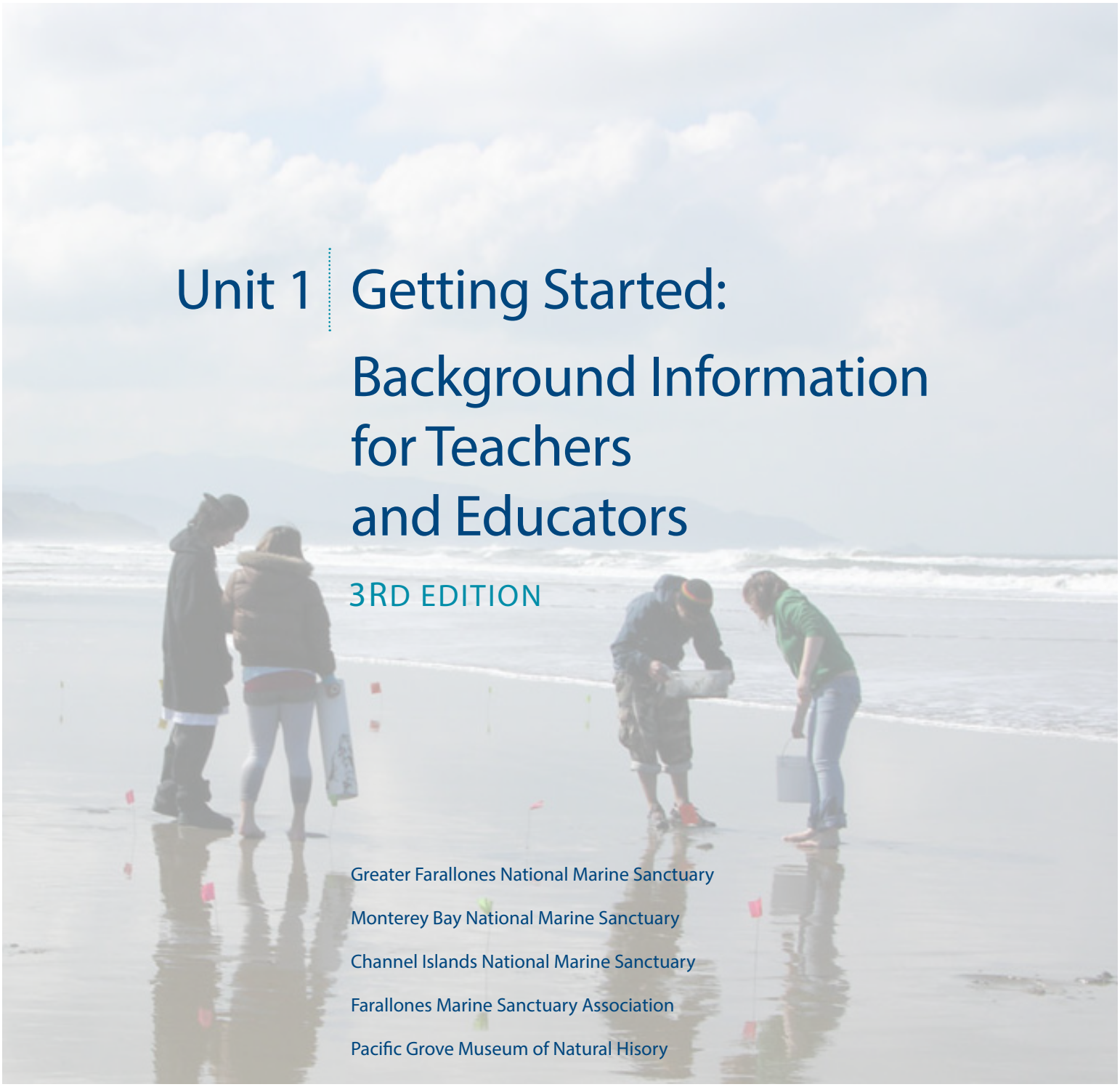
LiMPETS Sandy Beach Monitoring Program:
Curriculum Guide

National Marine Sanctuaries

NOAA



Unit 1 | Getting Started:

Background Information for Teachers and Educators

3RD EDITION

Greater Farallones National Marine Sanctuary

Monterey Bay National Marine Sanctuary

Channel Islands National Marine Sanctuary

Farallones Marine Sanctuary Association

Pacific Grove Museum of Natural Hisory

LiMPETS Long-term Monitoring Program and Experiential Training for Students

LiMPETS Curriculum

The LiMPETS curriculum was created by the Farallones Marine Sanctuary Association and updated by the Pacific Grove Museum of Natural History in partnership with many generous individuals and organizations. We would like to thank everyone for their countless and valuable contributions to this project.

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Using the LiMPETS Curriculum

The LiMPETS curriculum was designed for a broad range of participants; middle school and high school students, college undergraduates, environmental education organizations, and community groups. We encourage you to adapt and customize this curriculum to suit the needs of your unique class or group. However, there are some essential elements that are required in order to participate. At minimum, teachers or group leaders should set aside three days to conduct the essential elements of the program: one day for classroom preparation, one day for monitoring, and one day for data entry and assessment.

The following outlines both the required and optional elements of this curriculum:

Unit 1: Getting Started (required reading for teachers and group leaders)

Unit 2: Engage and Prepare: In-class Introductory Activities for Sandy Beach Monitoring

- ACTIVITY: The Essentials of LiMPETS In-class Preparation (required)
- ACTIVITY: Monitoring Mole Crabs in the Classroom (suggested)
- ACTIVITY: Investigating the "Crab" in Mole Crabs (optional)
- ACTIVITY: Sandy Beach Food Chain, Trophic Levels, and Biomagnification Game (optional)
- ASSESSMENT: Student Pre– and Post–Monitoring Reflection (optional)

Unit 3: Investigate and Archive: LiMPETS Sandy Beach Monitoring and Data Entry

- ACTIVITY: LiMPETS Sandy Beach Monitoring (required)
- ACTIVITY: Data Entry (required)
- ACTIVITY: Extension to Monitoring — Acanthocephalan Parasite Investigation (optional)

Unit 4: Analyze and Interpret: Data Analysis Activities for the Classroom (optional)

- ACTIVITY: Visualizing Data from a Great Day at the Beach
- ACTIVITY: Exploring Trends in Mole Crab Abundance Over Time

Unit 5: Communicate: Effectively Communicating Science and Taking Action in Your Community (optional)

- ACTIVITY: Student Pre– and Post–Monitoring Reflection
- ACTIVITY: Communicating Science Through Posters and Oral Presentations
- ACTIVITY: Taking Personal Action to Protect the Ocean — Us Vs Them

LiMPETS Program Overview & FAQs

LiMPETS Website Link – http://limpets.org/sb_involved.php.

WHAT IS LIMPETS?

LiMPETS (Long-term Monitoring Program and Experiential Training for Students) is an environmental monitoring and education program for students, educators, and volunteer groups. This hands-on program was developed to monitor the ocean and coastal ecosystems of California's national marine sanctuaries to increase awareness and stewardship of these important areas. Two distinct programs make up the core of the LiMPETS network: the Rocky Intertidal Monitoring Program and the Sandy Beach Monitoring Program. Both programs provide authentic, hands-on monitoring experiences that empower teachers, students, and the community to conduct real science and become ocean stewards. Approximately 5,000 students in California are involved with the collection of intertidal data as part of the LiMPETS network. From the Channel Islands in southern California to the Gulf of the Farallones in north-central California, students are using the same LiMPETS protocols to monitor their local intertidal areas. Visit the LiMPETS website at http://limpets.org to learn more about LiMPETS.

WHAT IS THE LIMPETS SANDY BEACH MONITORING PROGRAM?

Students taking part in the Sandy Beach Monitoring Program survey the distribution and abundance of the Pacific mole crab (Emerita analoga) at monitoring sites along the coast of California. Back at school, students enter their data into the online LiMPETS database. In addition, students are encouraged to analyze and share their results with the community through blogs, presentations, student-led tidepooling trips, and poster presentations at local conferences.

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WHY PARTICIPATE?

This program offers an in-depth and unique approach to learning and understanding the ecology of one of the world's most valued and dominant coastal ecosystems, the sandy beach. Through research-based monitoring, students develop their problem solving skills, gain experience using tools and methods employed by field scientists, and learn to analyze data. In addition, students make a valuable

contribution to science. This curriculum is aligned with Next Generation Science and Common Core Literacy and Math Standards for grades 6–12.

WHO CAN PARTICIPATE?

We work with many different types of school groups, informal environmental education and community organizations. The majority of our participants are high school teachers and students.

HOW MANY CAN PARTICIPATE?

Monitoring works best with groups of 5–25 students or volunteers. If there are more students in your class, Unit 3 includes tips for managing larger class sizes.

WHAT IS INVOLVED?

- Training: Teachers or group leaders complete a training by the local LiMPETS coordinator.
- Preparation: All participants are required to prepare for the monitoring experience using the tools and activities in this curriculum.
- Monitoring: We recommend that you explore your monitoring site and practice the monitoring techniques at least once before monitoring begins. How frequently should you monitor? That's up to you. Some participants monitor only once per year. Others monitor monthly.
- Data Entry: After data is collected, enter your data online at http://limpets.org.
- Analysis: Use the Data Analysis Unit in this curriculum and the online graphing tools to analyze results.
- Communication: Sharing your results is important too. Some participants attend scientific meetings, others create informational videos or lead community beach walks.

SUPPORT:

We provide direct support and a variety of free resources to communities within a 50-mile radius of a national marine sanctuary office. Offices are located in San Francisco, Santa Cuz, Monterey, and Santa Barbara. Services include equipment loan, assistance in the classroom and the field, support with data entry and analysis and more!

HOW DO I GET STARTED? See page 5 for more detailed information.

- Contact the LiMPETS coordinator in your area.
- Learn the protocols! Your LiMPETS coordinator will ask you to complete a training workshop before starting a LiMPETS program at your school or organization.
- Choose an established monitoring site. Your LiMPETS coordinator can help you.
- Borrow, build or purchase monitoring equipment.

TIME COMMITMENT:

A significant commitment by the teacher or adult leader is necessary to coordinate this project. Preparation is key! Learning to correctly perform the monitoring procedures can take time, but for the science geeks in your group, this is the best part.

Getting Started

LiMPETS Website Link – http://limpets.org/sb_involved.php.

Teachers and group leaders, the following outlines the necessary steps required to start a LiMPETS monitoring program at your school or organization.

1. Contact your local LiMPETS coordinator: Contact information available at http://limpets.org.

2. Attend a LiMPETS workshop or training: Visit the LiMPETS website for details about upcoming workshops in your area.

3. Choose a site: Choose a monitoring site that is of interest to you and your students. You can find interactive maps and detailed site descriptions on the LiMPETS website. Interested in participating in LiMPETS but located far away from one of our monitoring sites? Learn about our remote LiMPETS program on our LiMPETS website, http://limpets.org/sb_involved.php.

4. Determine a monitoring schedule: Review the monitoring protocols at your chosen site and determine a schedule for monitoring. Do you plan to monitor once per year, seasonally, monthly? You will need to conduct your surveys when the tide is fairly low (~ 3 ft or lower), ideally during the ebbing tide. For tide predictions online, visit http://tidesandcurrents.noaa.gov. You may also purchase a tide book such as Tidelog, www.tidelog.com.

5. Permits: No permit is required for monitoring; however, if you plan to collect crabs for parasite analysis, a fishing license or scientific collecting permit is needed. Your local LiMPETS coordinator has their own collection permit. So, if you do not wish to obtain a permit of your own, you will need to make sure that a LiMPETS coordinator can accompany you on your monitoring day(s).

6. Borrow, build, or purchase monitoring equipment: Before you start a LiMPETS monitoring program at your school or organization, you will need equipment. To borrow equipment, contact your local LiMPETS coordinator. Otherwise, you can build or purchase your own. A complete set of monitoring equipment costs approximately $200–$250 to assemble. To get started, use the equipment checklist on the following page (or at the LiMPETS website) to find out what equipment is needed. For instructions on how to build your own set of equipment, visit the website at http://limpets.org/sb_equip.php.

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7. Prepare your students in the classroom: The LiMPETS program requires that all participants are trained in-class prior to your scheduled monitoring day. There are two initial ways to prepare your students to monitor the sandy beach: a) schedule a classroom visit with your local LiMPETS coodinator and/or b) complete the

training presentation and the monitoring activities in this curriculum with your students.

8. Prepare your students in the field: Once you feel your students are ready, you may wish to visit your monitoring site to explore, practice monitoring, etc.

9. Monitoring day(s): If possible, your LiMPETS coordinator will be available to support you and your students in the field. Please review Unit 3 of this curriculum for protocols, data sheets, planning tips, student safety, and data quality control measures before you head to the beach.

10. Optional parasite investigation: In this optional extension to sandy beach monitoring, the presence of a parasitic worm (phlyum Acanthocephala) is investigated by collecting and dissecting mole crabs back in the classroom. A fishing permit or scientific collecting permit is needed to conduct this activity.

11. Data entry: Your data don't mean much without this important step. All participants are required to enter their data in the LiMPETS online database. Your LiMPETS coordinator will provide you with login information and data entry instructions. Entering LiMPETS data into one database ensures that everything is stored in one place and is available for analyses.

12. Post-monitoring activities: Students can create online graphs of their data, conduct analyses, and learn how to effectively communicate science to the community. The LiMPETS curriculum and website offers a broad range of tools, classroom activities and ideas.

A FEW NOTES ABOUT PREPARATION

Preparing yourself and your group for monitoring is essential for accurate results. Sandy beach monitoring can be wet, fun, and exciting. However, it can also be complicated and difficult to understand without proper preparation. The more often that you and your students visit the monitoring site, the more confident you will become with the monitoring procedures. Resources such as those found at the end of this unit will help you become more familiar with sandy beach ecology.

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LiMPETS Monitoring Sites
North-central California
www.limpets.org
Sandy Beach Monitoring Site
National Marine Sanctuary
SAN FRANCISCO
LOS ANGELES
Gulf of the Farallones National Marine Sanctuary
Cordell Bank National Marine Sanctuary
Monterey Bay National Marine Sanctuary
Channel Islands National Marine Sanctuary
PACIFIC OCEAN
Salmon Creek Beach - North
Salmon Creek Beach - South
Doran Beach
Limantour Beach
Stinson Beach
Muir Beach
Rodeo Beach - North
Rodeo Beach - South
Crissy Field
Baker Beach
Ocean Beach
Fort Funston
Linda Mar State Beach
Montara Beach
Surfer's Beach
Dunes Beach
Pescadero State Beach
Seabright Beach
Natural Bridges State Park
Sunset State Beach
Salinas River National Wildlife Refuge
Salinas River State Beach
Tioga St.
Asilomar Main Beach
Del Monte Beach
Tide Avenue
Refugio Beach
El Capitan Beach
Campus Point Beach
Goleta Beach County Park
Arroyo Burro Beach
Carpinteria State Beach
Silver Strand Beach
County Line Beach
RAT Beach
Cabrillo Beach
0
50
Nautical Miles
Contour Interval 100m
Tim Reed, GFNMS, 150601

EQUIPMENT CHECKLIST

LiMPETS Website Link – http://limpets.org/sb_equip.php.

	Quantity	Required Equipment	Optional Equipment	Notes or Purchase Info
PVC cores: 6-inch diameter	5	✔		Build your own. Instructions on LiMPETS website. Approx. $35 to purchase materials to make 5 cores.
6-quart clear plastic sieves	10	✔		Build your own. Approx. $50 to purchase materials to make 10 sieves.
Plastic calipers	5	✔		Available at Carolina Biological, www.carolina.com; #70-2647; $9 each.
2-gallon buckets	5	✔		Available at Carolina Biological, www.carolina.com, or Amazon, www.amazon.com; $5-10 each.
Marking / stake flags: approx. 15-inch	50	✔		Available at Ben Meadows, www.benmeadows.com, or Amazon, www.amazon.com; $13 for 100 flags.
50-m survey line (twisted poly rope): marked every meter	1	✔		Available at any hardware store; approx. $25.
10-m survey lines (twisted poly rope): marked every meter	5	✔		Available at any hardware store; approx. $25.
Measuring tape: metric	1	✔		Used to mark survey lines every meter. Available at most hardware stores.
Duct tape or permanent marker	1	✔		Used to mark survey lines every meter. Available at any hardware store.
Clipboards and pencils	5	✔		Available at any office supply store.
Field Log	1 copy	✔		Download from LiMPETS website.
Sand Crab Data Sheet	5 copies	✔		Download from LiMPETS website.
Random Number Table	1 copy	✔		Download from LiMPETS website.
Beaufort Wind Scale	1 copy	✔		Download from LiMPETS website.
Ambient Hand Held Wind Meter (includes built-in thermometer)	1–2		✔	Available at Ambient Weather, www.ambientweather.com; $23 each. Replaces need for thermometer and Beaufort Wind Scale.
Thermometer	1–2	✔		Available at Carolina Biological, www.carolina.com; #74-5435; Enviro-Safe Pocket Thermometer; $12 each
GPS	1		✔	Available at www.garmin.com; $150 and up
Bin to carry equipment	1		✔	Available at hardware stores; www.rubbermaid.com and www.target.com.
Collecting Permit	1	✔		A fishing license or scientific permit is required if collecting crabs for parasite analysis. Contact your LiMPETS coordinator for more information.
First aid, water, sunscreen, change of clothes			✔	…..for safety and comfort.

Why Monitor?

LiMPETS Website Link – http://limpets.org/why.php.

Our Beaches Are Important: The sandy beaches along the open coast of California are highly valued by people for the recreational and economic services they provide. However, beaches are often overlooked and underappreciated for the biodiversity of life they support. Several hundred species of invertebrates can be found on a single beach. These invertebrates are an important food resource for birds, mammals, and fish, including federally threatened species like the Western Snowy Plover. Beaches also provide unique and important ecological services. They filter seawater, recycle nutrients, support coastal fisheries, and provide critical habitat for endangered species such as turtles and birds (Schlacher et al., 2007).

Unfortunately, these unique and valued ecosystems are being increasingly threatened by human activities. Key threats to these systems include climate change and sea level rise, shoreline armoring and erosion, oil spills, sewage spills, litter, off-road vehicles, and wildlife disturbance. Monitoring sandy beach areas is therefore critical to evaluating the health of these coastal systems. With regional monitoring programs, we are able to assess the continued status of our sandy beaches and address current and future impacts better. California's National Marine Sanctuaries and partners have established a rigorous program for students to monitor one dominant and important sandy beach species, the Pacific mole crab.

Mole Crabs Are a Vital Part of the Beach Ecosystem: Mole crabs are one of the most important and abundant invertebrates on the beach. They can exceed 100,000 individuals m^{-1} on beaches of the central coast of California and elsewhere (Dugan et al., 2000). Mole crabs are also a vital link in the sandy beach food web and are important prey for birds, mammals, and fishes, including threatened species such as the Western Snowy Plover. Significant changes in mole crab populations can be an indicator of a larger problem in the ecosystem.

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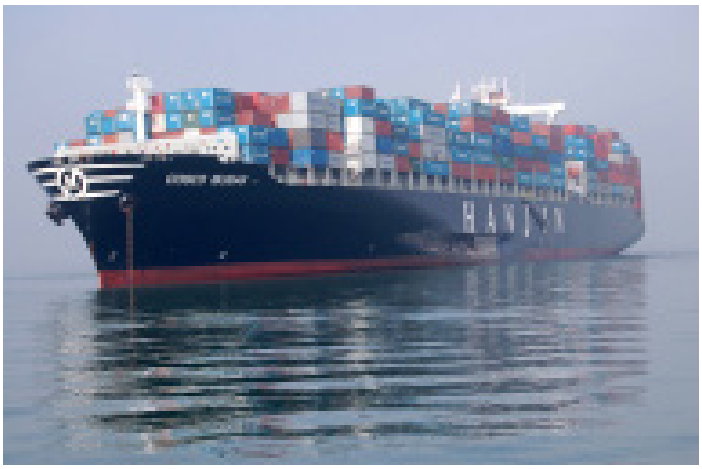
Monitoring Can Inspire Students: Getting wet and sandy at the beach, handling live mole crabs, taking careful and accurate measurements, using scientific tools…it is not for everyone. But for some, this is an experience of a lifetime. Some students develop a new love for science. Others develop a lasting connection with the ocean and the creatures living within it.

The Data Are Useful: Beyond the educational value of the LiMPETS program, the power of the LiMPETS network

lies in the large quantity of data that is being collected for California's national marine sanctuaries at more than 60 sites and over 600 miles of coastline. Annually, thousands of students and citizens compile baseline data against which future observations will be compared. By monitoring, students become the eyes and ears of the sanctuary, detecting changes in mole crab populations at beaches all along the coast and detecting possible problems, often before anyone else. Specifically, LiMPETS data is used in the following ways:

- For oil spills or other human-related events that can severely impact beach ecosystems. Though relatively uncommon, these events do happen. In 1984, the T/V Puerto Rican spilled 1.4 million gallons of oil into the water near the entrance to the San Francisco Bay. In 2006, two million gallons of untreated sewage spilled over a large swath of beach along the Santa Monica Bay — the largest spill of its kind in more than a decade. And in 2007, the Cosco Busan, a large container ship bound for South Korea, crashed into the base of the San Francisco Bay Bridge, spilling 58,000 gallons of heavy-duty bunker fuel oil into the San Francisco Bay. LiMPETS data can be used in these cases to help assess damage to affected beaches. After the 2007 Cosco Busan oil spill, LiMPETS data were requested by scientists and resource managers to help assess the damage caused by the spill.
- For California's system of marine protected areas (MPAs): LiMPETS received funding from the state of California to help determine how effective the new MPAs are in protecting fish, invertebrates, birds, and other natural resources. LiMPETS data has, in collaboration with other scientific studies, established baseline of data for sandy beach and rocky intertidal areas within the MPAs in the South Coast and North Central Coast regions of the state. For more information about MPA baseline reports visit: http://oceanspaces.org/monitoring
- For the national marine sanctuaries: LiMPETS data help California's national marine sanctuaries identify long-term trends in intertidal regions, detect emerging issues, and may inform resource management decisions.



NOAA

In November 2007, the M/V Cosco Busan struck the San Francisco Bay Bridge. The collision tore a 200-foot hole in its hull and spilled 58,000 gallons of heavy fuel oil into San Francisco Bay.

References

- Dugan, J. E., Hubbard, D. M., Engle, J. M., Martin, D. L., Richards,D. M., Davis, G. E., Lafferty, K. D., Ambrose, R. F. (2000). Macrofauna communities of exposed sandy beaches on the southern California mainland and Channel Islands. In D. Browne (Ed.), Fifth California islands symposium, outer continental shelf study (pp. 339–346). Camarillo, CA: Minerals Management Service (99-0038).
- Schlacher T.A., Dugan J.E., Schoeman D.S., Lastra M., Jones A., Scapini F., McLachlan A., Defeo O. (2007). Sandy Beaches at the Brink. Diversity and Distributions 13 (5), 556–560.

Background Information and Resources for Teachers

LiMPETS Website Link – http://limpets.org/resources_sb.php.

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 often overlooked for the diversity of life it supports.

The sandy beach is a harsh physical environment. The sand shifts. Food production is limited. Waves crash. The tide rises and falls. But still, thousands of mobile animals live along every foot of the shoreline.

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 sand dunes that border the sandy beach. Specialized animals inhabit this turbulent and varied habitat. This section will cover the physical habitat and the biological community of the California sandy beach (Project Ocean).

Waves

Ocean waves are created by the force of the wind blowing across the surface of the water. When waves reach the shore, their size 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

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to create the some big waves along the Pacific coast. In fact, these waves (from Pt. Conception to Cape Flattery) can be among the most powerful in the northern hemisphere.

Sandy beaches exposed to big, 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.

Prevailing sea conditions are reflected in the appearance of the beach. The slope of the beach and the 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. Beaches change appearance with the season. The bigger waves of 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.

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. Coastal watersheds are a major source of sand to California beaches. The sand that makes up beaches flows down creeks and rivers and then is deposited at the mouth, forming sandy beaches. Longshore currents generated by waves pick up sand from these larger deposits near creek and river mouths and move it along the coast to form more beaches.

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

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Sand from Pismo Beach, CA: quartz, chert, igneous rock and shell fragments.

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.

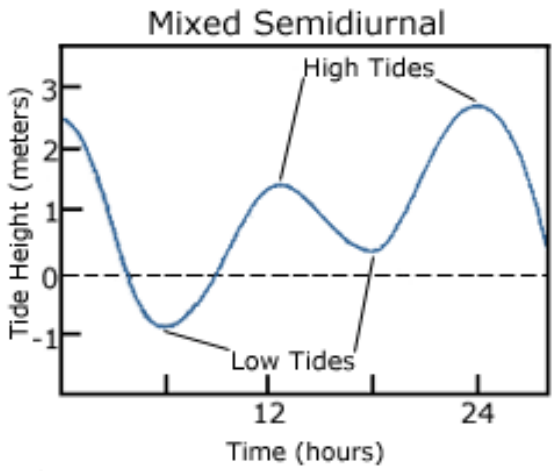
The amount of water that can be retained and held by beach sand depends on the size of the sand grains. Finer-grained sand holds more water than coarse-grained sand, but on average sand holds water in a volume equal to its own. That is, an average beach is half water and half sand. For this reason, when 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 (drying) 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 central California coast 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 their 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 (http://tidesandcurrents.noaa.gov/). The National Atmospheric and Oceanic Administration distributes regional tide tables each year.



An area has a mixed semidiurnal tidal cycle if it experiences two high and two low tides of different size every lunar day. Many areas on the western coast of North America experience these tidal cycles.

Food Web

The lack of attached plants and algae, which can't live on the beach's shifting intertidal sand, means that beach food webs depend almost entirely on food imported from other sources. The ocean provides the majority of these subsidies to beaches. 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.

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.

The sandy beach habitat provides little shelter or cover to avoid predation. During low tide, shorebirds, small mammals, and insects prey on mole 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. In order to avoid predation, mole crabs move up and down the beach with the tides to maintain their position in the swash zone, the most difficult place for both shore and sea predators to reach them.

Life on the Beach

Although it may not be obvious at first glance, a beach's constantly moving sand forms a very rich and productive intertidal habitat, particularly in California. In fact, thousands of mobile animals live along every foot of the shoreline. Most are hidden from view, buried in the sand, emerging only to feed or to move up and down the beach with the tides and waves.

The most difficult obstacle that sandy beach organisms face is the lack of a stable substrate on which to anchor themselves. 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 and there is continual abrasion by swirling sand. For most animals, the solution 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 (drying out), 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 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. 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. 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 central California beaches 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 around in the sand for food with their bills.

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Scurrying Sanderlings probe for invertebrates in the swash zone and the wrack.

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 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 give it very good swimming capabilities, an essential skill when it is stirred out of the sand by crashing waves.

The sand crab burrows end 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 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, except in the equatorial zone).

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 and in some cultures, as food.

There are not many predators down in the sand, but there are a few. The most effective are probably the moon snails. These large snails (10–15 cm across the shell) have an immense, conspicuous foot that 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

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Female mole crabs can produce up to 50,000 eggs at one time.

time between one crashing wave and the next (an average of 7 seconds). The Pismo clam 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

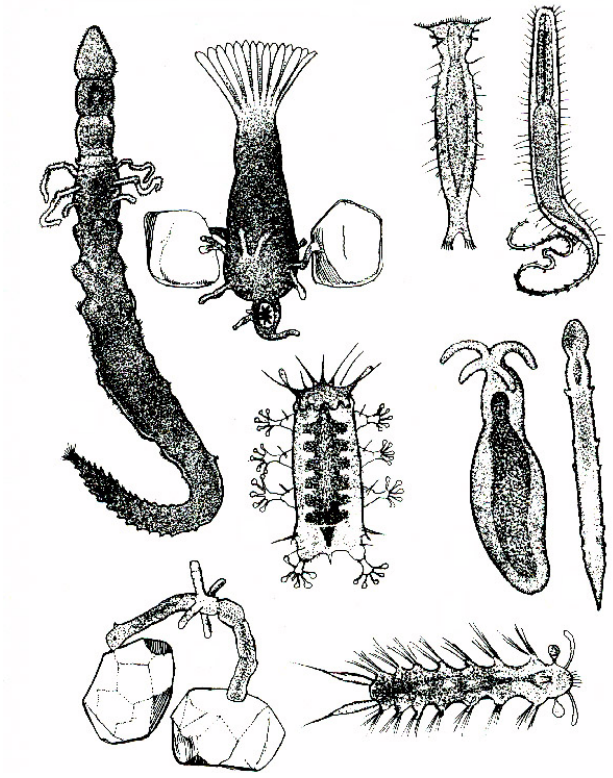
The most diverse and abundant organisms of the sandy beach habitat are too small to be seen with the naked eye. Because the sand holds water even when the tide is out, the minute spaces between the grains of sand are able to support a complex community of microorganisms that swim within the protective 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 are represented in the community of animals living 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. 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 study area. 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 they account 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. Surfperch and sand eels take advantage of the dislodging force of the waves to grab crabs and worms otherwise unobtainable.



Interstitial fauna.

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 easily accessible and are places of relaxation and exploration.

Although the sandy beach is often a place of beauty, some human activities threaten the habitat. Beaches in California suffer from a number of challenges, including water quality, coastal armoring and marine debris (SIMoN).

- Water quality: Various agencies and citizen groups monitor the water quality of sanctuary beaches. These groups collect water samples and test for levels of coliform bacteria, which are indicators of contaminants that may cause sickness in humans. Oil pollution is an important aspect of water quality and can come from many sources, including land runoff, poor vessel maintenance and spills from vessels. Oil spills from large vessels, like that of the 2007 Cosco Busan spill in the San Francisco Bay, often have long-term effects on beaches, with tar balls and oil residue washing up on shore for many months afterward.
- Coastal armoring: Throughout California, structures are installed to prevent the natural erosion of the coastline. This coastal armoring helps protect public and private property from destruction, however it can potentially damage or alter local coastal habitats and deprive beaches of sand. Sand deprivation may cause a loss of beach and intertidal areas through a process termed "passive erosion."

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Live oiled Surf Scoter from Cosco Busan oil spill.

- Marine debris: Refuse is carried by rivers, storm drains and wind from inland areas, and deposited directly on beach areas by visitors. Regardless of its origin, much of this refuse ends up on beaches and can pose a threat to seabirds, marine mammals and turtles. Since 1985, volunteers gather every year on the third Saturday of September for the California Coastal Cleanup Day event, to collect trash on beach areas up and down the state.
- Ocean acidification: Human activites such as burning fossil fuels and deforestation, have lead to a rapid increase in atmospheric carbon dioxide levels. The ocean absorbs approximately 1/3 of the atmospheric carbon dioxide from human activities, or anthropogenic carbon dioxide. Carbon dioxide acts as a weak acid when it dissolves in seawater. The dissolution of carbon dioxode causes a chemical reaction that consumes some of the chemical compounds that calcifying organisms, like oysters, use to build their shells. So the dissolution of anthropogenic carbon dioxide into the ocean is changing ocean chemistry and making it difficult for some organisms to live.

References:

Project Ocean: Sandy Beach Habitat Guide, Tarlton Institute for Marine Education, San Francisco, CA

"SIMoN - Beaches." Sanctuary Integrated Monitoring Network - SIMoN - web. 09 Aug 2015 http://sanctuarysimon.org/regional_sections/beaches/overview.php

Looking for more background information about sandy beaches and its inhabitants?

Check out the resources below.

SIMoN Sandy Beaches: The SIMoN (Sanctuary Integrated Monitoring Network) website has great, local descriptions of California sandy beach ecology and a searchable photo database. This is a great resource for up-to-date ecological and scientific information.

http://sanctuarysimon.org

MARE's Teacher Background for the Sandy Beach:
The Lawrence Hall of Science's MARE (Marine Activities, Resources and Education) website highlights ocean habitat homepages with helpful background information and classroom activities.

http://mare.lawrencehallofscience.org/curriculum/teacher-guides/gr2-sandy-beach

Sandy Beaches (California) by Jenny Anderson: Marine science online course for college students at Santa Barbara City College. This online lesson explores the physical processes involved in sandy beaches and the common life forms found on a typical California sandy beach. Nice photos accompany a concise description of our local sandy beaches.

http://www.marinebio.net/marinescience/03ecology/sbindex.htm

The Impacts of Beach Grooming: Kelp wrack and other natural beach debris provide an important food source and habitat for many creatures including shore birds. The California Sea Grant website provides an overview of the impacts of beach grooming on beach ecology.

https://caseagrant.ucsd.edu/project/explore-sandy-beach-ecosystems-of-southern-california/beach-grooming

LiMPETS Website Link – http://limpets.org/sanctuaries.php

LiMPETS is a California-based national marine sanctuary program. The national marine sanctuaries are a system of federally protected areas of the ocean. Much like our National Parks protect special places on land, our sanctuaries protect special places in the ocean. The Sanctuary System consists of 14 marine protected areas that encompass more than 150,000 square miles of marine and Great Lakes waters from Washington State to the Florida Keys, and from Lake Huron to American Samoa. There are 4 national marine sanctuaries in California; Cordell Bank, Greater Farallones, Monterey Bay, and Channel Islands.

The primary objective of a sanctuary is to protect its natural and cultural features while allowing people to use and enjoy the ocean in a sustainable way. Sanctuary waters provide a secure habitat for species close to extinction and protect historically significant shipwrecks and artifacts. Sanctuaries serve as natural classrooms and laboratories for children and researchers alike to promote understanding and stewardship of our oceans. For more information about the National Marine Sanctuary System, please visit http://sanctuaries.noaa.gov.

Scale varies in this perspective. Adapted from National Geographic Maps.