of ice removes only the water, and the salts are left behind in even greater concentration. The greatest densities occur beneath the ice shelves of Antarctica, where the dense water sinks to the bottom. These deep currents carry oxygen to the deep basins of the oceans and permit life to exist where it might otherwise be limited.

Coastal current patterns are much more complex than the open ocean currents because the water flow interacts with the seafloor and coastal promontories. Tidal currents and wind-driven surface currents change on a daily or seasonal cycle. Off the coast of San Francisco, the offshore current is the California Current, which flows to the south. Above the continental slope, a deep countercurrent called the Davidson Current flows to the north. Inshore in the Gulf of the Farallones, there are seasonal current patterns due to the changes in the winds.

The irregular topography of the continental shelf and slope impacts the flow of water. Islands, headlands, and seamounts (individual peaks that are below sea level) divert water flow and create complicated current patterns. Above seamounts, circular flow patterns, called eddies, may form for short periods of time, trapping the plankton there. Cordell Bank, a submerged island, is just north of the Gulf of the Farallones, and has a rich biological community on the seafloor and in the overlying water. Canyons along the continental shelf and headlands such as Point Reyes create complex flow patterns which impact the biological community.

Plankton

In most habitats on Earth, the most basic process supporting life is the production of food through *photosynthesis*. On land most of the food is produced by big plants, and only a small percentage of that is consumed, mostly by large herbivores. The rest decays and is recycled by bacteria and fungi. In the ocean, most of the food is produced by microscopic, single-celled algae, and almost all of it is consumed by small herbivores.

Algae require sunlight for photosynthesis. Sunlight sufficient for photosynthesis penetrates only a hundred meters in even the clearest parts of the ocean. But the average depth of the ocean is about 4 km. Clearly no plants can grow attached to the bottom and still reach up to the sunlit waters above. Only algae that are able to stay near the surface can survive. Smallness is a virtue here since the laws of physics dictate that small particles (single cells) sink slower than big particles (multicellular organisms). Lacking any means of locomotion against the pull of gravity, only microscopic size or some means of flotation can guarantee that algae stay suspended in the lighted zone. Algae also require *nutrients* such as nitrate for growth.

From the Greek word for drifter, *planktos*, *plankton* is used to describe the organisms that flow with the currents. *Phytoplankton* are single-celled algae, and *zooplankton* are the small animals that drift with the currents.

The most abundant and most productive phytoplankton in the ocean and in the Gulf of the Farallones are *diatoms*. These silica-encased, single-celled algae are also the largest in size (up to 0.2 mm across). Algae and all photosynthetic organisms require sunlight, water, carbon dioxide, and nutrients, such as nitrogen, for survival. Diatoms have no means of active locomotion and being encased in a silica shell they are slightly heavier than seawater, so they sink slowly. If they sink too deep, they descend below the lighted zone and can no longer survive. For this reason, diatoms are most prevalent in areas of upwelling where they are kept suspended near the surface, and there is a constant supply of nutrients. The richest fisheries in the world are found in upwelling regions, and diatoms are the dominant phytoplankton. During the spring, the diatom population increases exponentially to 500-2000 times their winter population, which is called a bloom.

The second most important phytoplankton are the *dinoflagellates*. Some species are luminescent and are responsible for the glowing wake of boats and crashing waves on beaches. Some have tiny whips or flagella, which move them about slowly. There are species whose sudden blooms produce the so-called "red tides." Red tides can be harmful if a toxic species blooms. Filter-feeding shellfish, such as mussels, accumulate the toxin but are not harmed by it. Humans and other vertebrates, on the other hand, can become ill or even die from eating mussels with high concentrations of the toxin. Some fish such as sardines and anchovies may die by directly ingesting the dinoflagellates.

Zooplankton are the floating animals. The most numerous, and therefore the most important, zooplankton in the ocean are the 1-10 mm copepods, which are a type of crustacean. In the Gulf of the Farallones, copepods are abundant, but it is the krill or *euphausiids*, another shrimp-like crustacean, which are the most abundant here. Larval stages of bottom invertebrates, such as the sea urchin, and fish are also zooplankton. Some are herbivores, eating the phytoplankton and bacteria, while other zooplankton are carnivores, eating smaller zooplankton. These animals are at the mercy of the currents, although some species are able to swim up and down in the water each day.

Gulf of the Farallones Seasons

Winter Storm Season

During winter months (mid November through early spring), atmospheric storms cause rough seas and, in turn, cause deep mixing of the ocean. Over the shelf, water is brought down to the sea floor and back up again (Figure 1). The water becomes well mixed, with the temperature, salinity, and concentration of nutrients the same at the surface and at depth. There is no thermocline during this season. Phytoplankton are carried in and out of the lighted surface waters and do not grow very quickly during this season.

Upwelling Season

In the spring and early summer, coastal winds blow from the north to the south, driving the offshore California Current and the process of upwelling (Figure 2). The California Current is part of the clockwise-flowing North Pacific subtropical gyre. Upwelling is the result of coastal winds and the Coriolis effect on the water above the shelf.

From the wind, air molecules collide with the surface water molecules and move the surface water. If the wind blows persistently for a long period of time, the motion is transferred down to lower water levels. The impact of the wind can reach to 100 m depth. The Coriolis effect causes the water to be deflected to the right of the wind in the Northern Hemisphere. During the spring, winds blow to the south and the surface water moves offshore to the west. Shelf water moves away from the shore, and deeper water from above the slope is brought to the surface. This deep water is cold and nutrient rich.

As dead organisms and waste material sink into the deeper water, decomposition by bacteria releases nutrients. The deeper water is not warmed by sunlight nor is there any light for photosynthesis by algae. Thus, nutrient concentrations are higher in the deep water than in surface water. Upwelling brings this cold nutrient-rich water to the surface.

Sunlight warms the ocean water and provides energy to drive photosynthesis by algae. Algae require nutrients for growth and use the nutrients from upwelling. Algae, especially diatoms, increase in abundance dramatically during the upwelling season. The blooms of diatoms provide food for the rest of the biological community, especially the commercial fisheries and wonderful populations of seabirds and marine mammals.

Upwelling comes in pulses of a week or so, with a relaxation period when the winds weaken. During the relaxation of upwelling, the offshore water flows back towards shore, carrying a soup of nutrients, algae, and zooplankton. Now, the diatoms can bloom and planktonic larvae of bottom animals are able to settle on the continental shelf. During upwelling, most plankton are carried offshore and are not as productive. Yet it is the process of upwelling that brings the nutrients to the surface which drives the high biological productivity in the Gulf of the Farallones.

Relaxation Season

During the late summer and fall, coastal winds die down, and the sea surface calms (Figure 3). The northward-flowing Davidson Current from the slope moves up onto the shelf in the Gulf of the Farallones. Warm water from the south moves into the Gulf, bringing nutrient-poor waters. Without strong winds to mix the water, a layer of warm, nutrient-poor water forms at the surface.

Dinoflagellates become the dominant algae during the late summer months, because they survive well in lower nutrient waters. A few species of dinoflagellates produce red tides. The zooplankton community changes to more carnivorous organisms, including ctenophores, which reproduce very quickly.

The cycle of the oceanographic seasons begins again in November with increased winds and storms.

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PROJECT OCEAN: Kelp Forest Habitat Guide. San Francisco Bay Chapter, Oceanic Society.
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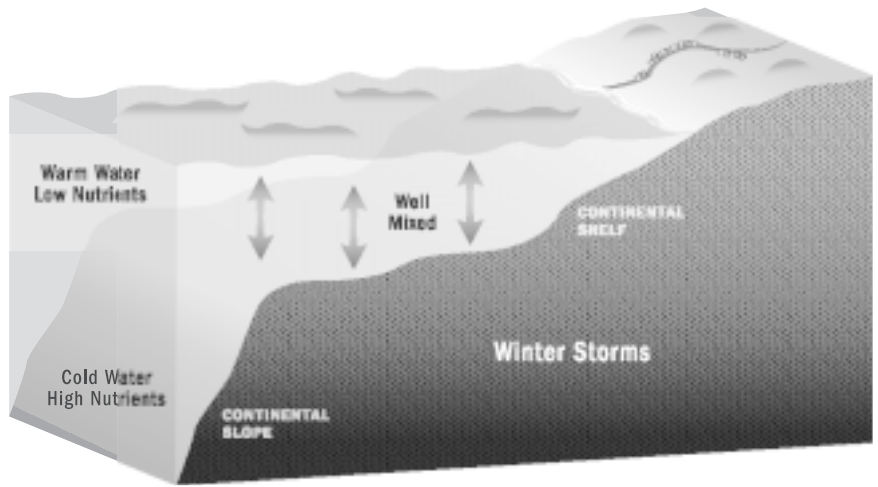


Figure 1: Winter: storms and strong winds

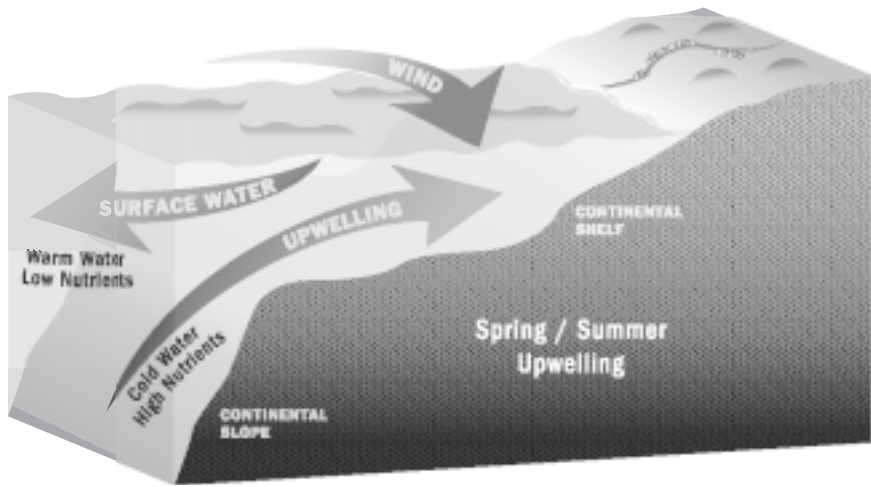


Figure 2: Spring/Summer: Upwelling

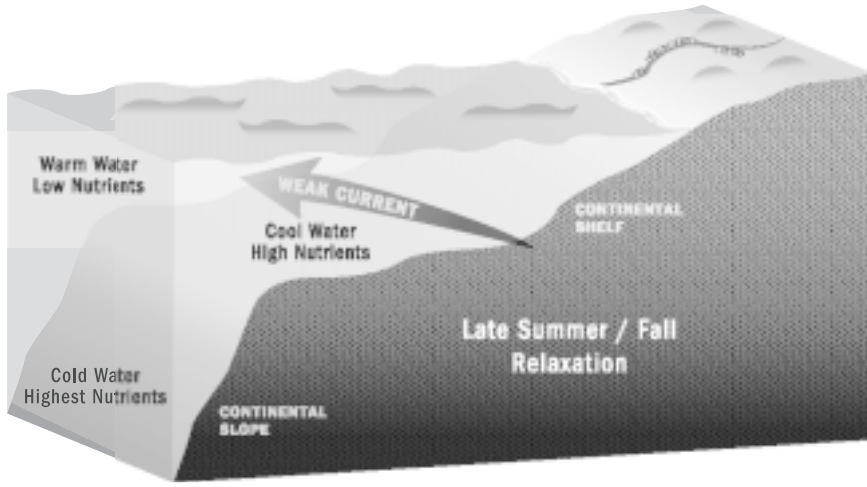


Figure 3: Late Summer/Fall: Relaxation

Glossary of Terms

Oceanography of the Gulf of the Farallones

Continental shelf	shallow, near-horizontal seafloor extending from the shoreline to a depth of about 100 - 150 m at the top of the continental slope. The grade is 0.1°.
Continental slope	sloping seafloor that begins at a depth of about 100 - 150 m and ends at about 3200 m. The slope is about a 3° grade in the Gulf of the Farallones.
Coriolis effect	an apparent force that arises because of the Earth's spin about its axis. Ocean water is deflected to the right of its motion in the Northern Hemisphere.
Current	a horizontal movement of water.
Current meter	an instrument used to measure the flow rate and direction of water.
Diatoms	microscopic, single-celled <i>phytoplankton</i> which have silica (glass-like) cell walls and are abundant in upwelling waters.
Dinoflagellates	microscopic, single-celled <i>phytoplankton</i> . They have flagella which provides them some locomotion. Some species cause toxic red tides.
Euphausiids	small shrimp-like crustaceans (type of Arthropods) that feed on <i>diatoms</i> and are food for many large whales. Commonly called krill.
Nutrients	chemical compounds required by algae and plants for normal growth, important nutrients are nitrate and phosphate.
Photosynthesis	the process used by algae and plants to convert carbon dioxide, water, and energy from light 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	organisms that have no control over the direction they travel. They are at the mercy of the currents and float in the water.
Salinity	the amount of salt in seawater. Measured as the weight of salt per unit weight of seawater.
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.

Oceanography of the Gulf of the Farallones

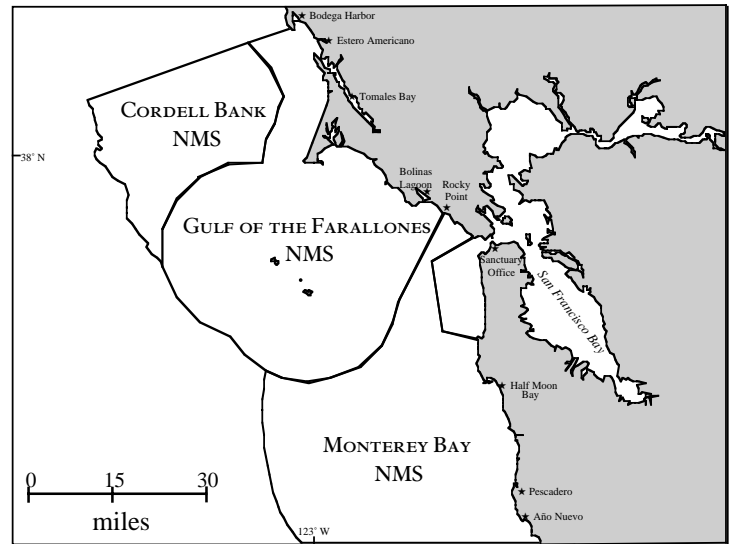
The Gulf of the Farallones is a unique oceanographic area. Just outside of San Francisco Bay, strong spring winds bring nutrient-rich water to the surface and create a rich biological community. The geological landscape under the water sets the scene and impacts the flow of water. Waves and surface currents are primarily wind-driven and result in three oceanographic seasons over this interesting region: winter storms, upwelling, and relaxation. The Gulf of the Farallones National Marine Sanctuary encompasses 948 square nautical miles (3,251 km²) of the offshore region of the Gulf of the Farallones.

Geology

Located just west of the Golden Gate Bridge, the Gulf of the Farallones covers the continental shelf and slope. From the shoreline to about 100 - 150 m deep, the shelf is nearly horizontal with rocky outcrops, gravel, sand, clay, and deposits of broken shells. Sand and silt cover much of the continental shelf. About 25 miles from the coast, the seafloor drops off, creating the continental slope with a grade of about 3°. The slope is from 100 - 150 m to about 3200 m and is covered with a more uniform sandy sediment. The Farallon Islands, located a few miles east of the slope, rise up from the continental shelf to the sea surface.

Winter Storms

During winter months (mid November through early spring), atmospheric storms cause rough seas and, in turn, cause deep mixing of the ocean. Water on the shelf is brought down to the seafloor and back up again.

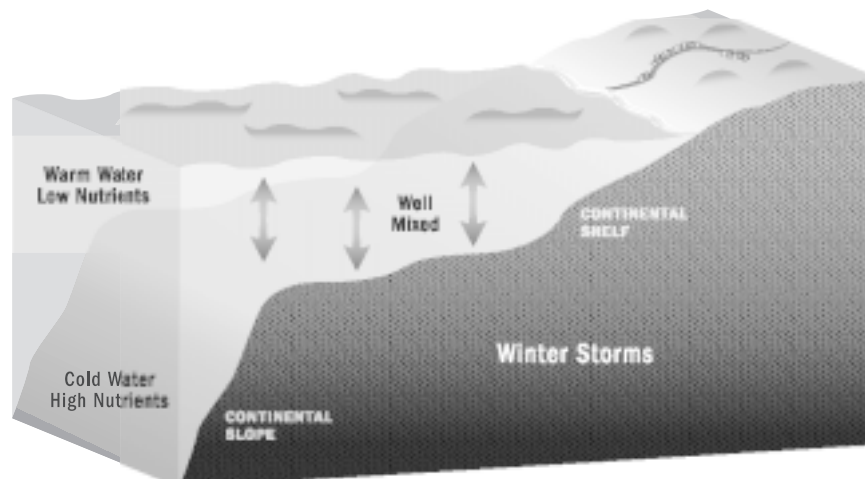


The water becomes well mixed, with the temperature, salinity, and concentration of nutrients the same at the surface as at depth.

Upwelling

In the spring and early summer, coastal winds blow from the north to the south driving the offshore California Current and the process of upwelling. The California Current is part of the clockwise-flowing North Pacific subtropical gyre. Upwelling is the result of coastal winds and the Coriolis effect on the water above the shelf.

Water traveling over a large distance appears to be deflected from its original direction of motion. Called the Coriolis effect, this phenomenon is due to



the fact that Earth is a rotating sphere. In the Northern Hemisphere, ocean water is deflected to the right of the wind that is pushing it. Along the California coast, northerly winds cause the surface water to move offshore to the west. As the spring wind blows, shelf water moves away from the shore, and deeper water from above the slope is brought to the surface. This deep water is cold and nutrient rich.

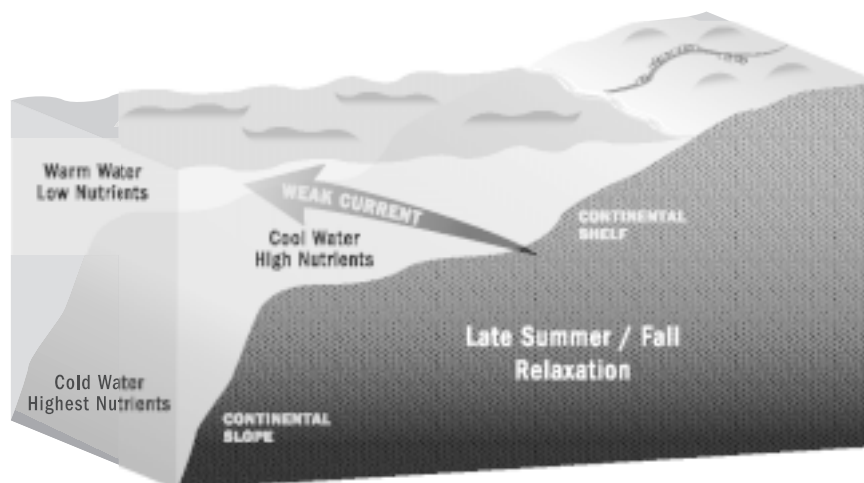
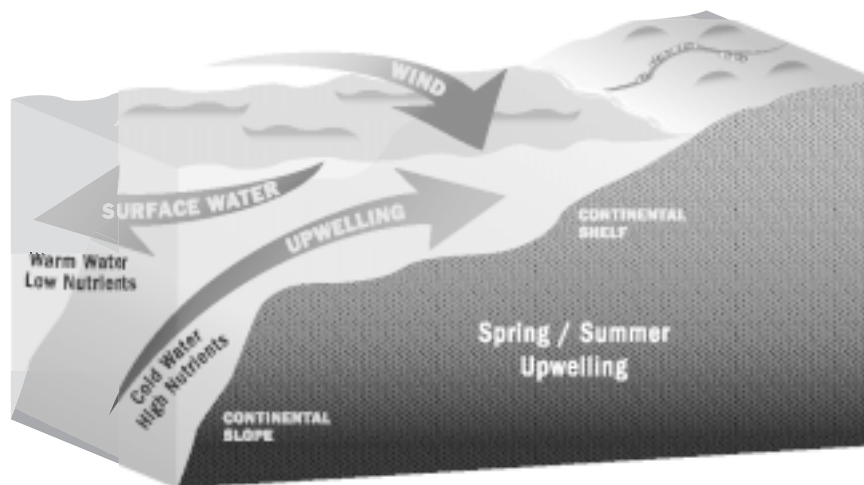
Sunlight warms the ocean water and provides energy for photosynthesis by algae. Algae require nutrients for growth and use the nutrients from upwelling. Deeper water is not warmed by sunlight nor do algae survive without sunlight. Thus, nutrient concentrations are higher in the deep water than in surface water. Upwelling brings this cold, nutrient-rich water to the surface. Algae, especially diatoms, increase in abundance dramatically during the upwelling season.

Upwelling comes in pulses of a week or so, with a relaxation period when the winds weaken. During the relaxation of upwelling, the offshore water flows

back towards shore, carrying a soup of nutrients, algae, and zooplankton. Now, the diatoms can bloom in the sunlit water, and pelagic larvae of benthic animals are able to settle on the continental shelf. During upwelling, most plankton are carried offshore and are not as productive.

Relaxation

During the late summer and fall, coastal winds die down, and the sea surface calms. The northward-flowing Davidson Current replaces wind-driven upwelling in the Gulf of the Farallones. Warm water from the south moves into the Gulf bringing nutrient-poor waters. Without strong winds, the water is not mixed, and a layer of warm, nutrient-poor water forms at the surface. Dinoflagellates become the dominant algae during the late summer months, because they survive well in lower nutrient waters better than diatoms. The cycle of the oceanographic seasons begins again in November with increased winds and storms.



Oceanography Activities

Coriolis Effect

Objective

Students will be able to describe what the Coriolis effect is and how it impacts water flow in the Northern Hemisphere.

Materials and Supplies

For each student group: 1 circular piece of cardboard similar to one that comes under pizza.

1 pin or nail

Chalkable globe and chalk (physics or astronomy teacher may have one) (optional)

Background

Winds and ocean currents all obey Newton's laws of motion (Principia - 1687) including $F=ma$. However, Newton (1642-1727) was very specific when he developed the laws, stating that they applied in an "inertial" or non-accelerating reference frame. We live on a spinning Earth, therefore when we make measurements our reference frame is rotating. A rotating reference frame is always accelerating inward toward the axis of rotation. In order to apply Newton's laws, we must account for this rotation and that is done by including the Coriolis parameter (named after Gustave Coriolis, 1792-1843). Due to our direction of rotation, motion is deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The size of the Coriolis parameter is very small and is only important in near-frictionless flows like atmospheric winds and ocean currents. It does not affect small scale flows like draining sinks and toilets. The consequence of living on a rotating planet is that motion is deflected and often becomes circular as evidenced by our storms and large scale ocean currents. The study of motion influenced by the Earth's rotation is called "geophysical fluids".

Activity

1. Each student group should pin or nail their circular piece of cardboard in the center to another piece of cardboard or wood, so that it can rotate freely. One student should rotate the cardboard at a constant rate while another student draws a straight line from the center outward.
2. What does the line look like? What happens as the line gets closer to the edge? Students should label each trial line and record their results.
3. Try rotating the cardboard in the opposite direction. Try drawing the line in the opposite direction – from the edge toward the center.
4. If you have students with advanced mathematical skills (trigonometry), they should use mathematics to describe what is happening. The speed of each point on the line is different, fastest at the edge and slowest at the center of the cardboard.
5. Bring the class together and discuss the results. Describe the cardboard as a flattened Earth. The center is the pole and the edge is the equator. Earth is rotating to the east (from above, Earth is rotating counterclockwise). Lead a discussion concluding that the Coriolis effect causes a deflection to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The center of the cardboard is like the North Pole in that it rotates slowest, and the edge is like the equator with the fastest speed.

6. If you have a chalkable globe, do a similar demonstration as above. Rotate the globe to the east at a constant rate. Have a student draw a line in the Northern Hemisphere in a north-south direction. What happens? Try drawing the line in the Southern Hemisphere or in a different direction. How do the lines vary? The line should be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.
7. Ask students about the direction of hurricanes and tornadoes. They both turn in a counterclockwise direction in the Northern Hemisphere and clockwise in the Southern Hemisphere. Why? The Coriolis effect.

The Coriolis effect does NOT impact the flow of water down a drain. In order to be impacted by the Coriolis effect, the object, water, or air must be traveling over a large distance. This website may be helpful: <http://www.ems.psu.edu/~fraser/Bad/BadCoriolis.html>

Extensions

Demonstrate that the Coriolis effect in the Southern Hemisphere is a mirror image of that in the north; air masses or water masses curve to the left no matter which direction they move, including east-west.

Visit a merry-go-round at the local park. Have students roll a ball across the rotating merry-go-round. They should see a deflection to the right as in the Northern Hemisphere.

Check out this quick-time movie of kids on a merry-go-round at: [http://ww2010.atmos.uiuc.edu/\(Gh\)/guides/mtr/fw/crls.rxml](http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/fw/crls.rxml)

Water Density: Salinity and Temperature Dependence

Objective

The movement of water in the deep ocean is determined by differences in density. In general, the ocean is in a stable, layered condition with the surface water being the least dense and the deepest water is the densest. During the relaxation period in the fall off the California coast, the water becomes stratified in this way. Students will learn about stratification and how temperature and salinity impact the density.

Materials and Supplies

Beakers

Paper dixie cups

Tape

Eye droppers (or pipettes)

Food coloring (4 colors)

Heat source – hot plate or teakettle, microwave, or very hot tap water

Cold source – ice, freezer, cooler, or very cold tap water

Water

Salt

Aquarium or clear plastic shoe box

Thermometers (optional)

Scales (optional)

Background

The density of seawater is dependent on temperature, salinity, and pressure. As the temperature decreases to 4° C, the density of water increases. As the salinity increases, the density of water increases. Temperature and salinity are not dependent on each other, although some processes are related to both. As the temperature increases, freshwater evaporates from the ocean and the salinity increases. Also, when seawater freezes, freshwater ice forms, and the remaining seawater has a higher salinity. Yet, sunlight can warm the ocean surface and the salinity may remain the same. Salinity increases with increased evaporation as well as with the creation of ice (both processes remove freshwater and leave the salt). River water and rain decrease the salinity. Pressure affects density in only the deepest parts of the ocean. In the shallow waters near the coast of California, pressure does not significantly change the density.

Activity

There are several ways to do this activity.

- A) You can make the water samples ahead of time and have the students figure out which water sample fits the descriptions.
- B) Or you can have the students make the water samples and then predict the behavior of the samples when slowly combined.
- C) Or you can do this as a demonstration with an aquarium filled with water and add different water samples.

For each of the activities, there are 5 different types of water:

- chilled salt water
- chilled freshwater
- room temperature salt water
- heated freshwater
- heated salt water

The densest water will be the chilled salt water and the least dense will be the heated freshwater. The densities of the other water samples will depend on the temperature and salinity. Average seawater has a salinity of 35 ppt, which can be made by adding enough water to 35 g of salt to make 1 kg of seawater. Make sure you add the salt before the water. You need to use a scale to weigh the water. Salinity is based on weight, not volume.

A. Mystery Samples

1. Prepare four different colored water samples. Add about 1 tablespoon of salt per liter for the salt water samples. Keep the chilled water in the refrigerator until students are ready. The warmed water should be somewhere between warm to the touch and boiling. Test the water to make sure that they have different densities. Use a beaker filled with room temperature freshwater and slowly add one sample at a time. Try to maintain a constant temperature for the chilled and heated samples.
2. Each student group should get a beaker with room temperature freshwater and eyedroppers.
3. Tell the students that sample A is blue, B is red, C is green, and D is yellow. Give them a list of the four water types you have made. They should investigate by slowly adding water samples to their beaker with the eyedroppers. They should record their observations and test their hypotheses with more experiments.

B. Predict the Behavior of Different Water Types

1. Give students the supplies and materials to make 4 water samples.
2. Average salinity water (35 g/kg) can be made by measuring 35 g of salt in a beaker and adding enough freshwater to have a total of 1 kg (1000 g) of seawater. You need to use a scale to weigh the water. Remember, salinity is based on weight, not on volume.

- Students can use the following table of water density (g/cm³) at specific temperature and salinity if you want them to be more precise.

Temperature (°C)	No Salt	Salt 20 g/kg	Salt 25 g/kg	Salt 30 g/kg	Salt 35 g/kg
0	.99984	1.01607	1.02008	1.02410	1.02813
5	.99996	1.01586	1.01980	1.02374	1.02770
10	.99970	1.01532	1.01920	1.02308	1.02697
15	.99910	1.01450	1.01832	1.02215	1.02599
20	.99820	1.01342	1.01720	1.02098	1.02478
25	.99704	1.01210	1.01585	1.01960	1.02336
30	.99565	1.01057	1.01428	1.01801	1.02175

- They should rank the density of the samples based on how they settle. The most dense sample will be at the bottom and the least dense at the top. Sample water should be slowly added to neutral water (room temperature freshwater) using an eyedropper.
- Students should investigate the variation of density with changes in temperature and salinity.
- Discuss how temperature and salinity impact the density of seawater.

C. Demonstration of Density Distribution of Water

- Fill the clear plastic shoebox or aquarium about half-full with room temperature freshwater.
- Tape a paper cup in each corner of the aquarium and puncture a small hole through the bottom of each cup.
- Make the four water types. The cold freshwater can be made by putting ice cubes and food coloring in a cup and letting it melt into the aquarium.
- Pour one water type into a cup at a time. The water type will drip into the aquarium water. Observe the relative densities of the water.
- Discuss how temperature and salinity impact the density of seawater.

Extensions

Make a hydrometer - from Coastal Awareness Resources for Teachers - NOAA (see reference below). This is an instrument that is calibrated to measure density.

Water is the best known solvent. Students can experiment with water as a solvent.

References

Salinity and Temperature: How Dense Can You Get? Linda Maston, Pease Middle School, San Antonio, TX. 1989.

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 to get a copy.

Coastal Ocean Upwelling

Objective

Students will observe how surface winds impact the flow of water on a seasonal basis by examining real data. Students will learn to analyze data presented in graphs.

Materials and Supplies

Copies of figures and worksheet

Access to the internet to get current data (optional)

Background

Students need to understand the process of coastal upwelling in order to understand the seasonal changes in the Gulf of the Farallones. Coastal upwelling is the dominant process during the spring and early summer. Strong winds blow from the north to the south. Due to the Coriolis effect, the surface water is deflected to the right of the wind, which is to the west and offshore of the coast. As the surface water is pushed away, deep water from above the slope moves up onto the shelf to replace the surface water that was moved offshore. An upwelling index can be calculated based on the wind stress and location. Scientists use the index to correlate upwelling with other patterns such as primary production and reproduction.

The data presented in this activity are from buoys near the Gulf of the Farallones that continuously measure oceanographic and atmospheric parameters.

Activity

1. Describe the upwelling index. It is a value that represents the amount of upwelling occurring at a specific location. It is calculated using the wind stress and location. Wind stress is the force of the wind pushing on the water, and that force depends on the wind speed. Location is important because the strength of the Coriolis effect changes with latitude. At the equator, the Coriolis effect is at a minimum, and it is at a maximum at both poles. It changes with the sine of the latitude.
2. Pass out the worksheet and figures to each student or group of students. Examine Figure 1. The solid line is the daily upwelling index (UI) for August 1999 through January 2001 at 39°N 125°W near the Gulf of the Farallones. It was smoothed using a mathematical filter. The black bars are the average UI for each month.

What is the trend in the daily UI? Is upwelling continuous in the spring? Is it easier to see a trend in the monthly averages? What is that trend? When are the highs? The lows? Positive values indicate upwelling while large negative numbers represent downwelling (this physical process is the opposite of upwelling). How much variation is there within a month? How long is one burst of upwelling? When does the next burst begin?

3. Examine Figure 2. The axes for this graph are the same. The dashed line is the average upwelling index (UI) from 1967 to 1991 which has been fit to a biharmonic curve which is why it looks so smooth. The shaded area is one standard deviation from the average UI.

What is the seasonal trend of the average UI? Compare the daily UI in Figure 1 to the average upwelling index in Figure 2 (lay Figure 1 over 2). Does the daily UI stay within one standard deviation of the average UI? What does that mean? The horizontal bars represent monthly averages of the daily UI. Do they stay within one standard deviation of the average?

4. If you have access to the internet, you can get the latest data at this location (39°N 125°W) and another nearby (36°N 122°W) to see regional differences. The Gulf of the Farallones is located between 37-38°N. Analysis of additional data is not included on the student worksheet. On the internet, go to: <http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/>. Go to Graphs of the last 18 months and jump to 39N 125W or 36 N 122 W

Compare the current data to the 1999-2001 data.

Is the UI higher currently? If so, that means more water is being upwelled - being brought from the deeper slope to the surface and offshore. How do you think this will impact the plankton?

Compare the current data at 39°N and at 36°N. How similar or different are these two stations?

5. Analyze seasonal changes of air temperature, sea temperature, and wind speed from a twelve-year period. These data were collected at buoy 46013 near Bodega Bay. You can view the data online at http://www.ndbc.noaa.gov/station_history.phtml?station=46013

Examine Figure 3. This is the air temperature at the buoy. What is the range of air temperature over the whole year? What is the maximum and minimum? Which month has the least variation? Students should answer these questions and write a short description. They should be able to make comparisons to the temperature pattern they experience on land. What processes are causing the seasonal pattern in the air temperature?

6. Examine Figure 4. This is the surface temperature of the water. What is the range of water temperature over the whole year? What is the maximum and minimum? Which month has the least variation? Students should answer these questions and write a short comparison between the air temperature and the sea temperature.

The air temperature range is greater than the sea surface temperature; this is because water has a high heat capacity. It takes lots of energy to change the temperature of water. Sunlight is the source of energy that warms the water and the air. Upwelling is the reason why the sea surface temperature is at a minimum in May and June.

7. Examine Figure 5. This is the wind speed at the same buoy. This figure should emphasize that the winds are blowing hard during the spring upwelling. Also, the average wind speed in the fall is lower than the rest of the year.

Extension

Where did the upwelling index come from? It was calculated from the following equation. In this extension, students will calculate the upwelling index for winds from the north, east, and south.

The upwelling index (UI) is the component of the wind stress (τ) from the north (actually parallel to the shore) divided by the Coriolis parameter (f). In its simplest form the index is:

$$UI = \frac{\tau \cos(\phi - \alpha)}{f} = \frac{\rho_a C_D W^2 \cos(\phi - \alpha)}{\frac{2\pi}{24h} \sin(\theta)} = \frac{0.002W^2 \cos(\phi - \alpha)}{7.29 \times 10^{-5} \sin(\theta)}$$

where:

ϕ = wind direction (0-360°),

α = coast orientation relative to north and having land on left,

θ = latitude (-90 to 90°),

τ = wind stress which depends on the square of the wind speed ($\rho_a C_D W^2$),

f = "Coriolis parameter" which depends only on latitude ($2\pi/24 \text{ h} \sin \theta$),

W = wind speed,

ρ_a = the air density, and

C_D = coefficient of drag for air.

This may look complicated but it is not really. The wind stress (τ) is reduced to 0.002 times the square of the wind speed (W) by assuming a constant air density (ρ_a) and drag (C_D). f is reduced to 7.29×10^{-5} by putting the parameter into units of seconds (24 h stands for 24 hours). Because the coastline angle (orientation = α) changes, the amount of upwelling differs along the coast. To simplify this, assume the coast is north-south so that $\alpha=0$. Coastal upwelling depends on three parameters: wind speed (W), wind direction (ϕ) and latitude (θ).

Calculate the upwelling index if the wind is blowing at 10 meters per second near San Francisco ($\theta = 39^\circ\text{N}$) for northerly, easterly, and southerly winds. (With winds, the direction is the direction from which the wind is blowing.)

First calculate f and τ :

$$f = 7.29 \times 10^{-5} (\sin(39)) = 7.29 \times 10^{-5} (.63) = 4.59 \times 10^{-5}$$

$$\tau = 0.002 W^2 = 0.002 (10^2) = 0.2$$

Once these two terms have been determined, then the UI is computed using the direction of the wind:

$$UI_{\text{North}} = \tau (\cos(0)) / f = 4.3 \times 10^4$$

$$UI_{\text{East}} = \tau (\cos(90)) / f = 0$$

$$UI_{\text{South}} = \tau (\cos(180)) / f = -4.3 \times 10^4$$

As you saw in the graphs, a positive UI means that water is upwelled. Ask when is there upwelling? (north wind) What is happening when the UI is negative? (water is downwelled, surface water is pushed down)

Coastal Ocean Upwelling Student Worksheet

1. Look at Figure 1. What is this graph about?_____
2. What is the x-axis?_____ What is the y-axis?_____
3. The solid line is the upwelling index (UI) from August 1999 to January 2001. Positive values mean upwelling. When was the maximum upwelling during this time period?_____ When was there no upwelling?_____
4. The black bars are the monthly average of the daily UI. How much variation is there in one month?
5. Describe the seasonal cycle of upwelling based on these data.

6. Look at Figure 2. The dashed line is the average upwelling index (UI) from 1967-1991. How many years of data were used in calculating the average?_____
7. Which months had the maximum upwelling?_____
8. Describe the seasonal cycle of upwelling based on the average data.

9. The shaded area is one standard deviation from the average UI (dashed line). Compare the average UI to the daily UI by laying Figure 1 over Figure 2. Is the daily UI similar to the average UI? Compare the trends.

10. Look at Figure 3. What is this graph about?_____
11. What is the x-axis?_____ What is the y-axis?_____
12. These data were collected at a buoy in the ocean at 38°13'37"N 123°19'43" W. This is the temperature of the air above the water. What is the range of air temperature?_____ Which month has the highest average air temperature?_____ Which month has the lowest average air temperature?_____
13. Compare the seasonal cycle of the average ocean air temperature to what you experience at home.

14. Look at Figure 4. What is this graph about?_____
15. What is the x-axis?_____ What is the y-axis?_____
16. These data were collected at the same buoy in the ocean. This is the temperature of the water at the surface - called sea temperature. What is the range of sea temperatures?_____ Which month has the highest average sea temperature?_____ Which month has the lowest average sea temperature?_____

17. Compare the seasonal cycle of the average air temperature to the average sea temperature.
18. The coldest sea surface temperature is in May and June, yet the air above is warmer than a few months before. Any ideas why?
19. Examine Figure 5. What is this graph about?_____
20. What is the x-axis?_____ What is the y-axis?_____
21. Again, these data were collected at the same buoy in the ocean. This is the wind speed above the buoy. Which month has the highest average wind speed?_____
22. Figure 5 only tells part of the wind story. Wind can vary in direction, speed, and duration (time it blows). Upwelling is driven by strong (fast) winds blowing to the southeast for an extended period of time. This figure only tells you about average speed. Examine the upwelling season in Figure 1 again, and think about how the wind varies to create the pulses of upwelling.
23. Describe the pattern of air temperature, sea temperature, and wind speed during the spring and fall months. Relate what you see in the data to what you know about upwelling.

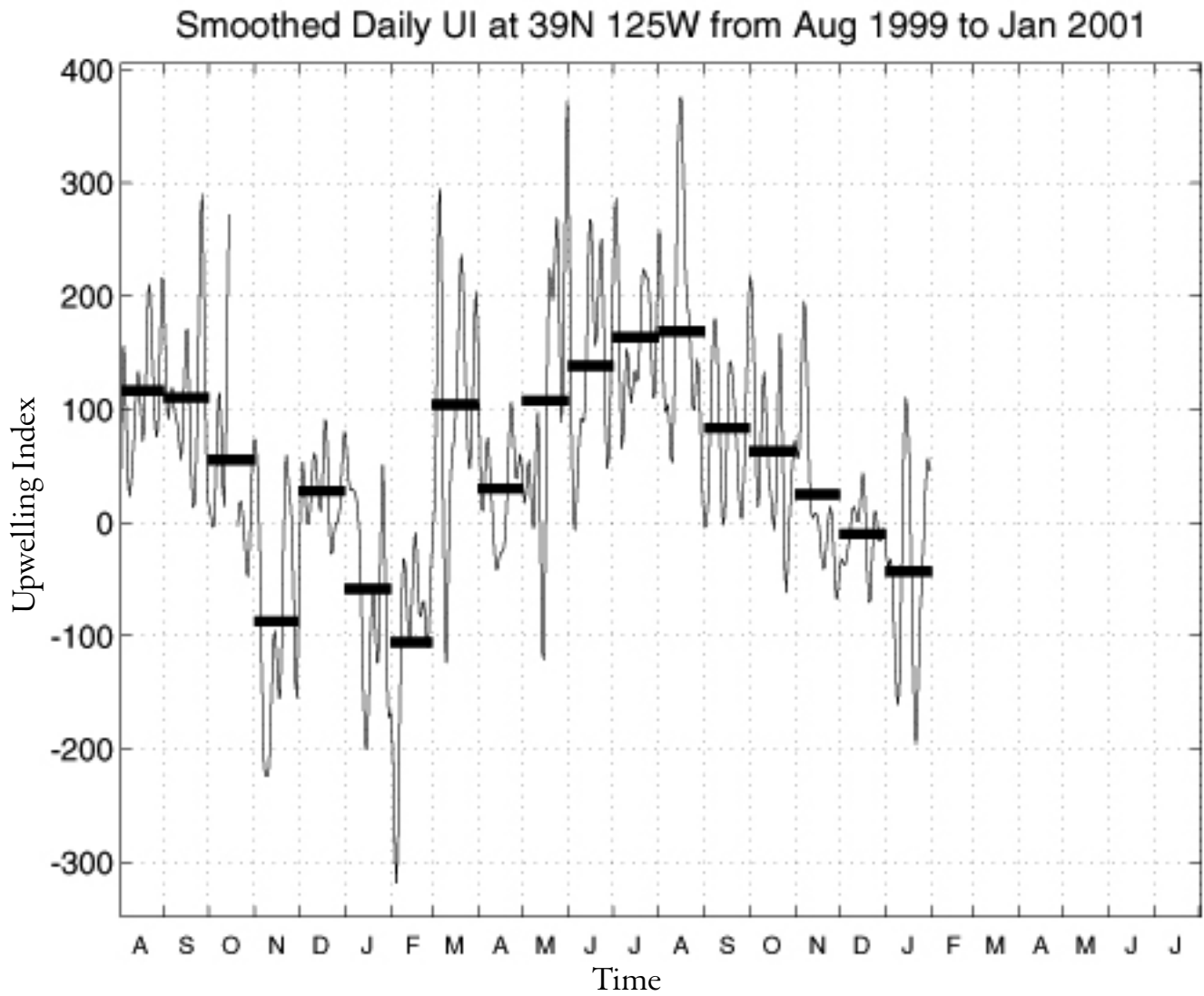


Figure 1: Upwelling Index (UI) at 39 N 125 W from August 1999 to January 2001. Computed by Pacific Fisheries Environmental Group of NOAA. Solid line is the daily upwelling index. Black bars are the monthly average upwelling indexes.

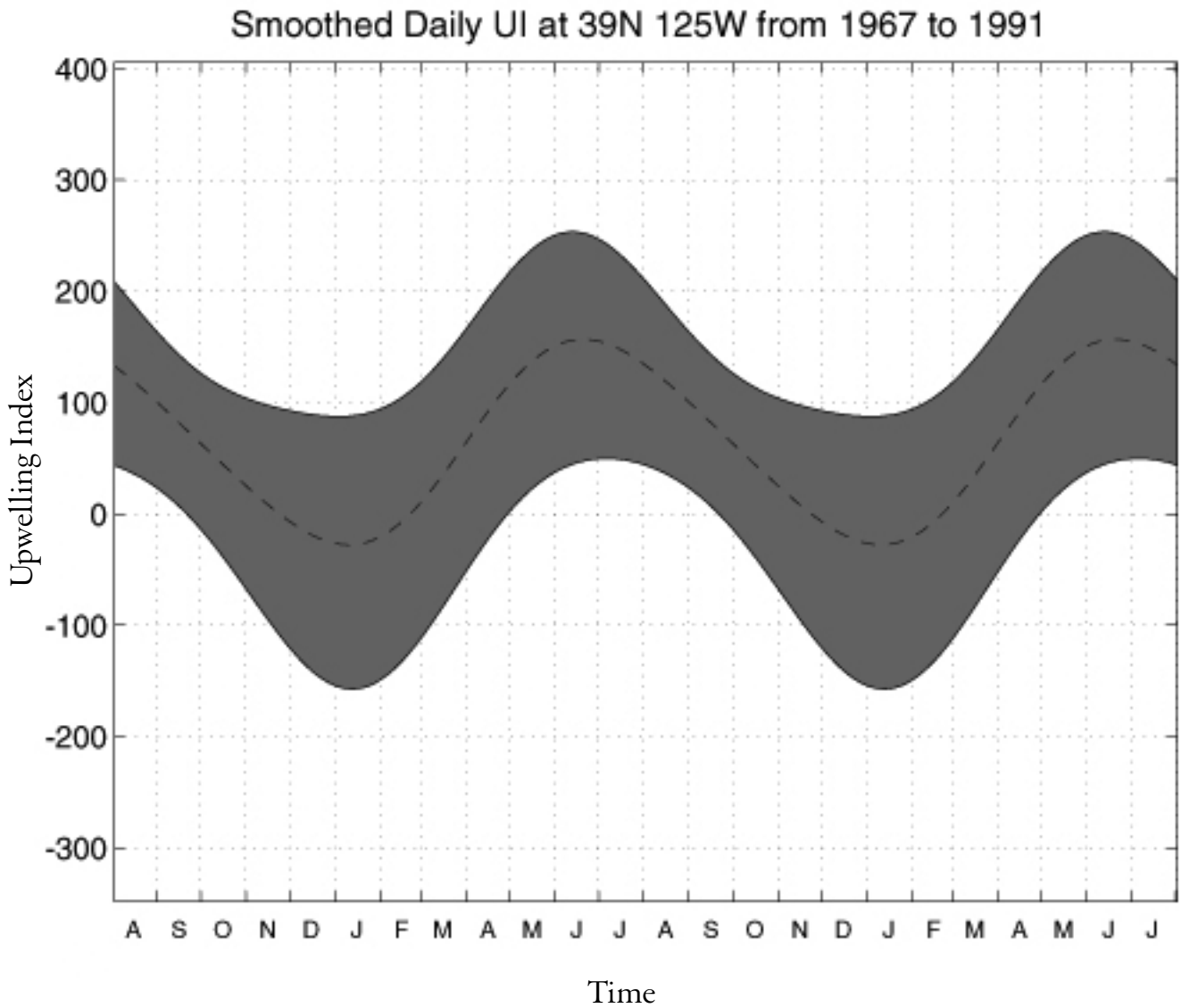


Figure 2: Smoothed daily upwelling index (UI) at 39 N 125 W from 1967 to 1991. Computed by Pacific Fisheries Environmental Group of NOAA. The dashed line is the average upwelling index (UI) from 1967 to 1991 which has been fit to a biharmonic curve which is why it looks so smooth. The shaded area is one standard deviation from the average UI.

46013 AIR TEMPERATURE (DEG. C) 4/81-12/93

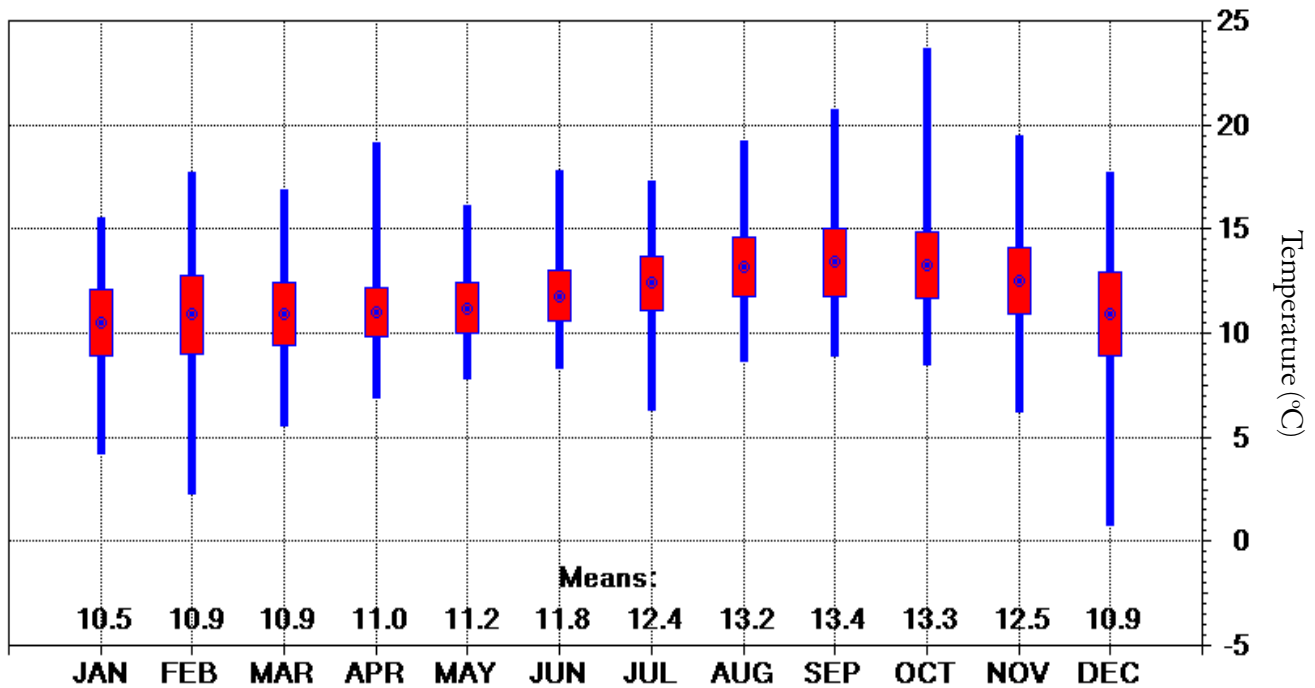


Figure 3: Air Temperature at Buoy 43013 at Bodega from April 1981 through December 1993. From the National Data Buoy Center. The average air temperature for each month is a dot in the middle of a box representing +/- one standard deviation. The range of air temperature is the long bar. The average of each month is indicated at the bottom of the graph.

46013 SEA TEMPERATURE (DEG. C) 4/81-12/93

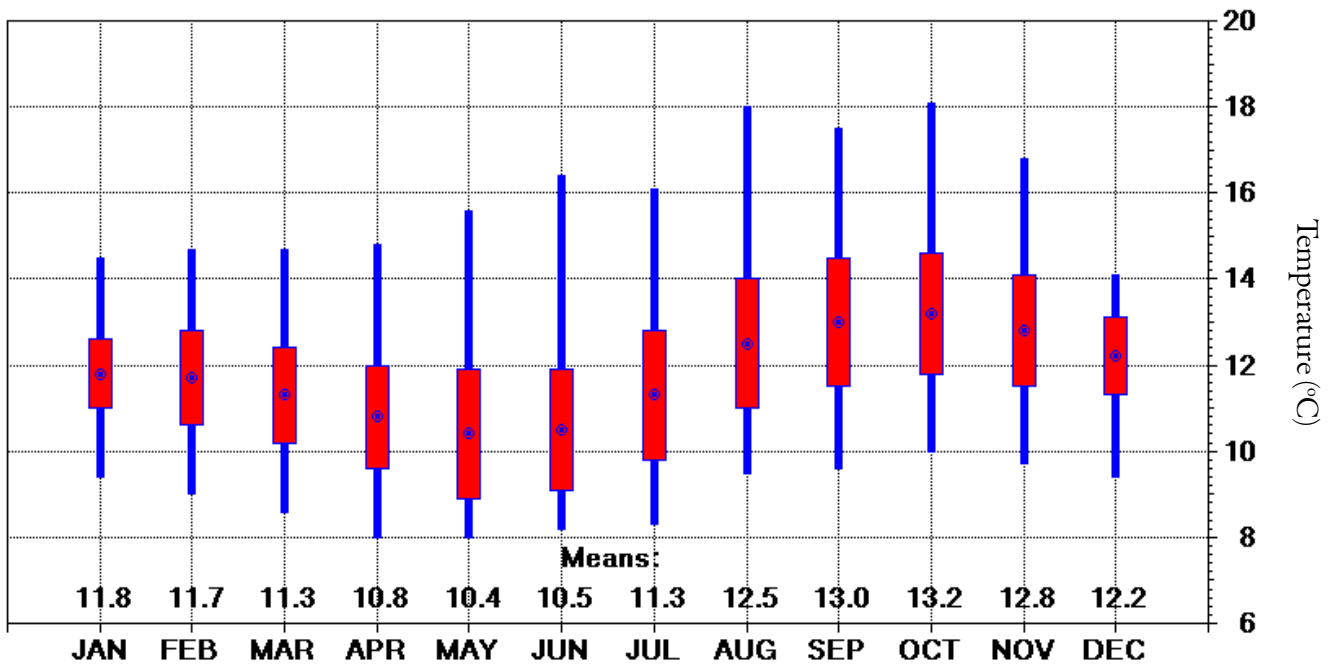


Figure 4: Sea Temperature at Buoy 43013 at Bodega from April 1981 through December 1993. From the National Data Buoy Center. The average sea temperature for each month is a dot in the middle of a box representing +/- one standard deviation. The range of sea temperature is the long bar. The average of each month is indicated at the bottom of the graph.

46013 AVG. WIND SPEED (KNOTS) 4/81-12/93

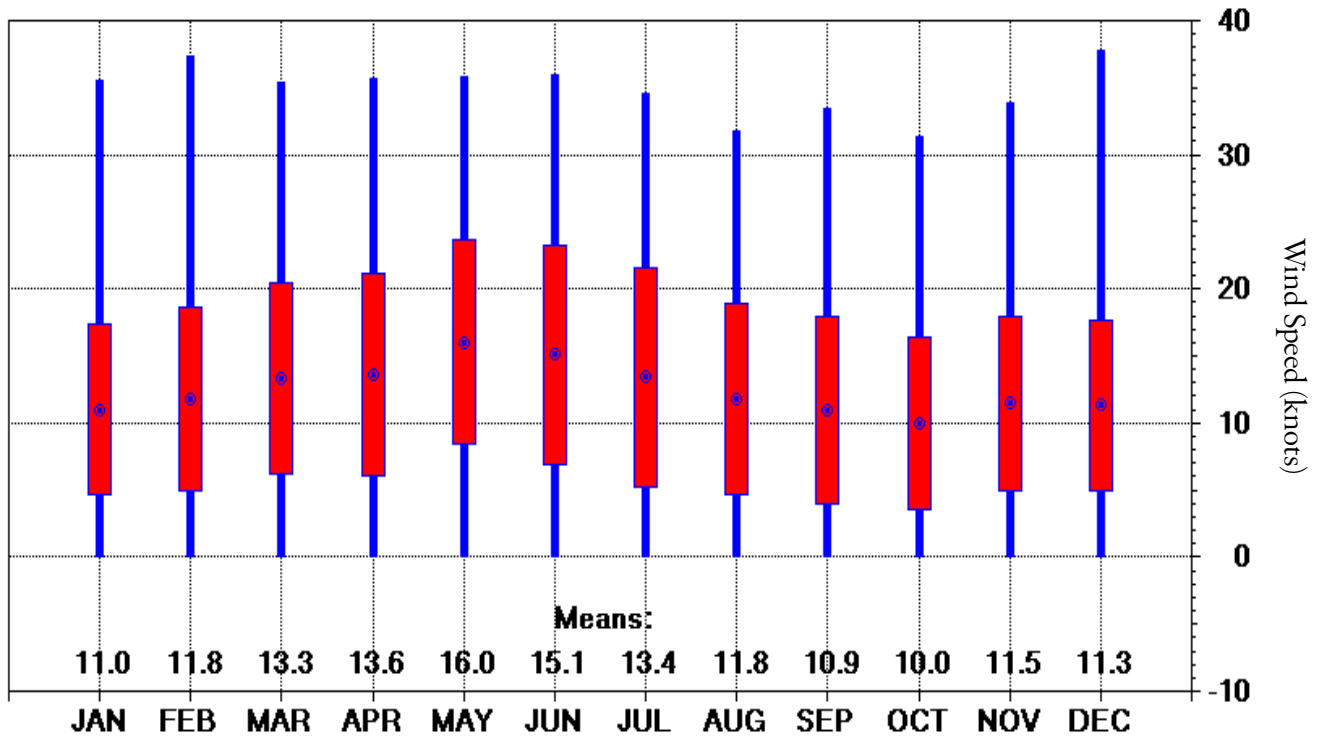


Figure 5: Wind Speed at Buoy 43013 at Bodega from April 1981 through December 1993. From the National Data Buoy Center. The average wind speed for each month is a dot in the middle of a box representing +/- one standard deviation. The range of wind speed is the long bar. The average of each month is indicated at the bottom of the graph.

Oceanography of the Gulf of the Farallones

Slide Show

#	Topic (photographer)	Script (<i>italicized words in glossary</i>)
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 oceanography of the Gulf of the Farallones.
2	Ocean view with bridge	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	Islands with birds (Jan Roletto)	The water surrounding the Farallon Islands 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.
4	Rough seas	Strong spring winds bring nutrient-rich water to the surface, which drives this rich biological community. 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. Today, we will discuss “a year in the life” of the Gulf of the Farallones.
5	Sanctuary map	The geological landscape sets the scene because it impacts the flow of the water. We will focus on the offshore 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 (3,251 km ²). It also includes the nearshore waters of Bodega Bay, Tomales Bay, and Bolinas Lagoon. The goal of the Sanctuary is to protect the resources of the marine environment.
6	Sidescan image (USGS Woods Hole)	<p>Here is the seafloor with the water removed. This is as if you are sitting west of San Francisco in the ocean water. North is to your left. As the legend shows, orange represents the shallow seafloor. The darker the blue, the deeper the seafloor.</p> <p>The <i>continental shelf</i> is the nearly horizontal seafloor, starting at the shoreline and extending to depths of about 100-150 meters. The Gulf of the Farallones is located over one of the widest areas of continental shelf along the Oregon and Northern California coast. About 25 miles from the coast, the seafloor drops off with a grade of about 3°. The <i>continental slope</i> begins at 100-150 meters and goes down to about 3200 meters in a very short horizontal distance. The rocky Farallon Islands rise up from the continental shelf to the sea surface, located just east of the continental slope.</p>

- 7 Sidescan instrument This is the type of instrument that collected the information for the previous picture. It is a side-scan sonar instrument. It sends out a pulse of sound which travels through the water, bounces off the sea floor, and returns to the instrument. It measures the time it takes for the sound to return. The distance to the sea floor is then calculated using the return time and the speed of sound. This instrument allows you to see the bottom even though the water is in your way.
- 8 Ocean water Now that you know what the sea floor looks like in this region, we will fill it up with water. The water here is a mixture of ocean water and freshwater from rivers. *Salinity* is the term used to describe the amount or concentration of salt in the water. Rivers and lakes have a salinity of zero, while the average ocean salinity is 35 ppt (parts per thousand). The Gulf of the Farallones has variable salinity, depending on the depth of the water and the amount of water flowing out of the San Francisco Bay. The average salinity in the Gulf of the Farallones is between 32 and 35 ppt.
- 9 CTD Instrument (Jamie Hall) In general, surface water has a lower salinity than deeper water. As you will learn today, there are different mixing patterns during the year and that influences the salinity distribution. Here is an instrument, called a CTD, that measures the salinity and temperature as it is lowered through the water. CTD stands for conductivity (which is used to determine salinity), temperature, and depth. It has electronic probes that detect the salinity and temperature. It sends a signal back to a computer on the ship with this information.
- 10 Seasons in the Gulf of the Farallones Now to the seasons. They are different than the traditional four seasons of winter, spring, summer, and fall. In the Gulf of the Farallones, there are only 3 seasons, and they have different characteristics than the terrestrial seasons. They are called winter storms, upwelling, and relaxation. By observing the winds and other patterns, scientists and naturalists figured out the general seasonal pattern. Each year there is some variability when each season begins, so this description is for an average year.
- 11 Winds and Storm (Dan Howard) We begin the cycle in mid-November with the winter season. Atmospheric storms cause rough seas and, in turn, cause deep mixing in the ocean.
- 12 Winter Storm Figure Water over the shelf is forced down to the sea floor and back up again. The energy of the winter storm winds is the driving force during this season. The water becomes well mixed, meaning the temperature, salinity, and concentration of *nutrients* become constant from the surface to the bottom. In addition, the plankton, which are microscopic algae and animals, are mixed up and down over the shelf.
- 13 Weather Vane Next comes a very special time of the year in the Gulf. In the spring and early summer, strong coastal winds blow from the north to the south, driving the offshore California Current and the process of *upwelling*. Upwelling is the result of the coastal winds and the phenomenon called the *Coriolis effect*.

- 14 Coriolis Figure Water or an air mass traveling over a large distance appears to be deflected from its original direction of motion. Called the Coriolis effect, this phenomenon is due to the fact that Earth is a rotating sphere. The mathematics to explain this are complicated so we will skip them today. The simple result is that in the Northern Hemisphere, ocean water is deflected to the right of the wind that is pushing it. In the Southern Hemisphere, the water is deflected to the left of the original direction.
- For example, if the wind is pushing water to the south (the original direction), the water will actually be deflected to the right (in the Northern Hemisphere) and will flow slightly to the west.
- 15 Upwelling Figure Along the California coast, the wind blows from the north to the south which is called a northerly wind. It causes the surface water to move offshore to the west. As the spring wind blows, shelf water moves away from the shore, and deeper water from above the slope is brought to the surface. This water is cold and nutrient rich.
- 16 Sunlight on the water Remember that this is spring and sunlight is increasing. It warms the ocean water and provides energy to algae which drives *photosynthesis*. Algae require nutrients for growth and use nutrients as quickly as they become available.
- 17 Upwelling Figure Since deeper water is not warmed by sunlight and algae cannot survive without sunlight, nutrient concentrations are higher in the deep water than in surface water. Upwelling brings this cold, nutrient-rich water to the surface to replace the warm, low-nutrient water offshore.
- 18 Diatoms Algae, especially *diatoms* as seen here, increase in abundance dramatically during upwelling. These *phytoplankton* use *photosynthesis* as their energy source. Next in the food web are the *zooplankton* which are the floating animals.
- 19 Krill (Jamie Hall) Diatoms are eaten by zooplankton such as krill, which are small shrimp-like animals. Krill, more formally called *euphausiids*, become very abundant in the surface water during the upwelling season.
- 20 Plankton net tow (Jamie Hall) Using nets like these, Sanctuary researchers know that there can be up to 75,000 krill per cubic meter in the water. That means for every 1 liter of water that you may happen to drink of the ocean, you would swallow 75 krill. Upwelling is important for all levels in the marine community – from the microscopic algae and animals to ...
- 21 Jack mackerel (Marin Skin Diving) small schooling fish and
- 22 Adult rockfish (T. Chess) rockfish to
- 23 Baleen of humpback whale baleen whales, which all eat the small *plankton*.

- 24 Birds Birds also take advantage of the abundant food.
- 25 Common Murre The cycles of many organisms depend on the upwelling season. The Common Murre lays its eggs in April so the chicks hatch in May. That is the best time for the fledglings to feed on juvenile rockfish. The rockfish feed on krill, and krill feed on diatoms. And why do diatoms become so abundant in the spring? Upwelling.
- 26 Food Chain The physical phenomenon of upwelling is crucial to the Gulf of the Farallones biological community. It is the driving force which replenishes the nutrients in the surface water by bringing the nutrient-rich deep water to the surface. How do we know this?
- 27 Niskin Bottle Sanctuary researchers take water samples at different depths during different seasons using an instrument such as this Niskin bottle. It is lowered down while both ends of the bottle are open. At a specific depth, the instrument is triggered, and the bottle is closed, trapping the water at that depth inside. Back on the ship, chemical tests are done on the water to determine the concentration of nutrients or other chemicals. By knowing the concentrations, researchers can better understand the seasonal cycles.
- 28 Water Temperature Graph This figure illustrates the temperature of the water 10 meters below the surface over a year. This tells us if upwelling of cold water is taking place. The x-axis is time, and the y-axis is the sea surface temperature. In blue, you can see that the sea surface is the coldest in April, May, and June. That is when the northerly winds are blowing, moving the surface water offshore and causing upwelling. Most plankton are also carried offshore during this time.
- Upwelling is not a constant process. It comes in pulses of a week or so, with a break when the wind weakens. During the subsidence of the wind, the water that was pushed offshore sloshes back. This is a time of growth for the diatoms and other plankton.
- 29 Fog Upwelling is the foggy season in the San Francisco Bay area. Cold water is at the surface and this interacts with the warm air above to produce fog. Next time you see fog during the spring, you should think about what is causing the fog and how that impacts the ecosystem in the water below.
- 30 Islands & humpback (Jim Cabbage) During the late summer and fall, coastal winds die down, and the sea surface calms. This is called the relaxation period. The northward-flowing Davidson Current replaces wind-driven upwelling over the shelf. This is a weak current.
- 31 Relaxation figure Warm water from the south moves into the Gulf of the Farallones, bringing nutrient-poor water. As the relaxation season progresses, the water on the shelf is not mixed up and down, and layers form. The surface layer is warm and becomes nutrient-poor as the phytoplankton use up most of the nutrients. The layers below are colder, because it is not warmed by the sun, and more dense. The deeper water does not mix with the fresher water flowing out of the San Francisco Bay.

- 32 Dinoflagellates (Richard Zingmark) Different than the diatoms of the upwelling season, *dinoflagellates* become the dominant algae during the late summer months because they survive well in lower nutrient waters.
- 33 Red tides (SW Fisheries Science) Some species of dinoflagellates increase in abundance very rapidly and can be seen at the surface. When this occurs, it is called a red tide. This darker/ browner area at the top of the slide is a red tide. Some dinoflagellates produce toxins that accumulate in shellfish and can pose a threat to wildlife and humans.
- 34 Siphonophore The zooplankton community also changes during the relaxation season. The Davidson Current brings carnivorous jellies, like this siphonophore, into the area. They eat at very high rates and reproduce at extremely high rates.
- Before we review the oceanographic seasons, what factors would you look at to determine what season it is now? (Wind, current, sea surface temperature, animals are all good answers).
- 35 Seasonal Figure The cycle of the oceanographic seasons begins again in the November with increased storms. Let's review the three seasons of the Gulf of the Farallones.
- The winter season is dominated by storms that mix-up the water on the shelf.
- The upwelling season is driven by strong northerly winds and the Coriolis effect which cause the surface water to be pushed offshore. Cold, nutrient-rich water from above the slope is brought to the surface. With increased sunlight and high concentration of nutrients, the diatoms increase in abundance, driving a rich biological community.
- During the relaxation season, the winds die down, reducing the mixing, and the water becomes layered. The surface becomes warm and nutrient-poor, while the deep water is cooled.
- 36 Islands (Jan Roletto) The seasons of the Gulf of the Farallones enhance the biological community of the region. We hope that by understanding the three seasons you can appreciate the beauty and the special environment near you.

Books and Resources

Charton, B., E.H. Immergent, and J.H. Tietjen, 1990. The Facts on File Dictionary of Marine Science. ISBN 0-8160-2369-7 (1988 edition).

Activity Books

Pipkin, B.W. et. al, 1987. Laboratory Exercises in Oceanography second edition. W.H. Freeman and Co. ISBN 0-7167-1810-3 (introductory college level)

Rowell, B. and W.L. Ryan, 1996. Methods in Introductory Oceanography. Wm. C. Brown Publishers. ISBN 0-697-28016-0 (introductory college level)

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.

Walker, S.H, K. Damon-Randall, and H.D. Walters, 1998. Oceanography and Coastal Processes Resource Guide. Institute for Marine Sciences – J.L. Scott Marine Educational Center and Aquarium, University of Southern Mississippi. Write to: PO Box 7000, Ocean Springs, MS 39566-7000 to get a copy.

Textbooks

Duxbury, A.C. and A.B. Duxbury, 1997. An Introduction to the World's Oceans, fifth edition. Wm. C. Brown Publishers. ISBN 0-697-28273-2

Pinet, P.R. 1998. Invitation to Oceanography: web-enhanced edition. Jones and Bartlett Publishers. ISBN 0-7637-0614-0

Thurman, H.V., 1997. Introductory Oceanography, eighth edition. Prentice Hall. ISBN 0-13-262015-4

Regional Descriptions

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.)

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.)

Videos from the Education Resource Library at the Farallones Marine Sanctuary Association

10th Anniversary of Gulf of the Farallones National Marine Sanctuary (C/6). CNN report. About 2.5 minutes.

Gulf of the Farallones (C/4) Collection of many different video clips about the Gulf of the Farallones. Natural history of elephant seals and sea birds. 15 minutes.

Farallones Radioactive Waste Disposal (F/5) Geraldo Rivera on NOW. View of the seafloor and the waste drums. About 7 minutes.

20th Anniversary of the Gulf of the Farallones National Marine Sanctuar Premiering in 2002.

Selected Web Sites

Oceanography of the Gulf of the Farallones

Oceanography

- Weather World 2010 Project: Coriolis Effect...
[http://ww2010.atmos.uiuc.edu/\(Gh\)/guides/mtr/fw/crls.rxml](http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/fw/crls.rxml)
- Getting around the Coriolis Effect ... <http://www.physics.ohio-state.edu/~dvandom/Edu/newcor.html>
- California Coast and Ocean: Upwelling ... <http://www.ocean98.org/cacoast2.htm>
- Bad Coriolis ... <http://www.ems.psu.edu/~fraser/Bad/BadCoriolis.html>
- A primer on ocean currents ... <http://www.whoi.edu/coastal-briefs/Coastal-Brief-94-05.html>
- Our Restless Tides ... <http://co-ops.nos.noaa.gov/restles1.html>
Booklet which explains the tides
- Waves ... <http://www.onr.navy.mil/focus/ocean/motion/wave1.html>
- Guide to Working at Sea ... <http://fermi.jhuapl.edu/book/index.html>
- Neptune's Web ... <http://pao.cnmoc.navy.mil/educate/neptune/neptune.htm>
- Ocean Science Activities for Teachers ... <http://www.vims.edu/bridge/>

Oceanographic Conditions in the Gulf of the Farallones and San Francisco Bay

- National Data Buoy Center ... <http://www.ndbc.noaa.gov/Maps/Southwest.shtml>
Check out the Bodega buoy #46013 and the San Francisco Bay buoy #46026
- Coastal Data Information Program ... <http://cdip.ucsd.edu/>
Check out the Point Reyes Buoy
- Pacific Fisheries Environmental Laboratory upwelling index ...
<http://www.pfeg.noaa.gov/products/products.html>
- NOAA's Coast Watch upwelling data ... http://cwatchwc.ucsd.edu/cgi-bin/el_nino.cgi
- History of San Francisco Bay ... <http://www.sfgate.com/cgi-bin/article.cgi?f=/chronicle/archive/1999/12/20/MN56977.DTL&type=printable>
- Disposal Issues of the Farallones Region ... <http://walrus.wr.usgs.gov/farallon/>
- San Francisco Wind Patterns ... <http://sfports.wr.usgs.gov/wind/>

Biology

- Plankton sampling ... <http://www.ios.bc.ca/ios/plankton/pictures/scrapb0.htm>
- Diatom Web Page ... <http://www.indiana.edu/~diatom/diatom.html>
- Eureka: Diatoms ... <http://hjs.geol.uib.no/html/diatoms/>
- Red Tides ... <http://www.marinelab.sarasota.fl.us/~mhenry/WREDTIDE.phtml>
- Dinoflagellates ... <http://www.geo.ucalgary.ca/~macrae/palynology/dinoflagellates/dinoflagellates.html>
- Bioluminescence ... <http://lifesci.ucsb.edu/~biolum/>
- Algal Blooms ... <http://www.nwfsc.noaa.gov/hab/blooms.htm>
- Microbial Oceanography ... <http://www.mbari.org/microbial/>
- Krill ... <http://www.ios.bc.ca/ios/plankton/~romaine/krillinf.htm>

Geology Virtual Fieldtrips

- Tour of Loihi and see maps, rocks, and wildlife of Hawaii's newest volcano ...
<http://www.soest.hawaii.edu/GG/HCV/loihi-tour.html>
- Geological Investigations on Northern Great Bahama Bank ... <http://comp.uark.edu/~sboss/ngbb.htm>
- Ocean Planet traveling exhibition by the Smithsonian Institute ...
http://seawifs.gsfc.nasa.gov/ocean_planet.html

Virtual Fieldtrips (continued)

- Jason Project exhibitions . . . <http://www.jasonproject.org/>
- Coastal Geology of Natural Bridges State Park . . . <http://emerald.ucsc.edu/~es10/fieldtripNBridge/>

Speaker List for Oceanography of the Gulf of the Farallones

Here are a list of experts with extensive knowledge on oceanography who may come speak to your class. They have agreed to be on this resource list for teachers. To schedule a speaker for your classroom, call the individual in your area. Availability and rates vary.

<u>Name</u>	<u>Affiliation</u>	<u>Contact information</u>
Dr. Jennifer Saltzman	Farallones Marine Sanctuary Assn.	415-561-6625, jsaltzman@farallones.org
Dr. Toby Garfield	San Francisco State University	415-339-2617, garfield@sfsu.edu