Coastal Ecosystem Curriculum: Sandy Beaches

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Gulf of the Farallones
National Marine Sanctuary

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.

Funding

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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

Sandy Beaches of the Gulf of the Farallones National Marine Sanctuary

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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 provjfie 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:

    a. Know biodiversity is the sum total different kinds of organisms.

- Students will know the biodiversity of the sandy beach habitat.

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

- Students will know there are very few producers in the sandy beach habitat and that animals depend on other parts of the ecosystem for food.

Earth Sciences
California Geology. 9. The geology of California underlies the state's wealth of natural resources as well as its natural hazards.

- Students will understand the complexity of the sandy beach environment.

Observations and Prediction of Tides

Physics
Motions and Forces. 1. Newton's laws predict the motion of most objects. Students will know:

e. The relationship between the universal law of gravitation and the effect of gravity on an object at the surface of Earth.

- Students will understand the difference between observations and predictions of tides.
- Students will describe the results of the force of gravity between the Moon, Sun, and Earth which are the tides.

Earth Sciences
California Geology. 9. The geology of California underlies the state's wealth of natural resources as well as its natural hazards.

- Students will be able to describe the daily pattern of water level along the coastline in California.

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

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

- Students will compare tidal observations and predictions to understand the usefulness of the tide models, which are used to make the predictions.

What is the Shape of the Beach? Beach Profile Survey

Earth Sciences
California Geology. 9. The geology of California underlies the state's wealth of natural resources as well as its natural hazards.

- Students will describe the shape of the California beach.

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 measure the height of the beach using line levels and meter sticks, and will record the data.
- Students will graph the relationship between distance and vertical height to represent the shape of the beach.

h. Read and interpret topographic and geologic maps.

- Students can create their own topographic maps using multiple beach profiles.

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

- Students will have the opportunity to relate the seasonal physical conditions of the ocean to the geology at the coastline. They can compare beach profiles at the same location over the seasons.

The Sandy Beach Habitat

Seashore habitats vary greatly, from mudflats to gentle, wave-lapped protected beaches to headlands exposed to the pounding fury of storms. Some are places of oozing mud, some are solid rock, and some are made of shifting sand. Along the shores, animals, algae, and plants have traits that allow them to survive in those specific conditions. Some shores, especially mudflats, are among the most productive and prolific environments on Earth. Others, especially rocky shores, are among the most diverse. But the shore most often pictured in the mind's eye, the wind-swept sandy beach, is the closest that the seashore comes to being a desert.

The sandy beach is a harsh physical environment. The sand shifts. There isn't much food produced at the beach. Waves crash. The *tide* rises and falls. The sandy beach begins underwater in the *subtidal* region, continues up through the crashing waves of the *surf zone*, into the *swash zone* where the waves cover and uncover the sand regularly up to the high tide line, and extends to the cliff or ssand dunes that border the sandy beach. Specialized animals inhabit this turbulent and varied habitat. This unit will cover the physical habitat and the biological community of the sandy beach specific to the Gulf of the Farallones National Marine Sanctuary (NMS). The Sanctuary protects and manages the sandy beach up to the mean high tide line.

Waves

Ocean waves are created by the force of the wind blowing across the surface of the water. The size of waves reaching the shore is determined by how fast the wind blows, over how long a time and distance it blows (called *fetch*), and from what direction it crosses the shore. Though wind speeds are not significantly different on the Atlantic and Pacific coasts of North America, the fetch, prevailing wind direction, and track of the storms towards the shore combine to create the highest energy beaches along the Pacific coast.

Sandy beaches exposed to high-energy, crashing waves are nearly uninhabitable, but given any amount of protection the number of organisms able to make a living there greatly increases. There are several ways that beaches can gain protection from ocean waves. Offshore islands, sand bars, and kelp beds all act to deflect and dampen the power of waves approaching the shore. Such protected beaches typically have smaller waves, more *organic* material mixed in with the sand, and more organisms living there. In the Gulf of the Farallones NMS, the beaches range from sand only to sand with cobbles or boulders, backed by bluffs or sand dunes.

Prevailing sea conditions are reflected in the appearance of the beach. Its slope and size of sand particles indicate the power of the waves that strike it. Steep slopes and coarser grains mean big waves. The high-energy beach is cleaned of the fine sediment, because water with higher velocity carries away small sediment. Wide, gradually sloped beaches have finer sand grains and smaller surf. The low-energy beach allows more organic material to accumulate and finer grains to hold more water in the sand at low tide. The lower velocity water cannot hold the sediment and deposits the sediment along the shore. Beaches change appearance with the season. Bigger waves of the winter storms pull sand offshore to form bars, leaving behind only the larger gravel or cobble. When the gentler seas of summer return, sand is redeposited on the beach, and the offshore bars diminish.

It has been estimated that the energy contained in an average wave front approaching a beach is equivalent to a line of automobiles, side by side, revving their engines at full throttle. There is little wonder that the size and character of waves are the primary physical feature that determines how beaches look and what lives on them. For example, the shape of the shell of clams and crabs reflects the pounding surf.

Sand

Quartz is the most common mineral on Earth. It is found in most types of rocks, and it is nearly insoluble in water. Not surprisingly, it is the most common constituent of sandy beaches. The sandy beach is composed of many other minerals as well, each with slightly different densities and colors. Sand is sorted across the beach by wind and waves which create distinct and intricate bands in the sand. Indeed, nearly every solid material on Earth, whether from non-living sources (abiogenic), such as rocks, or from living organisms (biogenic), such as shells and corals, is worked into sand. The beaches of New England are still transporting and sorting the sediment from the glaciers that retreated thousands of years ago. In volcanically active areas like Hawaii, the beaches may be dark black; the sands are the eroded remains of lava flows. In Florida, the white debris of coral reefs and calcium-shelled microorganisms are the most significant contributor to the sand.

Though sands may be produced right at the shore where waves crash against headlands and reefs, the great bulk of the beach sand around the world comes from the interior of the continents. As mountains are weathered, their fragments are brought down rivers and eventually deposited where the river currents slow down abruptly after emptying into the ocean. The sandy beaches of the Gulf of the Farallones NMS are made up of sediment weathered from terrestrial rocks.

Sediments are classified by particle size. Fine particles barely visible to the eye are called *mud*, particles more than 1/8" across are called *gravel,* and those particles intermediate in size are called *sand.* Where the sediments get deposited depends on the speed of the water carrying them. It takes more energy to carry larger particles. Therefore in very high surf zones, only gravel or cobbles may be left on shore. The smaller particles are easily resuspended and carried away by the water. The smaller particles of mud can only settle in calm water, such as inside bays or well offshore on the deep-sea floor. Wave action prevents their accumulation on open ocean beaches. On most beaches around the world, the energy of waves and currents is such that the average particle size is in that intermediate range called sand.

There may be little visible change in the day-to-day appearance of a sandy beach, but it is always in motion. No grain stays in one place for very long. Each *breaker* lifts millions of grains from one spot and deposits them at another. When the prevailing wave direction strikes the beach at an angle, sand grains are deposited by the receding backwash a short distance down the beach in the direction of the prevailing wind. This is called longshore transport. Though each movement of sand may be small, the overall movement of the sand is large. With an average of 8,000 waves per day and the 0.5 cm lateral movement of a sand grain with one wave, a sand grain is transported 40 meters in a day. Over the course of a year, sands may be moved considerable distances along the coast. If it were possible to watch individual grains, beaches would be seen, not as static geographical features, but as rivers of sand.

Where does the sand go? Most of the sand is transported along the shoreline, although some is moved across the continental shelf. There are deep-sea canyons that cut into the continental shelf along most shorelines. Longshore transport of sand continues until it reaches such a canyon, and then the sand is channeled down the canyon onto the deep-sea floor.

The average sand grain is 2.5 times as dense as seawater, but 2,000 times as dense as air. Consequently, only smaller grains are moved by the wind into dunes above the reach of the waves. Dune sand is noticeably different in appearance than beach sand. Air-borne grains are more rounded from abrasion, and their surface is frosted like old bottles on the beach. Their surfaces show the effects of sand blasting. In sharp contrast to this, sand grains that have only been carried by water are sharp-edged and clear. Each grain is surround by a film of water that clings to it by surface tension. On the beach, even in the midst of crashing surf, this water envelope keeps the grains from rubbing against each other. Wet sand grains are almost indestructible.

The amount of water that can be retained and held by beach sand depends on the size of the sand grains. Finer-grained sand holds more water than coarse-grained sand, but on average sand holds water in a volume equal to its own. That is, an average beach is half water and half sand. For this reason, when the tide is out and the beach is exposed to the Sun, only the upper few centimeters actually dry out. Conditions just a few inches below the surface do not change much in terms of wetness, temperature, or salinity. Even during rains, the flow of freshwater across the beach does not dilute the water held within the sand. Freshwater is less dense than saltwater and remains above it as it flows out to sea. Though the rigors of life are great in the sandy beach environment, as evidenced by the few species adapted to them, there are clear benefits for those animals that have adaptations. Surrounded by sand, they are not subjected to the desiccating stress of sunlight and air that species living on firm, but impenetrable, rocky shores must endure.

Tides

Tides are the periodic rise and fall of the sea level, resulting from the gravitational attraction and motions of the Earth, Moon, and Sun. Although most easily observed at the shoreline, the tidal forces impact the entire Earth. Along the California coast, there are *mixed semidiurnal tides*. Semidiurnal refers to two highs and two lows each tidal day, while mixed means that the heights of the tides during one tidal day are uneven.

The maximum *tidal range* along the coast of the Gulf of the Farallones NMS is about 3 m (9 feet), and the maximum tidal current is about 5 knots. When the Moon and Sun are aligned with the Earth during a new moon or a full moon, their gravitational pulls are combined. The result is more extreme tidal heights. These are called spring tides, and the tides are at its highest and lowest levels. When the Moon and Sun are at right angles with respect to Earth (the first and third quarter moons), the tidal range is the lowest. A tidal day is about one hour longer than the 24-hour day of the Sun, because the Moon revolves around Earth which is rotating. The tides come a little later each day.

Tides can be predicted quite well based on local observations of at least 19 years, the time period that covers most of the major tide-generating configurations of the Earth-Moon system. Once the tides are formed by the astronomical factors, tides are modified by the sea floor, coastline, and weather. Tide tables are predictions and cannot account for weather conditions. Tidal predictions are easily accessible in the newspaper or on the Internet. The National Atmospheric and Oceanic Administration distributes regional tide tables each year. Tide books for the Gulf of the Farallones NMS are available for free at the Sanctuary office.

Food Web

Very little food is produced in the sandy beach habitat. What primary productivity occurs in the sand comes from the microscopic algae in the top few centimeters of the sand. There are a few species of algae living between the sand grains near the surface, but the their total mass is very small. On protected beaches where the sand is much finer, more compact, and more stable, *diatoms* and *dinoflagellates* migrate vertically through the upper centimeters of the beach to capture sunlight at low tide. They serve as the productive base to the more complex *food web* of muddier backwater shores.

Without much primary production occurring in the sandy beach habitat, organisms depend on food produced in other habitats. Sandy beach organisms depend on organic debris called *detritus*, that is an important source of food in other marine habitats as well. Kelp, other macroalgae, and plants are washed to the shore and deposited on the sand. Called beach wrack, it is a valuable food source for many animals. The beach acts just like the sand filter bed in a sewage treatment pond, or, on a smaller scale, the sand filters in home aquaria. The rolling wave action maintains a very high oxygen level which allows bacteria to live well down into the sand. Bacteria breakdown 95% of all the organic matter deposited by the waves. Because the detritus does not build up in thick deposits, there are few sand-ingesting worms or other animals adapted to ingest the substrate directly to remove the digestible organic matter mixed in with the sand. This is a common feeding strategy in muddier substrates or in earth worm-rich backyards.

Another source of food is *plankton* and organic particles (detritus) kept suspended in the water by wave action. In the spring and summer when the upwelling of cold, nutrient-rich waters along the Pacific coast is at its highest, waves may be turned dark green indicating the presence of dense concentrations of phytoplankton.

When prevailing westerly winds slacken or shift, the surf may carry a brown froth that is often mistaken for pollution. This foam is merely the concentrated remains of dinoflagellates that have become trapped nearshore by the periodic cessation of upwelling and the associated currents that normally move the organisms away from the shore during the most productive seasons.

The sandy beach habitat provides little shelter or cover to avoid predation. During low tide, shorebirds, small mammals, and insects prey on sand crabs and other animals in the swash zone. High tide brings in another group of predators; fish, crabs, shrimp, and worms feed on the animals in the sand. Many shorebirds have camouflage for protection.

Life Cycle

The most difficult obstacle that sandy beach organisms face is the lack of a stable substrate on which to hold. The surface of the sand is constantly pounded, stirred, and shifted by waves to a depth of at least several inches. There is no means of attachment, there is continual abrasion by swirling sand, and life is nearly impossible. The solution, solved by only a handful of species, is to live in, not on, the sand. It is a swim, burrow, or be swept away habitat. Burrowing beneath the sand protects animals from predation, wave impact, *desiccation*, and extreme temperatures. Yet, life in the sand presents the problems of finding food and adequate oxygen.

Many species living on sandy beaches go through free-swimming larval stages and are carried by ocean currents as part of the plankton. This means that populations are able to move up and down the coast easily in response to favorable conditions. It also means that populations in any one area are not very stable and may fluctuate widely from year to year. Most sandy beach species only live 1-2 years, which makes annual variation more likely. Some clams are a notable exception to this pattern, however. For them, a long life span provides greater population stability, though it doesn't allow for rapid re-population if an environmental or human-caused calamity strikes. This is especially significant for some of the most commercially desirable large clams which live for 50 years or more.

Above the Waves

The highest reach of the tide is called the wrack line. It is the place where ocean debris is left onshore. The beach wrack reflects what lives just offshore and gets uprooted by big storm waves – sponges, olive shells, sand dollars, skate egg cases, plants, and algae. Kelp and other algae are the biggest contributors to the wrack in the Gulf of the Farallones region. Beach wrack also contains the drifting debris of the whole ocean – the dead and dying remains of fish, birds, and the formless masses of jellies. The flotsam and jetsam of merchant vessels, uprooted trees, and anything that floats and drifts at sea lands on sandy beaches.

Potentially, the wrack constitutes a plentiful source of food. But since it sits at the highest tide mark, it is out of reach for most of the intertidal community. There are a few species, however, that take advantage of this rich food source. One of these species is the commonly called beach hoppers or sand fleas which are small shrimp-like amphipods that feed on the beach wrack. They have gills that function almost like lungs yet must be kept wet to function. The beach hoppers must avoid direct contact with the water, because they will drown if submerged. They are able to get enough moisture from the damp sand to keep their gills functioning. During the day, beach hoppers burrow head first deep beneath the high tide line, often under the beach wrack. The burrows are plugged for disguise and protection. An open burrow is an abandoned one. Even though a great deal of work is invested in the burrow's construction, it lasts only one day – until the waves of the next high tide wash over it. At night, on a falling tide, beach hoppers swarm out to feast on the organic debris of the wrack. Their chief diet is the rotting kelp. To protect their eggs, the females carry them in a brood pouch found on the underside of their body. Beach hoppers can be very prolific, sometimes existing in densities of hundreds per square meter. They are prey for many shorebirds and beetles.

Probably the most familiar birds on the sandy beaches of the Gulf of the Farallones NMS are the little Sanderlings. These are the birds that move like little wind-up toys, darting back and forth at the edge of the crashing surf. With their bodies held motionless and their feet a blur, Sanderlings seem as anxious to avoid getting wet as they do to snatch an exposed mole crab or worm. Sanderlings aren't equipped to probe deep into the sand, so they try to find prey as it is stirred up by the waves and before it can re-burrow. The larger Willets have longer bills and longer legs and are less concerned about getting wet. They wade into the retreating surf to forage. With their longer bills, they are less restricted to finding loosened prey at the sand surface. The tips of their bills are sensitive and are able to detect tiny vibrations that indicate the presence of prey deeper in the sand. Willets and other long-billed probers like Marbled Godwits actually feel the sand for food with their bills.

Higher on the beach, small Snowy Plovers chase about in the dry sand and beach wrack to snatch flies, other insects, and beach hoppers on the beach wrack. On gravelly beaches too coarse to probe with their beaks or where thick lines of kelp cover hordes of beach hoppers, there is a group of shorebirds adapted to flip over rocks and debris in search of food. These small shorebirds are aptly named turnstones. The most noticeable birds of the beach and certainly the loudest are the ubiquitous gulls. These scavengers are opportunists that feed on most any food item tossed on the shore – whether by a wave or picnicker.

In the Swash Zone

On an exposed beach, perhaps only five or six species of animals will be found burrowing in the sand. If a beach has some protection, the number may reach 20-25 species, and the total *biomass* may be 20 times greater. Fine sand on protected beaches is better for burrowing, retains more water, and has more organic matter to provide food for deposit feeders. The swash zone is one of the most physically harsh environments, because the waves are crashing, and the water comes and goes several times per minute.

Commonly called the sand crab or mole crab, *Emerita analoga,* is the epitome of burrowing efficiency. While other crabs are able to move in any direction, the sand crab can only move backwards. Its legs move sand in one direction to bury itself quickly. Its rear legs are modified as paddles, which gives it very good swimming capability, an essential skill when it is stirred out of the sand by crashing waves.

The sand crab burrows tail first into the sand, with its head near the surface facing seaward. Only its eyes and antennae are held above the sand. When the wave recedes, its large antennae are unfurled to form a "V" through which the backwash is sifted. The antennae are feather-like with numerous fine projections. Around the mouth, modified appendages act as bottlebrushes, scraping and cleaning the antennae several times during each wave. The most common food items are phytoplankton, though small pieces of macroalgae and sand may be trapped. The straining capacity is so refined that sand crabs are even able to trap bacteria.

Population densities of the sand crabs are sometimes so great that individuals may be touching one another. They are usually segregated by size with the larger ones nearer the ocean and the smaller ones higher up in the intertidal zone. Since females are larger than males, there is a corresponding segregation of the sexes as well. The entire population moves up and down the beach with the tides, with the greatest concentrations nearest the breakers. They also move along the length of the beach if longshore currents are present.

Sand crabs live 2-3 years and are able to reproduce during their first year. The bright orange eggs are carried on the female's underside. They spend four months as planktonic *larvae*, and they can be carried great distances by currents. Consequently their distribution is highly variable and their range is great (Alaska to Chile).

The sandy beach habitat provides little shelter to avoid predation. During low tide, shorebirds are the principal predators of sand crabs, while during high tide fish take over this role. Shorebirds are not as significant a threat, because the larger bird species best able to catch them, such as willets and godwits, tend to spread out as they feed and consequently pass over populations quickly. Fish, especially surfperch, are a more significant threat. In fact, predation from the sea is probably the major evolutionary factor that propelled these crabs to adapt to the rigors of life at the leading edge of the surf. Humans use sand crabs as bait.

There are not many predators down in the sand, but there are a few. The most effective are probably the moon snails, *Polinices* and *Natica.* These large snails (10-15 cm across the shell) have an immense foot which when fully extended nearly envelopes its own shell. It can only be withdrawn after a slow process of discharging water. The moon snail creeps just below the surface of the sand searching for prey, primarily clams. Other in-sand predators include several species of the segmented polychaete worms including *Euzonas* and *Nepthys.* They are more common on protected beaches, but sometimes abundant on exposed shores as well. Though small, they are effective predators.

Clams are the dominant *filter feeders*, meaning that they filter the water for plankton and detritus. The fast burrowing razor clam, *Soliqua,* has a shell that is long and very fragile, not at all what one would expect for an animal living in the tough surf. Long siphons are projected up to the surface of the sand to pump water and food. The razor clam is able to burrow fast enough to reposition itself within the short time between one crashing wave and the next (an average of 7 seconds). The Pismo clam, *Tivela,* of southern California is massively built with a thick, strong, and smooth shell. This allows it to easily withstand the force of breakers. These clams cannot survive in quiet water; they require the high oxygen content of the surf. Unlike relatives adapted to quieter habitats, the siphon of the Pismo clam has filter-like projections across the opening that keep out sand.

Between the Sand Grains

The most diverse and abundant organisms of the sandy beach habitat are too small to be seen with the naked eye. Because the sand holds water even when the tide is out, the minute spaces between the grains of sand are able to support a complex community of microorganisms that swim within the protective film of the water that surrounds each grain. These are single-celled protozoans, nematodes, flatworms, larvae of other worms, and several crustaceans. Most of the major invertebrate groups have members which live in the *interstitial* water that surrounds each sand grain. This community is known as the interstitial fauna.

Many of the animals are small, specially adapted members of groups that are larger in other habitats – 2 mm sea cucumbers, 2 mm snails, and 0.3 mm polychaete worms. The single-celled protozoans found here, however, are often larger than their microscopic relatives found in other habitats. All species tend to be long and flat, which makes it easier for them to stay wrapped within the film of each grain. They also tend to have simplified bodies. At this size there is no need for complex digestive tracts or respiratory, circulatory, or excretory organs. Diffusion through their body walls is adequate to transport gases, food, and waste. Most have some mechanism for holding on to their one-grain world such as adhesive glands, hooks, or claws. The interstitial copepods do not have the large antennae that their free-swimming relatives use to dart about in the ocean. There is no room for that kind of locomotion. Instead, interstitial copepods wriggle. Nematodes are the most common animal here. One study identified 70 different species in a 50 cm^2 plot (less than 3 inches per side). It has been estimated that as many as one million animals may live in a square meter of sand!

There are three feeding strategies in the interstitial space: herbivores feeding on the *benthic* diatoms, deposit feeders ingesting detritus brought in by the waves, and suspension feeders that filter the water for plankton between the grains of sand. Though they are all microscopic in size, the interstitial fauna are so abundant that it accounts for the majority of the oxygen used and the carbon dioxide produced on the beach. Predators of the interstitial fauna include young flatfishes as well as shrimp and polychaete worms.

Beyond the Tides

Though unseen by the beach stroller, there are several fish species that are also a part of the sandy beach habitat. Skates, rays, and other flatfish patrol for prey just beyond the waves. When the tide is in, they have access to the intertidal crabs, clams, and worms. By flapping their "wings," they create their own surf-like action to blow away the sand and expose their prey. Some fish have adapted to feed just behind the leading edge of the breaking waves. Surfperches and sand eels take advantage of the dislodging force of the waves to grab crabs and worms otherwise unobtainable.

Though the empty shells of dead sand dollars are often washed up on beaches, the living animals are only found below the low tide. Sand dollars, with flat shells and short spines, are relatives of sea urchins and sea stars. They are able to work their way into the sediment and can even right themselves and re-burrow when turned upside down by a passing wave. Sand dollars feed by trapping detritus in mucous between their spines and carrying it to their mouths by the action of tiny hairs (cilia).

Human Impact

The seashore is a major recreational site for people all over the world. Sandy beaches are the most visited of all shore types. They are often easy to get onto, they don't show much wear and tear from great crowds, and probably just as important – it is a place of relaxation and exploration. For these reasons, sandy beaches are often held as public property. In many states, even where private homes are built near the shore, the beach itself is kept open to public access.

As we have seen, beaches are in constant motion. Sand moves seasonally on and offshore. It also moves along the coast in the prevailing direction of wind and waves. A shoreline that moves 25 meters in 50 years gets noticed when it is near a man-made structure that becomes threatened by the moving shoreline. The problem becomes especially urgent when a home is built on such a beach. The first reaction has often been to build some sort of seawall to keep the beach from eroding away. However the change in the shoreline from the seawall often causes unwanted erosion and deposition in other areas.

Along Ocean Beach in San Francisco, a submerged sill traps sand along the beach. This man-made structure has been considered a success by some people in that it keeps the sand on the beach during the winter and has not disrupted the normal sand cycle in other areas. In contrast, a groin was placed north of the mouth of Bolinas Lagoon to protect the Lagoon. Not only has it trapped sand behind the groin, sand is also accumulating to the south of the groin at the mouth of the Lagoon. The water is slowed down by the groin and deposits the sediment it had been carrying along the shore. This sand inhibits water flow out of the Lagoon which increases the siltation within the Lagoon itself.

The sandy beach is a major deposition area for algae and all the other material floating at the surface. Plastic and garbage end up on the beach and may be mistaken for food by birds and other animals. Oil from spills ends up on the beach, potentially covering the animals and their food with toxic oil. Pollution reaches the sandy beaches and impacts the marine life there. Although the sandy beach is often a place of beauty, some human activities threaten the habitat.

Gulf of the Farallones National Marine Sanctuary

Through the Beach Watch program, the Gulf of the Farallones NMS monitors the beaches along its boundary with the help of volunteers. Every two to four weeks dedicated citizen scientists survey their beaches for marine life and human activity. Fluctuations in bird and marine mammal populations are detected in the long-term database. Volunteers find and report oil or tarballs and collect and preserve oil samples as evidence. The Beach Watch program provides additional eyes and ears for protecting the Sanctuary's sandy beaches.

Adapted from Project Ocean: Sandy Beach Habitat Guide

Glossary of Terms
Sandy Beaches

Algae (singular-alga)	photosynthetic, aquatic or marine organisms that resemble plants but have no seeds or roots, ranging from one-celled diatoms to multicellular seaweed called macroalgae. The largest macroalgae are kelp.
Beach wrack	debris from the ocean that is washed onto the beach. It can include kelp, shells, sand dollars, birds, and fish.
Benthic	associated with the sea floor; pertaining to organisms living in or on the sea floor.
Biomass	total weight of living organisms.
Breaker	a wave that is unstable and collapses or breaks along the shoreline.
Detritus	dead organic matter and the microscopic decomposers that live on it.
Diatoms	microscopic, single-celled *algae* which have silica (glass-like) valves and are abundant in upwelling waters. Some species live in the shallow waters on the sediment.
Dinoflagellates	microscopic, single-celled organisms. Both plant and animal traits. They have flagella which provides them some locomotion. Some species live in the shallow waters on the sediment.
Fetch	area and distance across which wind interacts with the water surface to generate waves.
Filter feeder	an animal whose feeding strategy is to filter water for food. Examples from the sandy beach are clams and sand crabs.
Food web	all feeding relationships in a community.
Habitat	the place where organisms live.
Interstitial	refers to the space between sediment particles.
Intertidal zone	area between the high and low tide.
Larvae	immature pre-adult stages of an organism, which do not structurally resemble the adults. Often have different diets and habitats than the adults.
Longshore current	current produced by waves landing on shore at an angle to the shore; responsible for moving coastal sediment and natural erosion along beaches.
Mixed tide	daily tidal pattern of uneven high tides and uneven low tides.

Organic	matter that is produced by living organisms, a chemical compound with a backbone of carbon atoms.
Plankton	drifting organisms that have no control over the direction they travel; they are at the mercy of the currents.
Subtidal	the part of the continental shelf that is never exposed by low tide; area below the low tide zone.
Swash zone	area where water rushes up the beach after the wave has broken.
Tide	the periodic, rhythmic rise and fall of the sea surface.
Tidal range	the difference in sea level height between high tide and low tide.
Semidiurnal tide	daily tidal pattern of two high tides and two low tides.

Sanctuary Habitat: The Sandy Beach

Along the coast of the Gulf of the Farallones National Marine Sanctuary is the often-visited marine habitat of the sandy beach. The sand-covered area where the land meets the sea is a physically harsh habitat with only a small number of living organisms in comparison to other shoreline habitats. The daily ebb and flow of the tides and the action of waves and currents keep water in constant motion, while below the sand shifts.

The sandy beach begins underwater in the subtidal region, continues up through the crashing waves of the surf zone, into the swash zone where the waves cover and uncover the sand regularly up to the high tide line, and extends to the cliffs or sand dunes.

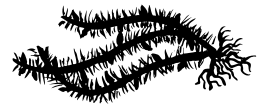
Specialized animals inhabit this turbulent habitat. The ability to move quickly to keep above the waterline or to burrow in the sand is a common adaptation among beach animals. Most beach animals make a living by filtering meals from the organic material that washes in with each wave. Beach organisms are vulnerable to human impact which often causes changes in their physical environment. These changes can be the result of pollution, careless building, or overuse. Humans that interact with the sandy beach must be mindful of the factors which affect it and are important to its health.

Sand and Water

In the Sanctuary, the beaches range from sand only to sand with cobbles or boulders. The slope of the beach and the size of the sand particles indicate the power of the waves that strike it. Steep slopes and larger-sized grains mean big waves. The high-energy beach is cleaned of the small particles because fast moving water can carry them easily. Wide, gradually sloped beaches have finer sand and smaller surf. The low energy beach allows finer grains to accumulate.

The sandy beach can change appearance seasonally. Bigger waves during winter storms pull sand offshore to form bars, leaving behind only the larger gravel or cobble. When the gentler seas of summer return, sand is redeposited on the beach.

The day-to-day appearance of a sandy beach may not change, but it is always in motion. No sand grain stays in one place for very long. Each breaker lifts millions of grains from one spot and deposits them at another. When the prevailing wave direction strikes the beach at an angle, sand grains are deposited by the receding backwash a short distance down the beach in the direction of the wind.



Life at the Sandy Beach

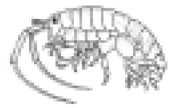
One of the most difficult obstacles that sandy beach organisms face is the lack of stable ground on which to hold. It is a swim, burrow, or be swept away habitat. Burrowing beneath the sand protects animals from predation, wave impact, drying out, and extreme temperatures. Yet, life in the sand presents the problems of finding food. The sandy beach habitat provides little shelter or cover to avoid predation. During low tide, shorebirds, small mammals, and insects prey on sand crabs and other animals in the swash zone. High tide brings in another group of predators – fish, crabs, shrimp, and worms feed on the animals in the sand.

Very little food grows in the sandy beach habitat. What photosynthesis there is at the sandy beach is from the microscopic algae in the top few centimeters of the sand. Most sandy beach animals depend on organic debris, called detritus, grown in other habitats. Kelp and other large algae are washed to the shore. The beach acts just like the sand filters in home aquaria, breaking the material into smaller pieces.

Clams and crabs filter plankton and detritus kept suspended in the water by wave action for their food. In the spring and summer when the upwelling of cold, nutrient-rich waters along the Pacific coast is at its highest, waves turn dark green indicating very abundant phytoplankton. When prevailing westerly winds slacken or shift, the surf may carry a brown froth that is often mistaken for pollution. This foam is merely the concentrated remains of phytoplankton.

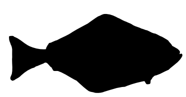
At the highest reach of the tide is the beach wrack, where the debris from the ocean is left onshore. The beach wrack reflects what lives just offshore and gets uprooted by big storm waves. Kelp and other algae are the biggest contributors to the wrack on the Gulf of the Farallones beaches. Beach wrack also contains the dead and dying remains of fish, birds, and the formless masses of jellies.

Commonly called beach hoppers, small shrimp-like amphipods feed on the rich food of beach wrack. They have gills that function almost like lungs yet must be kept wet from the damp sand to function. During the day, beach hoppers burrow head first deep beneath the high tide line, often under the beach wrack. At night on a falling tide, beach hoppers swarm out to feast on the organic debris of the wrack.



In the Swash Zone

Commonly called the sand crab or mole crab, *Emerita analoga* is the epitome of burrowing efficiency. While other crabs are able to move in any direction, the sand crab can only move backwards. Its rear legs are modified as paddles, which gives it very good swimming capability, an essential skill when it is stirred out of the sand by crashing waves. The sand crab burrows tail first into the sand, with its head near the surface facing seaward. Only its eyes and antennae are held above the sand. When a wave recedes, its large antennae are unfurled to form a "V" through which the backwash is sifted for phytoplankton. The entire population moves up and down the beach with the tides, with the greatest concentrations nearest the breakers.

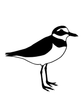


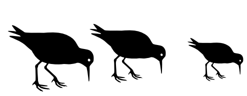
Beyond the Tides

Though unseen by the beach stroller, there are several fish species that live in the sandy beach habitat. Skates, rays, and other flatfish patrol for prey just beyond the waves. When the tide is in, they have access to the intertidal crabs, clams, and worms. By flapping their "wings," they create their own surf-like action to blow away the sand and expose their prey. Some fish feed just behind the leading edge of the breaking waves. Surfperches and sand eels take advantage of the dislodging force of the waves to grab crabs and worms otherwise unobtainable.

Above the Tides

Probably the most familiar birds of the sandy beach are the little Sanderlings. These are the birds that move like little wind-up toys, darting back and forth at the edge of the crashing surf. With their bodies held motionless and their feet a blur, Sanderlings seem as anxious to avoid getting wet as they do to snatch an exposed mole crab or worm. Sanderlings aren't equipped to probe deep into the sand, so they try to find prey as it is stirred up by the waves and before it can re-burrow. The larger Willets with longer bills are less restricted to finding loosened prey at the sand surface. The tips of their bills are sensitive and are able to feel tiny vibrations that indicate prey deeper in the sand.





Higher on the beach, above the wrack, small Snowy Plovers chase about in the dry sand and beach wrack to snatch insects and beach hoppers from the surface. The most noticeable birds of the beach, and certainly the loudest, are the ubiquitous gulls. These scavengers are opportunists that feed on most any food item tossed on the shore – whether by wave or picnicker.

Human Impact

Beaches are in constant motion with sand moving seasonally on and offshore and along the coast in the prevailing direction of wind and waves. A shoreline that moves 25 meters in 50 years gets noticed when it is near a manmade structure. Seawalls and groins have been used in the past to try to control the natural processes of erosion and deposition of sand. Building of any structure in the Sanctuary is strictly regulated, because it is very hard to correctly predict how the sand and water will flow around the new structure.

The sandy beach is a major deposition area for not only algae in beach wrack but for anything that floats at the surface – flotsam and jetsam of merchant vessels and uprooted trees. Plastic and garbage on the beach may be mistaken for food by birds and other animals. Oil from spills and chronic pollution washes onto sandy beaches, coating the sand grains and animals. Toxic chemicals of oil kill many animals and may pollute the sandy beach for many years.

Gulf of the Farallones National Marine Sanctuary

Through the Beach Watch program, the Gulf of the Farallones NMS monitors the beaches along its boundary with the help of volunteers. Every two to four weeks dedicated citizen scientists survey their beaches for marine life and human activity. Fluctuations in bird and marine mammal populations are detected in the long-term database. Volunteers find and report oil or tarballs on a beach and collect and preserve oil samples as evidence. The Beach Watch program provides additional eyes and ears for the Sanctuary's sandy beaches.

Observations and Predictions of Tides

Objective
Students will investigate the change in water level due to the tides. They will use local tide tables to graphically represent the water level and will compare observations to predictions. Students will use online data to analyze the current tidal conditions.

Materials
Tidal predictions for your location.
- San Francisco tidal predictions at
  http://www.co-ops.nos.noaa.gov/tab2wc1a.html#124
- Current San Francisco water level observations and predictions at
  http://tidesonline.nos.noaa.gov/monlist.shtml?region=wc

Butcher paper
Rulers
Colored pens, pencils, or crayons

Background
We have all heard about the tides – that it is the rise and fall of sea level. But have you or your students actually observed the change in water level? In this activity, student will investigate tidal predictions, tidal observations, and see for themselves the impact of the tides on the shoreline.

Activity
1. Have your students describe the tides and what causes them on a piece of paper using words and pictures. Give them about 5 minutes to do this.

2. Have groups of students discuss their ideas about tides.

3. Present the tidal predictions for a nearby location for the next 3 days or the predictions for October, 2001 at the Golden Gate. Ask the students what they would observe on the sandy beach during these 4 days.

San Francisco (Golden Gate), California
Tide Predictions (High and Low Waters) October, 2001
NOAA, National Ocean Service

Day	Time	Ht.	Time	Ht.	Time	Ht.	Time	Ht.
1 M	523am	L 0.7	1203pm	H 5.3	545pm	L 1.4	1158pm	H 5.4
2 Tu	552am	L 0.9	1225pm	H 5.4	616pm	L 1.1		
3 W	1238am	H 5.2	621am	L 1.2	1249pm	H 5.5	649pm	L 0.9
4 Th	120am	H 5.0	651am	L 1.6	115pm	H 5.6	725pm	L 0.6

Tidal predictions are available in the newspaper near the weather predictions, in tide books available from the Gulf of the Farallones National Marine Sanctuary, or on the Internet at:
http://www.co-ops.nos.noaa.gov/tp4days.html.

4. Discuss what the tidal predictions mean. The time in this chart is given with a.m. and p.m. so you know if it is morning or afternoon; other prediction sources may use a 24 hour clock. The height of the tide is related to the mean low water level. A height preceded by a minus sign means that the water level will be below mean low water. No minus sign indicates the height of the water above mean low water.

5. Students should think about how the sand is covered and uncovered during the tidal cycle, or how the water level on a dock or pier changes. Student groups should make life-size representations of the tidal predictions. Make a graph of the tidal predictions on butcher paper. The y-axis should be tidal height, and the x-axis should be time of day.

   It is important for students to see the vertical height that the water is moving. Compare the vertical distance and the horizontal distance that the water covers and uncovers.

6. Ask what they notice about the cycle of the tide. Does it change over a day? Compare the height of the highs and lows. How many hours is one cycle? Why is the cycle not a factor of 24 hours (one solar day)? Remember that the tides are dominated by the Moon and a lunar day is 24 hours and 50 minutes. Why is there a difference? Because the Earth is spinning on its axis as the Moon is rotating around Earth.

   On the California coast, the tides are mixed semidiurnal. This means that there are 2 uneven high tides and 2 uneven low tides each tidal day.

   Spring tides have the highest tidal range with the highest high and lowest low tides. This occurs twice each month during the full and new moon when the Earth, Moon, and Sun are in a line. During the first and third quarter of the moon, neap tides have the lowest tidal range with the lowest high tides and highest low tides during the month.

7. Tidal predictions are predictions, just as the name says. What is actually observed may be different because of current weather conditions and because pedictions are based on previous observations. Students can compare tidal predictions and observations in several places in San Francisco Bay on the Internet. In this activity, the tides at the Golden Gate Bridge will be analyzed, although you may wish to look at another location that is closer to your school.

8. Go to http://www.co-ops.nos.noaa.gov/sfports/picsgif.html

   This page lists all the real time data available in San Francisco Bay. Click on the button for the water levels at the Golden Gate (Figure 1 - May 7, 2001). The water level figure shows the predicted water level (blue line) for the last 18 hours and the next 6 hours and the observed water level (red +) for the last 18 hours. Is there a difference? Have your students give suggestions as to why.

9. Go to http://tidesonline.nos.noaa.gov/monlist.shtml?region=wc

   Select San Francisco to view the observations and predictions of water level, and observed winds, air temperature, and air pressure (Figure 2 - May 13, 2001). You should use the current information if you have web access. Use wind and air pressure data to help explain differences between the observed and predicted water level.

10. Water level changes every day, at a different time and different height. We often don't think about what is going on at the shoreline when we are not there. Here is a chance for your students to keep an eye on the water. Assign each student one week during the school year. During their assigned week, they need to check the tidal predictions and observations each day. They should make some type of report of their

observations of the water level each week. Some suggestions are to make a graph of their observations; to describe if it was a week of spring or neap tides; to record the water level with photographs or measurements; and to observe the shoreline conditions in person or through online cameras (There is a camera at Año Nuevo State Park (http://parks.ca.gov/default.asp?page_id=523) although the camera does not always seem to work and the directions might be a bit confusing.)

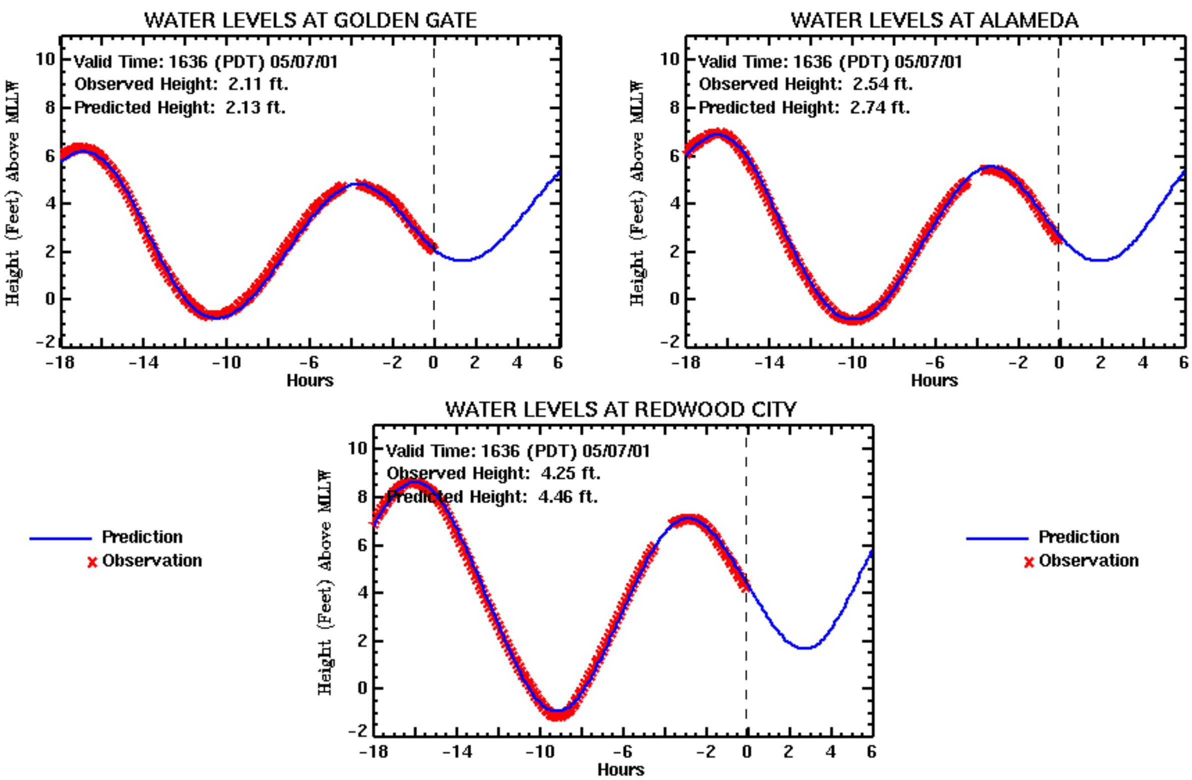


Figure 1. Water level in the San Francisco Bay on May 7, 2001.
From http://co-ops.nos.noaa.gov/sfports/

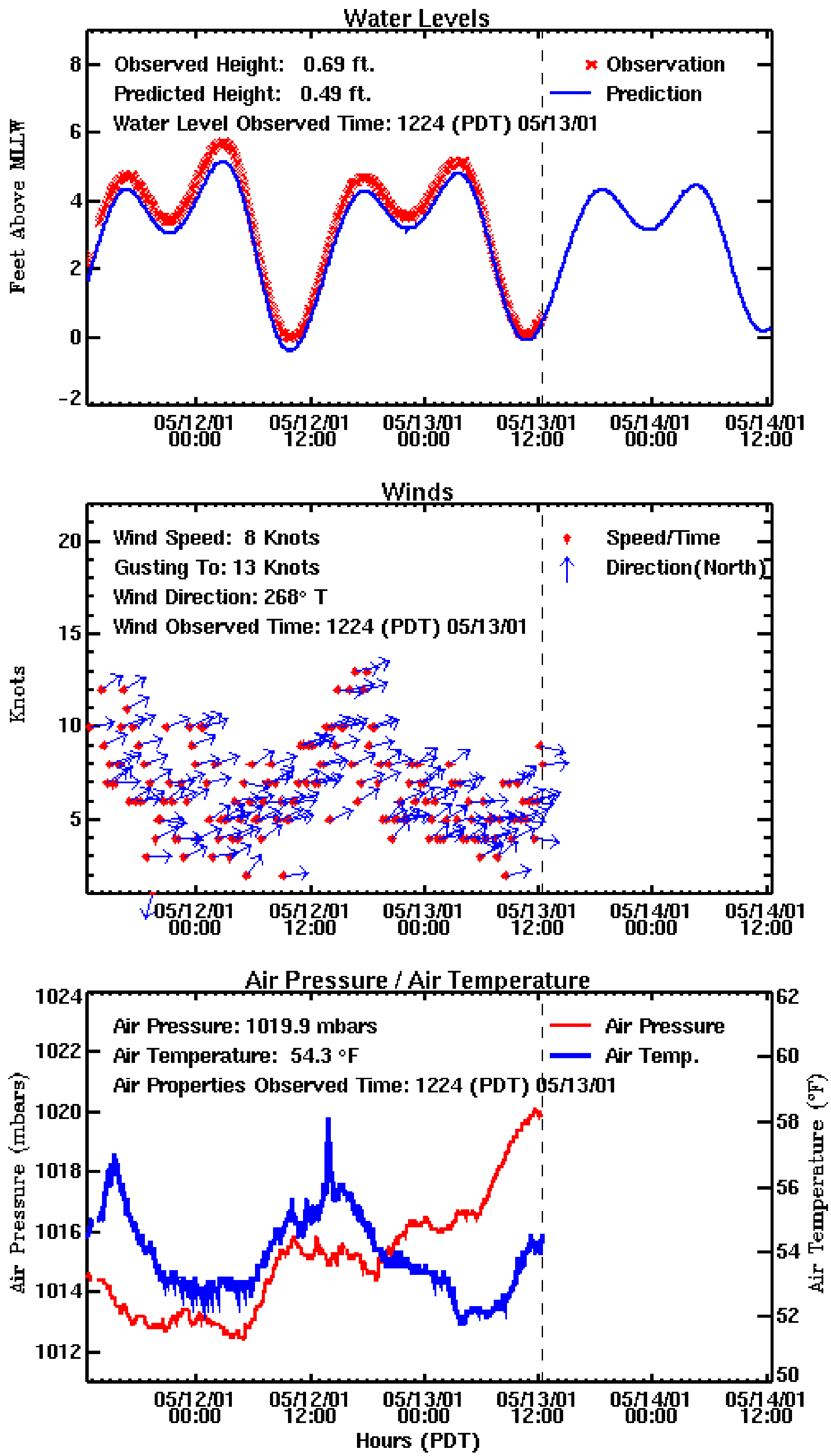


Figure 2. Oceanographic Conditions at San Francisco on May 13, 2001.
From http://tidesonline.nos.noaa.gov/monlist.shtml?region=wc

What is the Shape of the Beach? Beach Profile Survey

Objective

Students will measure the slope of the beach and learn about the processes that change the slope of the beach.

Materials

Compass
GPS meter
Tape measure (meters)
For each group:
Transit rods: 4 meter sticks (2 connected to each other) or 2 rods marked every 1 cm (minimum length 6 m)
(a single "2x4" cut in half lengthwise, garden stakes, dowel rods, or aluminum poles from a volleyball game)
Line level (from hardware store for <$2)
String/Line (1.5 meters in length) (should not stretch too much)
Survey flags or any marker that can be used on the beach
Data sheet, clipboard, pencil
Spreadsheet software or graph paper
Appropriate clothing and gear for getting wet

Background

The shape and height of beaches change seasonally. During the winter, sand is removed from the beach by the crashing waves of winter storms. Beginning in the spring, sand is redeposited on the beach forming a larger beach in the summer. By measuring the beach shape at the same location over time, the change in the amount of sand can be determined. Scientists study beach profiles and water level over many years to determine the change in sea level.

A teacher can collect a long-term data set with different classes by choosing a starting point that can be easily relocated during the next season or year. Depending on number of students, a class may survey several transects. Students in later years can compare their data to previous classes.

At the beach, students will determine the slope of the beach along a transect using simple tools to measure the height and distance from one spot to the next. In the classroom, students will plot the data they collected into a graph of the beach profile. Students should work in groups of at least 4 students.

Activity

Before you get to the beach

1. Explain procedure before going to the beach.
2. Divide students into groups of at least 4 people. Two students will hold the transit rods, one student will level the string, and one student will record the data.
3. Review the data sheet and what needs to be recorded.
4. Practice taking measurements outside on a small hill or even a wheelchair ramp.
5. Discuss safety and how far the students should go into the water, if at all.

At the beach

1. Select a starting point. This location should be easy to relocate for future sampling. It is best to use a permanent object that will not be eroded as a reference to the starting point. A tree, a post, or a building are good reference points. Using a compass and tape measure, select a starting point that is on the sandy beach, and record its position to the reference points. Record this information for each transect line. Each student group should survey a different transect line.
2. Set the transect line perpendicular to the shoreline. Mark this line with survey flags or a stick at the water line. If you have multiple transects, the lines will not be parallel if the beach is not straight. Record the compass bearing for each transect line. The distance between transects lines should be recorded also.
3. Tie the string to both transit poles so there is 1.0 meters of string between them. The string should be able to be moved up and down easily. If the beach is very long and very flat the string (distance between measurements) can be increased to 1.5 or 2 meters.
4. Place one transit pole at the starting point, and the other will be 1.0 meters along the transect line toward the water.
5. Place the string on the starting point transit pole at the 1.0 meter mark. Using the line level, make the string level by raising or lowering the string on the other transit pole. Record the height on the data sheet as the foresight height.
6. Keep the second transit pole in place and move the starting transit pole to the other side, closer to the water. Keep the string at the same level on the second transit pole and make the string level by raising or lowering the string on the transit pole closest to the water.

   By surveying this way, the string is kept at the same height along the beach. Students measure the vertical distance from the string down to the sand. By keeping the string in the same place as the poles step down the beach, the string will stay at this same height. (See the sample data and figure).

7. Continue moving the transit pole that is farther from the water, leveling the string and recording the foresight measurement. Record any special observations such as beach wrack and water level.
   - Distance measured is the distance between the two poles.
   - Initial height is the height of the string on the starting pole. All the vertical measurements will be calculated with this initial height. If the beach drops more than 1 meter, the string may need to be readjusted. The new initial height must be recorded and used in calculations for the points after the readjustment.
   - Foresight is the vertical height of the level string on the second pole.

8. Survey into the water as far as possible. Think about safety (waves) and how wet can the students get (cold).
9. Before you leave the beach, make sure the data sheets have been completely filled in and that you have the data to take back to the classroom.

In the classroom

1. Students should enter the data into a spreadsheet program or calculate and graph the data by hand.
2. Calculate the elevation for each point along the transect by subtracting the foresight from the initial height. This will result in a negative number for most of the beach. Calculate the cumulative distance for each point by adding the previous cumulative distance to the distance to the that point. If the string is 1.0 meters, the cumulative distance will increase by one for each point.
3. Students should make graphs of the distance (x-axis) vs. elevation (y-axis) for each transect. Some spreadsheet programs will plot a 3 dimensional graph which would show the whole beach with more than one transect.
4. Make comparisons with data collected at the same beach during other seasons or years.

Extensions

Make a physical 3-dimensional model of the beach. Make sure the scales on the x and y axis are equal (i.e. 1 inch vertical equals 1 inch horizontal) or at least indicate the scale in both directions. Trace the graphs of the transects onto cardboard or card stock. Cut out the shape of the beach for each transect. Place the graphs at the appropriate distance from each other and cover with a piece of paper to represent the beach. Label the water level, beach wrack line, and any other features observed at the beach.

Mathematics. Here is a chance for students to think about what the numbers that they measured mean in terms of geometry. You could collaborate with the math teacher on the analysis of the data. Students should be able to determine the angle of the slope of the beach and the distance between 2 points along their transect. The survey measures the horizontal distance. Students can calculate the actual distance along the sloping beach.

Beach Profile Data Sheet

Date ____________ Group Members ____________

Profile Location: ____________

Distance ____________

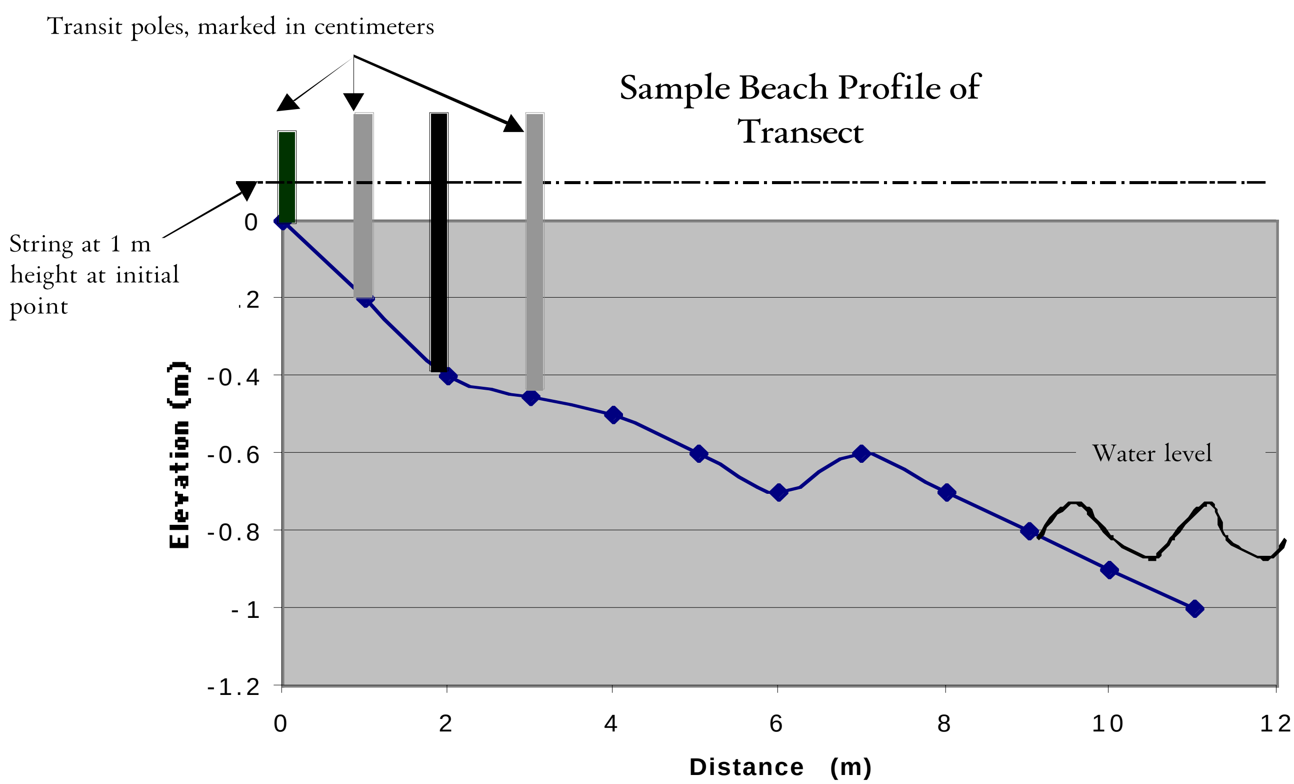
Compass Bearing ____________

time of high/low tide ____________

Notes	Distance (m) measured	Cumulative Distance (m) calculated	Initial Height (m) measured	Foresight (m) measured	Elevation (m) calculated
starting point	0	0	1	1	0

Sample Data of Beach Profile

Notes	Distance (m) measured	Cumulative Distance (m) calculated	Initial Height (m) measured	Foresight (m) measured	Elevation (m) calculated
starting point	0	0	1	1	0
	1	1	1	1.2	-0.2
Beach Wrack	1	2	1	1.4	-0.4
	1	3	1	1.45	-0.45
	1	4	1	1.5	-0.5
	1	5	1	1.6	-0.6
Wet Sand	1	6	1	1.7	-0.7
	1	7	1	1.6	-0.6
	1	8	1	1.7	-0.7
Water Level	1	9	1	1.8	-0.8
	1	10	1	1.9	-0.9
	1	11	1	2	-1



The line on the graph represents the shape of the beach. Note the vertical exaggeration (0.2 m vertical equals about 1 m horizontal).

Activities at the Beach

There are a million and one things that you can do at the beach, so you need to decide which of the following fit best with your students and time at the beach. Some of these take only a short time and can be done after a beach profile survey, while others should be followed up in the classroom. Classroom activities that relate to the sandy beach habitat include stream table experiments focusing on erosion and sediment transport and wave table experiments focusing on how waves form, travel, and break at the shoreline.

Measuring Tidal Change. Mark a stake in centimeter intervals or use a meter stick. At the beach, drive the stake into the sand so that the water covers the lower part of the stake after the waves have receded. Have one student record the water level every 10 minutes while you are at the beach. Is the tide coming in or going out? Measure the vertical height change as the tide changes. In the classroom, graph the data.

Longshore Currents. Is there a longshore current? This is the current that runs along the beach, driven by the waves and the angle at which they reach the shoreline. It can be observed with a floating object. We recommend an orange or apple because it will not pollute the beach if you cannot retrieve it at the end. Measure the speed of the current with a watch (or stop watch) and tape measure. Record the start time, stop time, distance the orange traveled, and the shape of the shoreline. Speed (velocity) is distance divided by time. Different student groups can measure and then compare their results at the same location or along different parts of the shoreline.

Oil Spills. How would a small oil spill affect the beach? Use non-polluting material (leaves, shavings, or sawdust) to represent drops of oil. Pick a dock or some prominence and throw the "oil" into the water. Observe what happens. How fast does it spread? How big of an area does it cover? Does it reach the sandy beach?

Bird Behavior. Stop and watch the birds. How many different species are there? What are they doing? Choose a group to watch for 10 minutes. Observe their behavior of feeding, walking, grooming, and flying. Compare different species. Bring binoculars and bird identification keys.

Beach Wrack Assessment. How much beach wrack is on the beach? Record the amount of wrack (none, low, medium, and high) every 5 meters as you walk along the beach. What is the beach wrack composed of? Is it more abundant in some places than others? Are the birds feeding on the wrack? Review the beach wrack amount and composition in relationship to the bird behavior and longshore currents.

Sand Analysis. Sand varies in grain size and composition. Take a small sample of sand and look at it. An easy way to collect and label samples at different spots along the beach is with cellophane tape and 3x5 cards. Make a loop with the tape, attach it to the card, and then press it into the sand. Write on the card where the sand is from. You can also collect sand in empty film canisters. While at the beach, look through a magnifying glass or take it back to the classroom to look through a microscope. Compare samples from the swash zone, high tide, and farther up the beach. A set of nested sieves can be used to determine the amount of different grain sizes.

Students can learn about the origin and age of the sand by examining the individual grains. A few suggestions are to examine the mineral composition, color, luster, clarity, and texture. There are groups that collect and trade sand, including some schools. Look at sand from different beaches in your area or from other coastlines. Check out the International Sand Collectors at http://www3.ewebcity.com/aaronm1063/ for more information.

Credits: Coastal Awareness: A Resource Guide for Teachers. NOAA.

Sandy Beaches
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 sandy beach *habitat* in the Gulf of the Farallones National Marine Sanctuary. The production of this slide show was funded by the *PUERTO RICAN* Oil Spill Restoration Fund.
2	Map of Sanctuary	The Gulf of the Farallones is located just outside of San Francisco Bay. The northern boundary is at Bodega Head and the southern land boundary is just north of Muir Beach at Rocky Point. Point Reyes National Seashore and the Golden Gate National Recreation Area manage most of the land bordering the Sanctuary. The boundary of the National Marine Sanctuaries is at the mean high tide level.
		Another National Marine Sanctuary – the Monterey Bay National Marine Sanctuary protects the shoreline south of the Gulf of the Farallones Sanctuary.
3	Point Reyes (Kip Evans)	Sandy beaches are where the ocean and land meet. They appear to be devoid of life except for the children you may see chasing waves, but there is much more than meets the eye.
4	Birds	Birds are the dominant vertebrates, while crabs and worms live in the sand.
		Some questions for you to think about as you view the images of the sandy beach. Why are some beaches sandy and others full of rocks? Where does the sand come from? There are no plants, so where does the food come from? And how do humans impact the sandy beach?
5	Waves	The water beating against the shore and the small particles of rock create the habitat of the sandy beach. Physical and geological processes influence the evolution and maintenance of the sandy beach. Today you will learn about these processes and the organisms that make the sandy beach their home.
6	Waves at shore	Water flows toward the shoreline, back and forth, and waves crash. We must look at the waves, because they move the sand and the water on the beach. Where do the waves come from? Wind-driven waves may form right near the shoreline or they may be generated halfway around the world. As the wave moves through the water, water molecules themselves move only a small distance as the wave passes by.
7	Rope	A good model to think about when trying to understand ocean waves is a wave moving along a piece of rope. If you held one end of the rope and created a wave, the rope would go up and down while the wave moves past. In a similar fashion, the water particles move up and down as a wave passes by.

8	Waves at shore	The wind-driven waves seen at the shore are different than oceanic currents. Currents actually move the water particles from one location to another, while waves move through the water and the water particles themselves are not transported very far. In the open ocean, the waves at the surface do not impact the sea floor, nor does the sea floor impact the waves. But as waves move over the continental shelf and into the shallower water, the properties of the waves change. It begins to interact or "feel" the sea floor. The wave slows down, the wavelength decreases, and the wave height increases as it interacts with the sea floor.
9	Breaking waves	The increased wave height means that waves look bigger as they get closer to shore. You've all probably seen waves break – why do they do this?
10	Wave tunnel	The wave gets too tall and it becomes unstable. The top of the wave crashes over the top of the crest of the wave to the delight of surfers.
11	Surf at Point Reyes	As waves come to shore, the speed of the wave changes with the depth of the water below. Most shorelines are not straight so when the waves come into shore, one part of the wave is over deeper water and another part is over shallower water. The part of the wave over deeper water is faster and catches up with the shallower part of the wave. This actually bends the wave to be parallel with the shoreline and is called refraction. As the wave bends or refracts along the seashore, a current develops that runs parallel to the shore. This is called *longshore drift*.
12	Eroding cliff	Back to one of our first questions – where does the sand come from? It comes from everywhere! Sand is the broken down remains of the Earth. It may be from mountains, carried down to the ocean in rivers and streams. Shells and bones are broken apart and become part of the sand. The hard parts of *plankton* end up in the sand. Sandy beaches near active volcanoes are often covered in black, volcanic sand. In the Gulf of the Farallones National Marine Sanctuary, the sand is from north of the region and from the San Francisco Bay watershed. It is made of mostly the mineral quartz that was eroded from rocks on land.
13	Stinson Beach (R. Frear)	Sand is brought to the beach by the creeks and rivers and then is distributed along the shoreline by the waves and longshore current. The waves carry the sand grains to the shore and build them into a beach. The speed of the water and size of the sand grains determines when the sand is picked up or deposited. A key point to remember is that it takes more energy or speed to carry larger particles of sand and less energy to carry smaller particles.
14	Cobble beach	Here we have a cobble beach with large particles. It took a lot of energy to build this beach. High energy waves move, or deposit, the large sand and cobbles while at the same time they carry away the smaller sand.

15	Beach (R. Frear)	Each breaking wave picks up sand and moves the sand particles up the beach face. Also, some sand flows like a river along the shoreline, transported by the longshore current. In the Gulf of the Farallones region, the longshore current is primarily southward. The combination of wind-driven currents and tidal currents during certain times of the year deposit sand, dead birds, and other debris on the beach.
16	Tarball	On the south side of Point Reyes, the sandy beaches are areas of high deposition. Tar balls, which are semi-solid pieces of fuel and crude oil, are deposited on the beaches. Fresh tarballs are deposited in the fall and early winter. The high wave energy of the winter storms uncovers old tarballs deposited years ago. In the spring, the slower waves leave more sand which recover the old and new tar balls.
17	Summer beach (L. Grella)	This is a picture of Drakes Beach in the Point Reyes National Seashore which borders the Gulf of the Farallones Sanctuary. What do you notice about this beach? It is very wide and covered in sand. Have you ever gone to a beach during the summer when the beach is wide and full of sand and then ….
18	Winter beach (L. Grella)	returned during the winter and there wasn't much beach left? You may think that it is just because of the *tide* but it probably is not. Winter storms have strong waves that crash down upon the sandy beach. These waves take sand away from the beach and deposit it in deeper water. Animals that live at the sandy beach must be able to survive the changing habitat.
19	Earth and Moon	There is one more physical process that you must keep in mind when thinking about the sandy beach habitat, and that is the tides. As the Earth turns, the gravitational pull of the Moon and the Sun cause the ocean surface to rise and fall every day. What would you or a bird see if you were to sit on the beach all day? The water level would move up and down the beach, covering and uncovering the sand every six hours. The waves continue to come to shore and break as they approach the shoreline, arriving every 10-15 seconds. The waves are independent of the tides. What is a high tide? That is when the water level is high on the beach covering most of sand and the animals that live there. What is low tide? That is when the water level is low and uncovers the sand.
20	Tide chart	Here is a graph of the water level in San Francisco for 5 days in April 2001. The x-axis is the time and date and the y-axis is the water level. There are 2 highs and 2 lows each day, but the time and height changes each day. The blue line in the predicted tide and the red line is what was observed.

		The changes in the tide level take about 6 hours here. Along the Pacific coast of the United States including the Gulf of the Farallones, there are 2 high tides and 2 low tides every tidal day. A tidal day is 24 hours and 50 minutes. Does anyone know why it is longer than 24 hours? It is because the tides are dominated by the Moon's revolution about Earth rather than Earth's rotation about its axis which takes 24 hours.
21	Interstitial animals	Let's look at the organisms that make the sandy beach their home. First are the smallest members of this community called *interstitial* organisms. The space between sand grains is called the interstitial space. That is where these very small animals live. There are small worms, very flat crustaceans, and even tiny sea cucumbers. They live in the moist sand and feed on the dead organic material that accumulates in the sand.
22	Worms	There are also much larger worms which live in the sand. You have probably seen the holes left by the worms when they move to the surface to breathe and feed from the crashing waves.
23	Sand crab	A favorite food for many of the coastal birds, the sand crab, lives in the sandy shore between the high and low tide levels. They are found where the waves wash up and down the beach in the zone called the *swash zone*. Large groups of these animals move along the beach with the longshore movement of the sand.
24	Female sand crab	When spring arrives, great numbers of sand crabs can be found at the shoreline. They breed from February to October, usually at night. The females carry the bright orange eggs for about a month.
		Sand crabs seem to disappear from the beaches in the wintertime, because they are probably in offshore sandbars. The winter storms that transport the sand offshore also carry the sand crabs living in the sand.
25	Swash zone	Sand crabs live in the swash zone between the highest and lowest extent of the waves. Above and below this zone are predators – above are the birds such as the Sanderlings, and below are the surfperch. As the tide rises and falls, the sand crabs stay in the swash zone for safety.
26	Sand Crab Diagram	The sand crab burrows backwards into the sand, up to the level of its eyes. Sitting with its back to the shore mostly under the sand, the crab *filters* plankton with its feather-like antennae.
27	Dinoflagellate	What do the sand crabs eat? They eat *dinoflagellates* which are a type of phytoplankton or floating single-celled *algae*. These phytoplankton are one of the primary producers in the sandy beach *food web.*
28	Beach hoppers	Moving up the beach above the water level, you've probably seen beach hoppers bouncing about. During the day, they hide and remain out of sight under the sand. At night, they come out to eat seaweed. It is much safer at night because the birds cannot see them.

Beach hoppers are in the same taxonomic group as crabs and copepods called crustacea. Its curved body and long jumping legs allow it to hop several feet with one jump. The beach hopper digs tunnels in the sand for its home and uses its legs to kick.

29 Beach wrack

Another major food source for the animals of the sandy beach habitat is the *beach wrack* which is the floating kelp, algae, and plants that washes up onto beaches. The wrack serves as a protective covering as well as an important food source for many small scavenging animals, including the beach hoppers and flies.

30 Beach wrack

The kelp is broken into smaller particles by the waves, and pieces of *organic* matter settle to the sea floor, providing food for worms and clams. This organic matter is called *detritus.*

So far we have talked about two food sources – the plankton that the sand crabs eat and the beach wrack that the beach hoppers eat. A third group of algae in the sandy beach habitat are single-celled algae that live on the sand. These algae are similar to their planktonic relatives, yet they are much less abundant.

31 Stinson

Sand dunes are the backdrop along many sandy beaches. The animals living there such as raccoons and foxes venture onto the sandy beach to feed on the beach wrack during the night.

At the Point Reyes National Seashore, researchers are working to restore the coastal dunes and are monitoring two endangered plants that are found in the sand dunes.

32 Moon Snail (Kip Evans)

Moving back out and deeper into the water is the *subtidal* zone which is past the *breakers.* Moon snails can be found there. These are very large footed snails that eat clams and other mollusks in the sand.

33 Sand Dollar

Dead sand dollars can be found washed up on the sandy beach. They also live beyond the breakers on the sandy bottom. They feed on the detritus and bottom algae. Or where the water is moving quickly, they stand vertically and become suspension feeders, eating the floating plankton and algae.

34 Surf perch (T. Chess)

One of the major predators of sand crabs are surfperch. They live just beyond the breakers and around pilings, feeding on the animals in the sand. They are also a favorite catch by people fishing from the sandy beach.

35 Willet

The sandy beach habitat is a feeding ground for many birds. There isn't much protection, so prey animals burrow into the sand and come out only at night if at all.

This Willet is a common visitor to sandy beaches, as well as more protected bays and estuaries. Willets have long, straight bills, perfectly suited for foraging worms and other small burrowing animals. They can sense small vibrations with their bills to find their prey.

36	Sanderlings (R. Allen)	Sanderlings are small sandpipers found commonly along our beaches. These little birds spend hours following the waves up and back, as they feed between the tides. Look at the length of their beak. It is short so they can only reach the animals in the top of the sand, primarily worms, but some sand crabs also.
37	Snowy Plover	High up on the shore you might see a Snowy Plover. These little birds breed along the open beaches and dunes. They lay their eggs in the upper reaches of the beach. Some areas are restricted from humans and dogs to protect these birds. Notice how well these birds are camouflaged on the beach. It is important to obey the restrictions even if you can't see the birds.
38	Surf Scoter	Often seen just beyond the breaking waves are Surf Scoters, called scoters because the scoot through the breaking waves. They dive into the water to capture mollusks and crustaceans to eat.
39	Gulls	Almost always at the beach, you will see gulls. Scavenging birds like gulls make a hearty meal on whatever food they can find. Gulls serve the important role of cleaning up dead fish and other organic debris left by the tide.
40	Brown Pelicans	Some of the sandy beach inhabitants are seasonal residents like these Brown Pelicans. They grace our local beaches during the summer months. Brown Pelicans are a common sight along Ocean Beach, gliding along the water's surface diving for a meal of fish.
41	Elephant seals	Other seasonal visitors to beaches are members of the pinniped family – the seals and sea lions. Elephant seals inhabit beaches on islands like the Farallones and coastal beaches. They use the sandy beaches to haul out to rest, breed, and give birth.
42	Humans on beach	This is the marine habitat that humans probably use the most. I'm sure you can all name a few ways. Recreation is the main use – for sun bathing, beach combing for seashells . . .
43	Horseback rider	horseback riding . . .
44	Kayaker	kayaking and surfing . . .
45	Clammers	. . .fishing and clamming.
46	Clammers with clams	Clams live in the soft sediments, both sand and mud bottoms. As you see here, collecting clams can be very disturbing to other animals. The clammers destroy worm tubes and other structures that the animals build and use to get food and oxygen.
47	Pollution	What other human evidence is found at the beach? Trash from our daily visits to the beach, plus all the trash that blows off boats or that ends up in the coastal waters after storms, ends up on the sandy beach.

48	People and garbage	Adopt-a-beach and other coastal clean-up programs involve the public and students like you in the protection of this important habitat.
49	T/V *PUERTO RICAN* (Herz)	Another human threat to the sandy beach and other shoreline habitats are oil spills. In 1984, the Tanker Vessel *PUERTO RICAN* was carrying 100,000 barrels of oil (lube oil, additives, and bunker oil) near the San Francisco Bay Entrance Channel, just outside of the Gulf of the Farallones National Marine Sanctuary. There were two explosions which broke open the tanker on the port side. The tanker was towed out to sea that same day to minimize the impact on the coastal environment.
50	Oil near Farallones (Herz)	The winds were calm and cleanup began the next day. After two days, the oil slick extended for one mile with a width of 200 yards and a sheen extending an additional mile. While being towed farther out to sea, the tanker broke in two with much of the oil cargo sinking to the bottom.
51	Oil very close Islands (Herz)	Six days later, a light brown slick surrounded the Southeast Farallon Island. Oil was seen on a few elephant seals and a dozen seabirds. There was even some oil on the beach.
52	Map of Oil Spill	Here is a map of the oil slick. The numbers on the map indicate the date in chronological order. The oil moved north of the islands and around Point Reyes. Some of the oil was removed from the seawater by skimming the sea surface. At the entrance to Bodega Bay – at the top of the map, deflection booms were deployed to protect the bay habitat.
53	Oiled Grebes (M. Brown)	Over 2,800 birds died from the oil spill. Here are two grebes with oil on them. Oil has an immediate effect on the birds. It coats their feathers which reduces the insulating effect of the feathers, and the birds often die of hypothermia. The toxic oil may also be ingested when the birds preen themselves.
54	Doran Beach	Oil reached Doran Beach, which is just to the south of Bodega Harbor, 10 days after the initial explosion. The biological community living there was probably impacted by the toxic oil. Students at Tomales High School have begun monitoring the sand crabs at this beach to establish a baseline data set of their abundance that will be used for management purposes.
55	Western Sandpiper (C. Zumwalt)	How do our needs as people affect the ocean? That is a question for you to help decide. At the edge of the land and the sea is this wonderful sandy beach habitat. You can help prevent oil from reaching the ocean by simply disposing of used oil properly. Also, you can join organized beach clean-ups, or just do it when you are hanging out at the beach.
56	Sunset	The sandy beach habitat near the Gulf of the Farallones represents an important biological community. 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
Sandy Beaches

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Selected Web Sites
Sandy Beaches

- Pt. Reyes Ecosystem Field Trip – Coastal Beach and Dune… http://online.sfsu.edu/~bholzman/ptreyes/tripcbd.htm
- Sandy Beaches along the Northwest Coast… http://lanecc.edu/science/zonation/sandybea.htm
- Sand … http://www.paccd.cc.ca.us/instadmn/physcidv/geol_dp/dndougla/SAND/SANDHP.htm
- Sandy Beach Intertidal Zonation… http://www.mcn.org/1/macpark/Lsn5.htm
- Beach Habitat… http://www.onr.navy.mil/focus/ocean/habitats/default.htm
- Sand Studies… http://www.netaxs.com/~sparky/sand_studies.html
- Sands of the World… http://www.chariho.k12.ri.us/curriculum/MISmart/ocean/sands.htm
- Musical Sand Index…http://www.bigai.ne.jp/~miwa/sand/index.html

<u>Tides</u>

- Current water level and predictions … http://tidesonline.nos.noaa.gov
- Everything about tides, observations, and predictions … http://www.co-ops.nos.noaa.gov
- Tidal predictions for the next year … http://www.saltwatertides.com
- Daily Tides and Current predictions … http://www.tides.com/cgi-bin/tcweb.exe