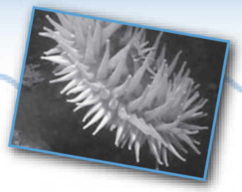
ECOSYSTEM OBSERVATIONS

For the Monterey Bay National Marine Sanctuary

2006

NATIONAL MARINE SANCTUARIES
MONTEREY BAY



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In Memoriam

With sadness we learned of the passing of Daphne M. White, a former colleague, on January 1, 2007. Daphne worked for NOAA in a variety of positions from 1975 to 1993. In 1990, she came to the Monterey area to help establish the Monterey Bay National Marine Sanctuary and was instrumental in shaping its early years. After her retirement in 1993, she continued to volunteer for sanctuary conservation and education activities. Daphne was a great supporter of this publication and helped edit it for many years. In honor of her memory and contributions to the sanctuary, we dedicate this issue to Daphne.

Welcome

This was an incredible year for the Monterey Bay National Marine Sanctuary – one in which many major long-planned projects led by our staff and community partners became a reality. Major projects that came to fruition in 2006 include the opening of a new visitor center near our southern boundary, the Coastal Discovery Center at San Simeon Bay and our first archeological cruise to map one of the many historic sites in the sanctuary, the submerged wreck of the USS *Macon*.

We also welcomed the arrival and dedication of our new 67-foot research vessel, the *Fulmar*, which will greatly expand our capabilities for doing research in the sanctuary's offshore waters. In addition, at long last, the Draft Joint Management Plan for the three central coast sanctuaries was released and public hearings completed. All of these projects herald major new initiatives and directions for the Monterey Bay sanctuary in the coming decade; you can read more about them in the following articles.

This year also brought some internal changes. William Douros, superintendent since 1998, moved on to a new position as regional superintendent of West Coast Sanctuaries, overseeing the five sanctuaries on the west coast. We had the privilege of each taking a six-month turn at the sanctuary's helm during this transition period of 2006. It has been an exciting ride, and we look forward to continued successes by the program staff and their many partners in the coming year.

–Holly Price and Karen Grimmer, Acting Superintendents
NOAA's Monterey Bay National Marine Sanctuary

2006 Program Activities for the Monterey Bay National Marine Sanctuary

Designated in 1992, the Monterey Bay National Marine Sanctuary is our nation's second largest marine protected area and is managed by the National Oceanic and Atmospheric Administration (NOAA). Located off central California, the sanctuary features wave-swept beaches, lush kelp forests and one of the deepest underwater canyons in North America. An abundance of life, from tiny plankton to huge blue whales, thrives in these waters.

Our mission – to understand and protect the coastal ecosystem and cultural resources of the Monterey Bay sanctuary – is carried out through resource protection, education and outreach, research and monitoring, and program operations. Following is a summary of each program's major accomplishments during 2006.

Resource Protection

Resource protection issues in the sanctuary are wide ranging, from pollution and coastal development to wildlife or ecosystem disturbance. The resource protection team works with its partners to reduce or prevent detrimental human impacts on sanctuary resources, while recognizing the many uses of the marine environment along its long coastline.

In the past year, we continued to address the spread of coastal armoring such as seawalls and riprap along beaches, focusing on southern Monterey Bay. A multi-stakeholder group completed an assessment of options available for responding to erosion while minimizing impacts to beaches. In coordination with the Association of Monterey Bay Area Governments, we also completed an evaluation of the environmental and socioeconomic impacts of seawater desalination projects in the Monterey Bay region.


Photo by MBNMS/NOAA

Sanctuary 'Volunteer of the Year' Mary Buck Scannell monitors water quality.

A working group of scientists, environmentalists, fishermen and other ocean users continued to evaluate the potential utility and design of marine protected areas (MPAs) in federal waters of the sanctuary. Staff also participated extensively with the State of California's Marine Life Protection Act Initiative to design MPAs in state waters of the sanctuary.

The Water Quality Protection Program led efforts in the watersheds to reduce contaminated runoff to the sanctuary from agricultural and urban areas. The Agriculture Water Quality Alliance, a coalition of groups working to carry out the sanctuary's Agriculture and Rural Lands Plan, completed six years of delivering a 15-hour Farm Water Quality Planning Course, educating more than 1,700 farmers about water quality and conservation practices to prevent pollution.

Monitoring data collected by Sanctuary Citizen Watershed Monitoring Network volunteers over the years resulted in the initiation of two new water quality studies. Based on historical results from the annual Snapshot Day, a targeted long-term monitoring program was initiated in two Salinas drainages to understand urban and agricultural impacts better. Similarly, high metal concentrations detected during First Flush events led to a copper/zinc source tracking study in a local urban watershed.

Staff gained experience in responding to another type of pollution, catastrophic oil spills, by participating in 'Safe Seas 2006,' a major interagency oil-spill drill led by NOAA in collaboration with the U.S. Coast Guard and the State of California. A series of drills over the summer offered training in evaluation of habitat and species impacts, oil-spill response protocols, communications, and field and command center operations.

Our enforcement staff received more than 200 notifications of potential violations during 2006 and investigated a variety of incidents including discharges, wildlife disturbance and vessel groundings. A settlement of $3 million was received from the parties responsible for discharging 15 large shipping containers into the sanctuary. The funds will be used to fund projects to protect and restore the seabed.

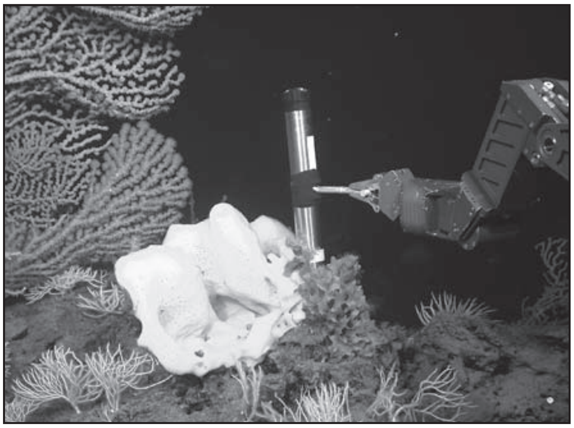
As we head into 2007, the resource protection team looks forward to working with its many partners on existing efforts and new programs to carry out the recommendations in the new Monterey Bay Sanctuary Management Plan.

Research

The purpose of the research program is to address resource management needs for scientific information. With a large sanctuary and many human impacts to diverse habitats, the job of providing scientific insight is significant. Fortunately, we benefit from the knowledge of world-class marine scientists through the sanctuary's Research Activity Panel and the Sanctuary Integrated Monitoring Network (SIMoN) Science Committee. In this summary, we provide a flavor of the research program by highlighting some of our 2006 accomplishments.

The sanctuary led two important cruises aboard the Monterey Bay Aquarium Research Institute's (MBARI) R/V *Western Flyer*. In January, we studied coral distribution patterns on Davidson Seamount, while guiding the British Broadcasting Corporation (BBC) to locations for filming deep-sea corals. The BBC also searched in the Atlantic Ocean and around Hawaii before finding the dramatic coral images needed for the production of *Planet Earth*, to be released in the United States in 2007. As we develop a taxonomic guide for Davidson Seamount we have, so far, discovered 15 new species: nine sponges, five corals and one hydroid. Later in the year, we revisited and completed a photo mosaic of the rigid airship, USS *Macon*, working with our collaborators. This submerged cultural resource received national attention, and the sanctuary mandate to protect the wreck will proceed by nominating the site for inclusion in the National Register of Historic Places.

One of the more ominous threats to the sanctuary is a large oil spill. Our research team contributed to the 'Safe Seas 2006' multi-agency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Current meter placed near corals and sponges at the top of Davidson Seamount to measure local currents exercise, overseeing a contract to update the *Atlas of the Sensitivity of Coastal Environments and Wildlife to Spilled Oil for Central California*. Knowing habitats, sensitive species and cultural resource information, kilometer by kilometer along the shore, is key for effective oil-spill response and damage assessment. This atlas is also a basic source of information for responding to smaller incidents such as boat groundings and landslides.

The SIMoN program continues to fund and track monitoring programs. For example, we initiated a California Coastal and Marine Mapping Initiative in collaboration with the State of California. This habitat mapping work is key in the designation and monitoring of marine reserves. SIMoN studies were also completed to address the impacts of the Moss Landing power plant discharge, the hydrodynamics of Elkhorn Slough related to tidal erosion, and the biological sensitivity of Big Sur rocky shores and nearshore subtidal areas that may be impacted from the disposal of landslide material.


Photo by MBNMS/NOAA

The sanctuary's new R/V Fulmar

SIMoN expanded its range, too, by working with the Gulf of the Farallones sanctuary to add mapping staff and to initiate its own SIMoN Science Committee. Finally, the SIMoN web site continues to provide characterization and monitoring information for students, the media, scientists and managers. Our most popular new feature is the SIMoN photo database, where more than 2,500 images of sanctuary species and places are available to download. For more information on research and new web offerings, be sure to check our web sites (www.montereybay.noaa.gov; www.mbnms-simon.org) periodically.

Education and Outreach

This year, we went a long way in supporting our mission, to '*promote understanding, support and participation in the protection and conservation of the Monterey Bay National Marine Sanctuary.*' We opened a visitor center and continued the development of two others, enhanced our volunteer program, strengthened public outreach and initiated the sanctuary's first maritime heritage project.

The highlight of the year was the grand opening of the Coastal Discovery Center at San Simeon Bay. This cooperatively planned interpretive center showcases the natural and cultural history of the area and the protection the sanctuary and State Parks afford the central California coast. More than 40 volunteers have been trained to greet and interpret the wonders of the coast for visitors to this new facility. The 2007 focus will be on public program development – so stay tuned!

Thirteenth Annual Sanctuary Reflections Awards

Ruth Vreeland Public Official Award: *Ceil Cirillo, City of Santa Cruz Redevelopment Agency*

Citizen: *Ron Massengill, Cambria*

Conservation: *Jim Webb, Cambria Fishing Club*

Education: *Kenton Parker, Elkhorn Slough National Estuarine Research Reserve*

Science/Research: *Dr. Mark Carr, Department of Ecology and Evolutionary Biology, University of California Santa Cruz*

Business: *Adventures by the Sea*

Organization/Institution: *Natural Resources Conservation Service*

Special Recognition: *Dr. Chris Harrold, Director of Conservation Research, Monterey Bay Aquarium*

Monterey Bay Sanctuary Volunteer of the Year

Mary Buck Scannell, *Sanctuary Citizen Watershed Monitoring Network*

Another boost to our facilities programming was a $1.325 million grant for the continued development of the sanctuary visitor center in Santa Cruz. The Sanctuary Program granted these funds to the city to cover the final architectural design, site improvements and a variety of required studies. Finally, the highly anticipated Pigeon Point visitor facility is scheduled to open in time for peak summer visitation in 2007.

Our invaluable volunteers were recognized at an awards reception separate from the *Currents Symposium*, where we also honored the recipients of the *Sanctuary Reflections* and *Volunteer of the Year* Awards. We all agreed that it is so important to celebrate those who dedicate their time to protecting the sanctuary, and we intend to make this an annual event. We also began developing a new Volunteer Plan, to better coordinate and enhance existing programs like TeamOCEAN, Beach COMBERS, BAY NET and the Citizen Watershed Monitoring Network and to develop new opportunities.

Developing an informed public is one of our primary objectives. Products like the newly published *MBNMS Field Guide*, combined with programming, help central coast citizens learn their role in protecting the sanctuary. This year our MERITO after-school program trained 20 teachers and engaged more than 425 students. MERITO field experiences continue to be highly effective in connecting individuals and their activities to the sanctuary.

Finally, the education team covered new ground with the expedition to revisit the sunken USS *Macon*. An ambitious outreach plan called for a new web site, live web-based video feed (30,000 people logged on), a Teacher-at-Sea program, five lectures, commemorative pins, postcards, posters, curriculum and a DVD. We've completed all but the last three, which should be available this spring.

We look forward to 2007 and the new challenges it will bring, as we continue to develop our centers, outreach programs and opportunities for public involvement.

Program Operations

The program operations team, as always, provided critical support to the education, research and resource protection teams. We celebrated the delivery of our new 66-foot catamaran research vessel, *Fulmar* (*see photo, above*), in August during a dedication at its home port in Monterey. Approximately 100 invited guests participated in the ceremony, including Sanctuary Advisory Council members, representatives of NOAA and the U.S. Coast Guard, Mayor Dan Albert of Monterey and Congressman Sam Farr.

Mrs. Anita Ferrante, a local member of the Italian fishing community, served as the vessel's matriarch and performed the christening. Later in the day, public tours were held, and more than 300 people boarded the *Fulmar* to learn about her mission capabilities.

The *Fulmar* will be used for up to 180 missions in 2007, including benthic monitoring along the remote Big Sur coastline, marine mammal and seabird observations, tagging studies, oceanographic monitoring, archeological/cultural research and baseline data collection for emerging issues such as invasive species and marine reserves.

The Sanctuary Advisory Council elected Deborah Streeter to serve another term as chair and Kaitilin Gaffney to serve again as secretary. This year the council's efforts focused on the Joint Management Plan Review, the Marine Life Protection Act process and NOAA's 'Safe Seas 2006' drill, among other topics.

Joint Management Plan Review

Over the course of the past five years, the public and sanctuary advisory councils for the Cordell Bank, Gulf of the Farallones and Monterey Bay sanctuaries have participated extensively in our Joint Management Plan Review, helping shape the future direction and management of these three contiguous sites. The incredible interest, support and dedication of thousands of individuals who took time to participate in this important effort culminated in October 2006 with the release of the long-awaited Draft Management Plans, Proposed Rules and Draft Environmental Impact Statements for each site. Public hearings were held in November and December to gather final comments on the issues and regulations proposed in these documents.

Once finalized in 2007, the plans will guide management of each sanctuary for years to come. The Monterey Bay sanctuary plan identifies more than 25 critical issues our program should address in the coming years, including coastal armoring, desalination, introduced species, motorized personal watercraft, beach closures, cruise ship discharges, wildlife disturbance, tidepool protection, ecosystem monitoring, fishing-related education and research, and interpretive facilities, among others. The plan is a revision of the original Monterey Bay sanctuary management plan, adopted with sanctuary designation in 1992, and is focused on how to best understand and protect the sanctuary's resources. To view the latest management plan documents, visit: http://www.sanctuaries.nos.noaa.gov/jointplan/.

SIMoN Says

The Sanctuary Integrated Monitoring Program (SIMoN; www.mbnms-simon.org) is an integrated, long-term program that funds and tracks sanctuary monitoring programs along the central and northern California coastline, synthesizing and presenting the research to resource managers, scientists and the public.

The SIMoN web site offers a searchable database of more than 2,500 digital images that show the sanctuary's unique collection of organisms, habitats and management issues. Visitors can search by species name or keyword and download high-resolution images. The photo database contains:

- 300+ images of marine mammals
- 200+ images of fishes
- 700+ images of invertebrates and algae
- 600+ images of research projects and events
- 300+ images of sanctuary locations

To view these images, go to http://mbnms-simon.org/photos.

Photo by Josh Pederson, MBNMS/NOAA

Images of the beautiful sanctuary coastline are available in the SIMoN photo database.

Ocean Observatories on SIMoN

The SIMoN program is directly involved with the nation's ongoing thrust to develop an Integrated Ocean Observing System (IOOS). For example, the SIMoN web site provides access to the National Marine Sanctuary Program's West Coast Observations, a key provider of nearshore temperature and current data in the five West Coast sanctuaries (http://mbnms-simon.org/wco).

SIMoN also provides technical support to the Central and Northern California Ocean Observing System (CeNCOOS) by maintaining the oceanObs data discovery system. This database, which is available to the public, contains information on the ocean-observing activities in the CeNCOOS region. The oceanObs inventory contains information on:

- 40+ ocean-observing programs
- 150+ data products
- 400+ data collection locations

Movements and Habitat Use of Sooty Shearwaters in Central California National Marine Sanctuaries

Each year, hundreds of thousands to millions of Sooty Shearwaters, *Puffinus griseus*, wing their way across the Pacific Ocean from breeding colonies in New Zealand and Chile to the West Coast of North America. Off California and throughout the northeast Pacific, sooties are the most abundant seabird. Within Monterey Bay, their annual consumption of important prey species like northern anchovy and market squid is substantial (thousands of metric tons) – in similar quantities to annual harvests reported by commercial seine-net fishermen operating primarily from Moss Landing and Monterey harbors.

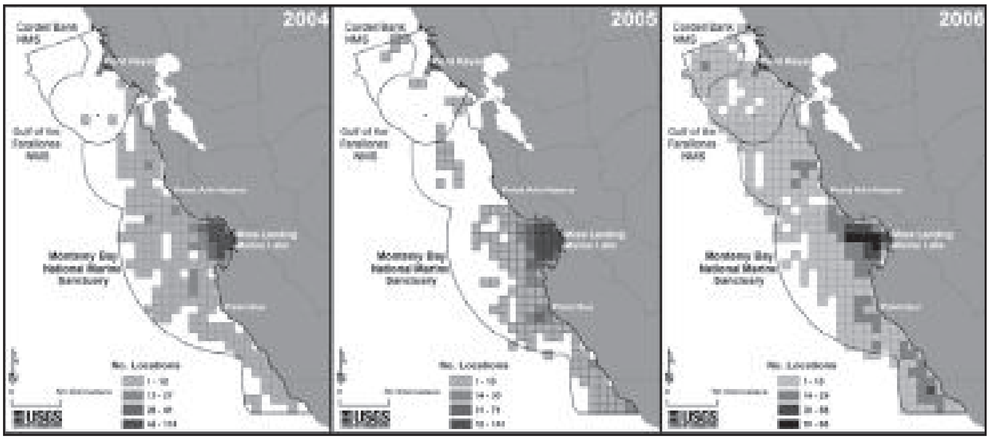


Figure 1. The distribution of Sooty Shearwater locations (number of locations per 9×9 kilometer grid cells) within the three central California national marine sanctuaries during the summers of 2004 to 2006 indicates that Monterey Bay is consistently delineated as the area of greatest use by shearwaters foraging throughout central California. Whereas marked shearwaters were largely confined to the Monterey Bay sanctuary in 2004 and 2005, they ranged throughout the three central California sanctuaries in 2006; and consistent with observations of many local beachgoers, shearwaters were relatively absent from nearshore waters. We hypothesize that differences in the annual distribution and movements of sooties are tied to variable prey distributions, which in turn are tied to conditions determined by variability in upwelling conditions.

During the summer of 2006, with support from SIMoN, a team of scientists from the U.S. Geological Survey (USGS), Moss Landing Marine Laboratories (MLML) and several other institutions continued a collaborative effort to understand how dominant avian predators interact with the dynamic California Current marine ecosystem. Using satellite tracking technology, we have followed the movements and migration of sooties that visit the network of national marine sanctuaries off the U.S. West Coast every year since 2004. For two to three months each summer we use small satellite transmitters (PTTs) to obtain multiple accurate locations per day from individual birds that were originally captured within Monterey Bay. Because non-breeding sooties are not constrained by the need to return to their colonies (as they are while in New Zealand and Chile) and because they often occur within large flocks that depend on abundant forage resources, tracking individuals gives us insight to the population foraging off the West Coast of North America.

Our goal is to get the inside view of sanctuary habitats from the perspective of the shearwaters. Because satellite tracking is accurate, continuous and unlimited spatially, we can use data from tracked shearwaters to map important habitats where entire communities of animals – including other seabirds, marine mammals and predatory fishes – aggregate to forage (*Figure 1*).

We will integrate information from the sooties with physical and biological oceanographic data to obtain a more complete understanding about how oceanographic processes and patterns influence dynamic habitats of central California's ocean ecosystem. Several years of tracking will help us understand how shearwaters and their principal prey respond to variable oceanographic conditions.

More information on this project, including images and links to tracking data, can be found on the SIMoN web site at http://mbnms-simon.org/other/moreLinks/whats_new_sooty_tagging.php. Thanks to Josh Adams, USGS, and James T. Harvey, MLML, for writing this article.

The Status of 'At-Risk' Species in the Sanctuary

The populations of some animals – such as krill and jellies – are thriving in sanctuary waters. However, other species are considered to be 'at risk' because their population sizes are reduced or declining. Reduced or declining populations may be caused by human exploitation, habitat degradation, disease, environmental change or a combination of these factors. The sanctuary, through its research, education and resource management programs, has the ability to help improve the status of many at-risk species. However, to make the sanctuary's efforts most effective, we must identify both the species that are at risk and the actions that will be the most beneficial for each species.

Photo by Josh Pederson, MBNMS/NOAA

Brown Pelican, Pelecanus occidentalis, an at-risk species

To that end, SIMoN has begun the At-Risk Species Project. The first phase of this project involved compiling a list of all the species occurring in sanctuary waters that are designated as being at risk by a variety of resource management agencies and conservation groups. The second, and ongoing, phase involves creating status reports for at-risk species. The status reports cover a variety of topics including geographic range, abundance, migration patterns, threats, current research projects, conservation efforts and actions the sanctuary can take to help improve the status of at-risk species. The recommended actions may include research projects to collect data needed to improve resource management or outreach programs to help increase public awareness of at-risk populations and the habitats they use. All the material compiled for this project, including lists of at-risk species; status reports; and links to photos, videos and educational materials, are available on the SIMoN web site at http://mbnms-simon.org/risk.

CONTRIBUTED

Ecosystem Observations

Intertidal and Subtidal Marine Resource Surveys along the Big Sur Coastline

The Monterey Bay National Marine Sanctuary worked closely with the California Department of Transportation (CalTrans) and several other local, state and federal agencies to develop the Big Sur Coast Highway Management Plan (CHMP). Highway 1 in Big Sur is often subject to delays and closures due to storms, washouts and landslides. The purpose of the CHMP is to identify sustainable strategies that ensure the safe and efficient operation of the highway while protecting the unique qualities and sensitive terrestrial and marine resources of this remarkable coastline.

As one part of the CHMP, the sanctuary designed and funded a project to survey intertidal and nearshore subtidal marine resources along a 70-mile stretch of Big Sur coastline between Carmel River and San Carpoforo Creek. Staff scientists worked with researchers from the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) to collect data on local geology and physical features (e.g., slope, wave action, nearshore currents) as well as species diversity, abundance and the presence of economically important and threatened or endangered species.

The data were then used to inform a decision-making framework to evaluate the potential ecological impacts from landslides to intertidal and shallow (less than 20 meters deep) subtidal habitats and the biological communities they support. Many of these habitats, especially rocky intertidal and subtidal kelp forests, support species-rich biological communities and species of special interest.

The approach to informing the decision-making framework included three objectives: (1) developing sensitivity indices of intertidal and shallow subtidal biological communities to landslides, (2) developing models, based on relationships between habitat variables and biotic communities, in order to predict sensitivity of communities in unsampled sections of the coast and (3) assessing differences in subtidal biological communities at sites that differed in their proximity to point sources of landslide material.

For the first objective, the indices of biological sensitivity used to characterize the vulnerability of a community to landslides were based on several factors, including the probability of occurrence of one or more species of special interest (e.g., threatened, rare or economically important species), the species richness of the community, the relative abundance of species of particular ecological importance and the likelihood of prolonged impact (i.e., retention of sediments and rock) based on the physical attributes of the environment. In addition, researchers classified the diversity of intertidal habitat types (e.g., sandy coves, cobble beaches, boulder fields, reef benches). When simplified, 39 percent was classified as rocky, 31 percent sandy, 29 percent a mix of rocky and sandy habitats, and less than 1 percent remained unclassified. The combination of biological and physical criteria resulted in a gradient of relative sensitivity of biological communities in the intertidal and shallow subtidal habitats of the CHMP study region.

The second objective was to develop predictive models based on empirical relationships between habitat variables (e.g., exposure to swell, reef relief, substratum type) and species assemblages to estimate the sensitivity of communities in unsurveyed sections of the coast. In order to do this, the 70-mile coastline was broken into 58 sections based on geology and substrate type. Of these, 21 had been surveyed and the remaining 37 were modeled. After assigning a community to each of the 37 sections, all 58 sections were compared to each other and assigned a relative 'value' based on a composite of several variables. These values (highest, high, medium, low and lowest) reflect several aspects of the biological and physical features of the site and how they contribute to ecosystem sensitivity and respond to landslides. Sections in the 'highest' category are particularly diverse and most susceptible to the effects of burial, scour and turbidity (e.g., heterogeneous rocky benches). In contrast, 'lowest' value sections had low diversity values and were more resilient to the effects of landslides.

In the intertidal zone, 10 percent of the coastline had the highest value, 27 percent high, 47 percent medium, 2 percent low, and 14 percent lowest. Beaches typically received low or lowest values, while

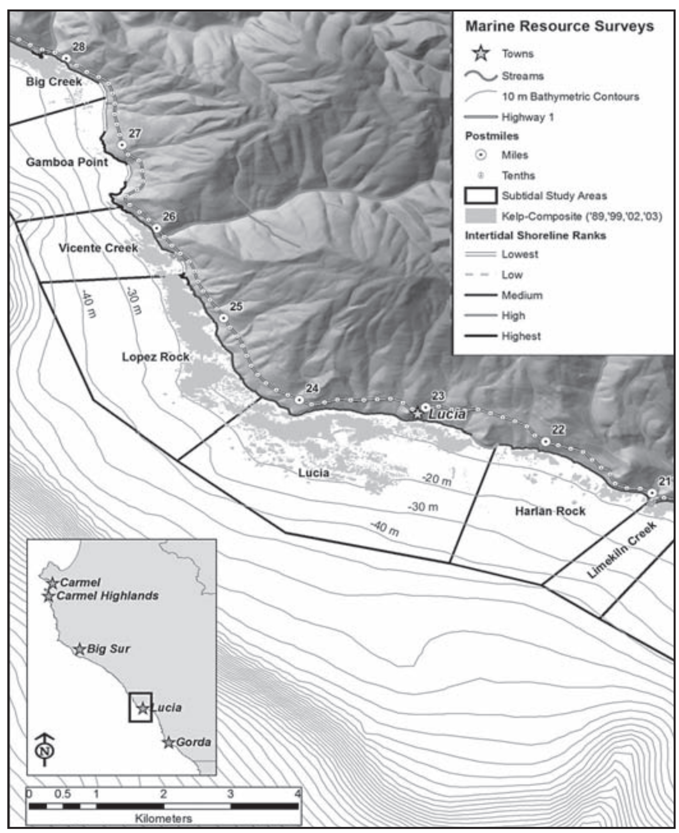


Figure 1. Seventy miles of the Big Sur coastline (shown in the inset) were subdivided into intertidal and subtidal sections of relatively continuous habitat type (e.g., in the intertidal, boulder field vs. rocky bench vs. sandy beach). Each section was ranked based on a composite of species richness, presence of managed species and the ability to recover from landslides.

contiguous rocky benches were usually high or highest. In the subtidal (depths less than 20 meters), only 1 percent received the highest value, 29 percent high, 27 percent medium, 22 percent low, and 1 percent lowest. An additional 20 percent was not classified due to a lack of information.

The final objective of the project involved a comparison of the biological communities at three pairs of subtidal sites near and far from point sources of existing erosion. Researchers did not detect differences in the biological communities related to their proximity to sites of erosion.

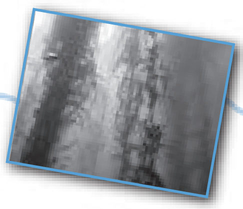
Resource protection staff will use these data during the next significant landslide event and to inform decisions on related permit requests by CalTrans. By knowing which species are present, and what we still have to learn, staff have several response options available.

The results of this study are available on the SIMoN web site at http://www.mbnms-simon.org/sections/rockyShores/project_info.php?pid=100280&sec=rs.

– STEVE LONHART
MONTEREY BAY NATIONAL MARINE SANCTUARY

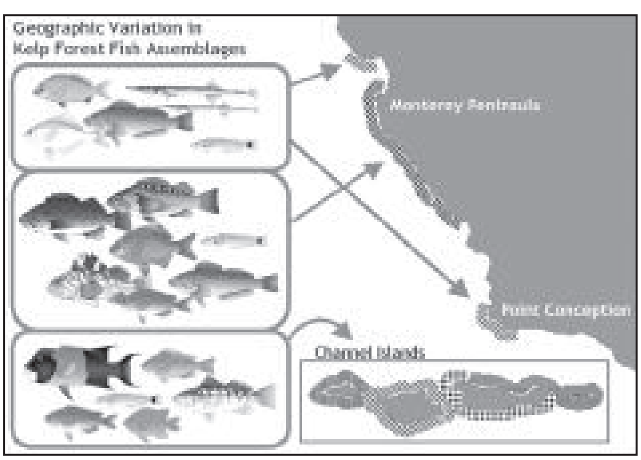
Photo by Steve Lonhart, MBNMS/NOAA

Natural and human-caused landslides can bury rocky-shore habitat.



Geographic Patterns of Kelp Forest Community Structure

Forests of giant kelp, *Macrocystis pyrifera*, are among the most productive and species-rich ecosystems on earth. They also support a wide variety of recreational and commercial fisheries and non-consumptive uses (e.g., kayaking, SCUBA diving). However, most ecological studies of kelp forest communities are restricted to one or two study sites over periods of only two to three years. Thus, our understanding of the environmental and ecological processes that influence the structure and dynamics of these ecosystems is limited to those processes that act at such restricted spatial and temporal scales.



Fish images courtesy of Dr. Larry Allen, California State University Northridge

Figure 1. Geographic patterns of kelp forest fish assemblages revealed by the long-term PISCO-Monterey Bay National Marine Sanctuary kelp forest monitoring program. A cluster analysis found five distinct species assemblages indicated by pattern fill along the coastline, and these were generalized into three types of fish assemblage.

Longer-term, larger-scale studies allow ecologists to examine the effects of processes that vary over much longer time periods and across broader geographic areas. For example, oceanographic conditions and the geological features of the sea bottom vary along the coast, which may influence the kinds and numbers of species that inhabit kelp forests. Studies that span such geographic variation can detect relationships between this variation in habitats and kelp forest communities. Similarly, to understand the effects of El Niño or La Niña events, studies that span several of these events and intervening periods allow ecologists to determine how populations and communities respond to such episodic perturbations. Models of climate change predict changes in the intensity and frequency of El Niño and la Niña events. Therefore, understanding how kelp forest ecosystems respond to these episodic events can inform predictions of how kelp forests will respond to pending climate change.

In collaboration with the Monterey Bay and Channel Islands National Marine Sanctuaries, the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) has conducted annual surveys since 1999 to quantify the structure (i.e., kinds and numbers of species) and dynamics (i.e., year-to-year variation) of the algae, invertebrates and fishes that make up kelp forest communities along the coast of southern and central California (covering a range of more than 400 kilometers). This region spans several major sources of geologic, oceanographic and ecological variation on both islands and the mainland. At each of the 50 sites surveyed once each year, divers estimate the abundance (and sizes) of many of the common species that constitute kelp forest communities. (See *http://www.piscoweb.org/research/community.*)

These large-scale surveys indicate that kelp forest ecosystems and the algae, invertebrates and fishes they support vary markedly across this geographic expanse. Multiple years of sampling indicate that the geographic patterns that appear in these surveys are persistent from year to year. Moreover, there are strong relationships among the composition of these ecological communities and several aspects of the oceanographic and geological environment.

Some patterns are not surprising. For example, the kinds and relative abundance of reef fishes that inhabit kelp forests differ most markedly to the north and south of Point Conception (*Figure 1, previous page*). Fishes to the south are warm-water species related to tropical families (damselfishes, sea basses, wrasses) whereas fishes to the north include more colder-water species (rockfishes, surf perches, greenlings).

However, differences within each of these regions also occur, and they appear to be related to variation in oceanographic conditions and features of the rocky reef. For example, fish assemblages vary from east to west across the Channel Islands, reflecting similar patterns north and south of Point Conception (i.e., 'cold water' versus 'warm water' species) and a gradient in water temperatures along the islands. Likewise, fish assemblages north of Monterey Bay are actually more similar to those off Point Conception than they are to the Monterey Peninsula. The occurrence of these particular fish assemblages corresponds with the occurrence of low-relief, sandstone reefs that are highly exposed to ocean swells. Similarly, the species composition of algal communities corresponds with the exposure of sites to strong northwest swells and also varies with the abundance of cobble and boulders among sites.

These geographic patterns are important for several reasons. First, they indicate how differences in oceanographic and geological features support different species and how changes in these aspects of the environment (e.g., oceanographic responses to climate change) will influence the species that inhabit these ecosystems. They also indicate that the diversity of species that inhabit kelp forest ecosystems is not represented in a single or few forests, but instead is spread up and down the coast. Thus, measures to protect biodiversity (e.g., marine protected areas) need to be distributed across this geographic range of variation in oceanographic and other habitat features to include and protect the breadth of diversity of species in kelp forests. These patterns also help to identify reference sites that can be used to compare with and evaluate the effects of establishing marine protected areas. Finally, these large scale, long-term monitoring studies allow us to understand where the large number of smaller-scale studies (i.e., single sites) apply to the rest of the coast and under what oceanographic conditions they apply (i.e., warm versus cold water regimes).

Expanding our perspective of kelp forest ecosystems in time and space is providing new insights into how and why kelp forests communities naturally differ from one another. This helps managers distinguish these changes from those that might be caused by the many human uses of kelp forests.

–*Mark H. Carr, Dan Malone, Mark Readdie and Jennifer Caselle*
Department of Ecology and Evolutionary Biology, University of California Santa Cruz

Sand Waves of the Golden Gate

The mouth of San Francisco Bay was mapped in high-resolution multibeam sonar for the first time ever in 2004 and 2005. The survey, performed over 44 days by the Seafloor Mapping Lab at California State University Monterey Bay, consisted of 1.1 billion soundings and covered an area of 154 square kilometers (60 square miles). The survey showed that significant bathymetric changes have occurred over the past 50 years at the mouth of San Francisco Bay and that the study area contains sand waves that are among the largest, and bedform morphologies (seafloor shapes) that are among the most varied, in the world.

Some of the largest sand waves are located just west of the Golden Gate Bridge (*Figure 1*). These waves have been formed by abundant sediment and extremely powerful tidal currents of up to 2.5 meters per second. This massive sand wave field covers an area of approximately 4 square kilometers in water depths ranging from 30 meters (98 feet) to 106 meters. More than 40 distinct sand waves were identified, with an average wavelength of 82 meters and an average height of 6 meters. The maximum wavelength and height are 220 meters and 10 meters, respectively. Sand wave crests can be traced continuously for as far as 2 kilometers across the mouth of this energetic tidal inlet, where each tide forces 2 billion cubic meters (528 billion gallons) of water through the Golden Gate. The resulting strong currents sweep large volumes of sediment between the narrow rocky headlands, spanned by the Golden Gate Bridge, into the bay during the flooding tide and toward the Pacific Ocean during the ebbing tide.

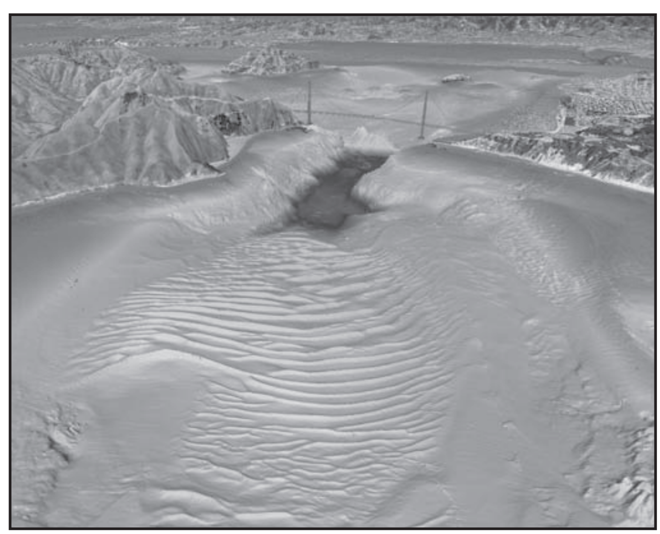


Figure 1. View from the west toward San Francisco Bay showing the massive sand wave field. The city of San Francisco is in the upper right hand portion of the image.

This recent survey has documented that the bathymetry at the mouth of San Francisco Bay has changed considerably since the last complete survey was conducted by the National Oceanic and

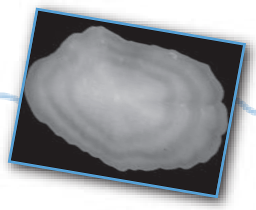
Atmospheric Administration's (NOAA) National Ocean Service in 1956. The large-scale morphological trend is sediment loss. The average depth change in the region was -70 centimeters (-2.3 feet, erosion), which amounts to about 105 million cubic meters (137 million cubic yards) of sediment loss in the common survey area in 50 years. The outer lobe of the ebb tidal delta (i.e., the bar at the mouth of San Francisco Bay) is completely dominated by erosion. Several likely causes for the observed trend include the reduction in tidal prism or currents of approximately 30 percent due to San Francisco Bay development, a decrease in sediment supply due to removal by sand mining inside the bay of approximately 50 million cubic meters since the middle of the 20th century, and a reduced influx of hydraulic mining debris from the Sacramento River.

The multibeam survey at the mouth of San Francisco Bay revealed fascinating geomorphic features, but this research also has practical implications for a number of societal issues. The flux of sand and gravel between San Francisco Bay and the coastal ocean is an important component of the littoral (coastal) sediment budget. Understanding the mechanisms of transport and the quantity of material transported are integral to the proper management of sediment in the region. Key sediment management-related issues include dredging of the navigation channel, local coastal erosion, sand mining for construction and fill, and sources of sediment for beach nourishment. The giant sand waves are also expected to be important to the ebb and flood tidal currents at the entrance to San Francisco Bay because their effective roughness retards the flow, and eddies shed from flow separations near the crests cause substantial turbulence. The flow and turbulence influenced by the giant sand waves probably affect the mixing and dispersion of pollutants and contaminants both within and outside the bay.

This research was supported by the U.S. Geological Survey, the United States Army Corps of Engineers, San Francisco District and NOAA's Coastal Observation Technology System (COTS) Center for Integrative Coastal Observation, Research and Education (CICORE) program.

For more information on this research program, visit http://walrus.wr.usgs.gov/coastal_processes/. For data, go to http://seafloor.csumb.edu/SFMLwebDATA.htm. For more maps and images, see http://pubs.usgs.gov/sim/2006/2944/.

– Patrick Barnard
United States Geological Survey



Estuaries as Nursery Habitat for Juvenile Flatfishes

Estuaries supply many vital ecological services, including nutrient cycling, water filtration and, most notably, food and shelter for a great abundance and diversity of wildlife. Because juveniles of many fish and invertebrate species are abundant in estuaries, these habitats are widely considered to be important 'nurseries,' and this nursery role is often cited to support protection and conservation of these areas. However, the nursery role of estuaries has not been evaluated for many species.

Along the central coast of California estuaries are few in number, small in size and vulnerable to degradation from surrounding human activities and industries. Though many fish and invertebrate species have juvenile stages that occur in these estuaries, very few species are dependent solely on estuaries. Instead, juveniles use both estuaries and other, more abundant, habitats such as coastal sandy bottom. In this case, a nursery habitat is defined as the habitat that contributes disproportionately more individuals that become adults relative to other juvenile habitats.

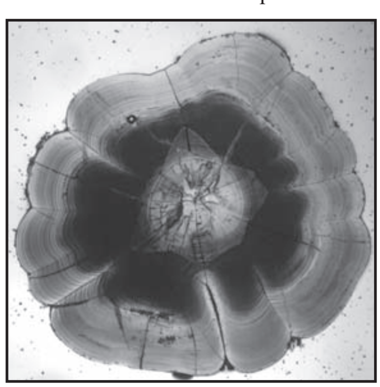


Photo by Jennifer Brown, MBNMS/NOAA

Otolith from a juvenile speckled sanddab

Do estuaries along the central coast act as nursery habitats for juvenile fishes? To address this question, I explored whether estuaries were contributing more individuals to the adult population than an equivalent area of sandy coastal habitat. To differentiate between adult fishes that had previously resided in estuaries and those that had resided along the coast, I compared the chemical composition of otoliths from two flatfish species: the English sole, *Parophrys vetulus*, and the speckled sanddab, *Citharichthys stigmaeus*. Otoliths are bones in the inner ear that grow continuously over the life of the fish. As an otolith grows, it records both the fish's growth rate and the surrounding water's chemistry. Fishes living in habitats that differ substantially in physical and chemical properties (e.g., temperature, salinity, terrestrial run-off) often record those differences in their otoliths. This chronological record of differences in the surrounding aquatic environment can be used by researchers to identify the fishes' current and prior residences.

To determine if fishes living in estuaries and on the coast had different chemical 'habitat tags' in their otoliths, juvenile fishes were collected from multiple estuaries and coastal sites along the central California coast over three years (1998-2000). Chemical analysis revealed that the otoliths from fishes collected from estuaries differed significantly in chemical composition from those collected on the coast. This difference between estuarine and coastal fishes was found over the entire region and for all three years. The chemical habitat tag was used to assign an individual fish to the habitat type (estuary or coast) from which it was collected with close to 80 percent accuracy. Because the habitat tag is permanently stored in the juvenile portion of the otolith, it could also be used to identify the juvenile habitat previously used by an adult fish.

The chemical habitat tag was examined in adult English sole collected during bottom-trawl fishing operations in the Monterey Bay region. Only fish born in 1998-2000 (the years that juvenile fish were collected) were selected for the analysis. By examining the chemical composition of the juvenile core extracted from adult otoliths, the adults were assigned to estuarine and coastal habitat groups. The percentage of the adults identified as having resided as juveniles in estuarine habitats was estimated to be approximately 50 percent. However, Elkhorn Slough (the only major estuary in the Monterey Bay region) constitutes only about 6 percent of the available juvenile habitat. This result strongly suggests that estuarine habitats in this region are nursery habitats, because they contribute more individuals to the adult English sole population than would be expected based on the relative amount of available estuarine habitat in the region.

Why might estuaries contribute proportionally more fishes than sandy coastal habitats? The relative quality of juvenile habitats is often assessed by comparing the growth rates of individuals residing in alternative habitat types. To compare growth rates in estuaries and along the coast, I employed two methods for measuring habitat-specific growth rates: a caging experiment and a comparison of the widths of daily bands in otoliths (used as a proxy for daily growth rates). In the caging experiment, growth rates were compared for juvenile sole and sanddabs residing in cages that were installed in Elkhorn Slough and along the sandy coast.

Comparison of the results from both methods indicated that estuaries in central California supported faster growth rates than coastal habitats. Higher growth rates during the juvenile phase can have a marked influence on an individual's success in both the juvenile and subsequent adult phases. For example, rapidly growing juveniles will be less vulnerable to size-selective mortality and will attain a larger size at the end of the juvenile period, which may improve recruitment success to the adult habitat. However, additional research is needed to examine differences in growth rates, as well as survivorship and density, in alternative juvenile habitats and to improve our understanding of estuaries' nursery role in central California.

Many estuarine habitats in California and around the globe are vulnerable to loss or deterioration from a variety of processes, including erosion, pollution and urbanization. Conservation of these estuarine 'nursery' habitats would protect an important source of new individuals to offshore adult populations and appears to be a useful strategy for maintaining high levels of recruitment to harvested flatfish populations in central California.

–Jennifer Brown
Sanctuary Integrated Monitoring Network (SIMoN)

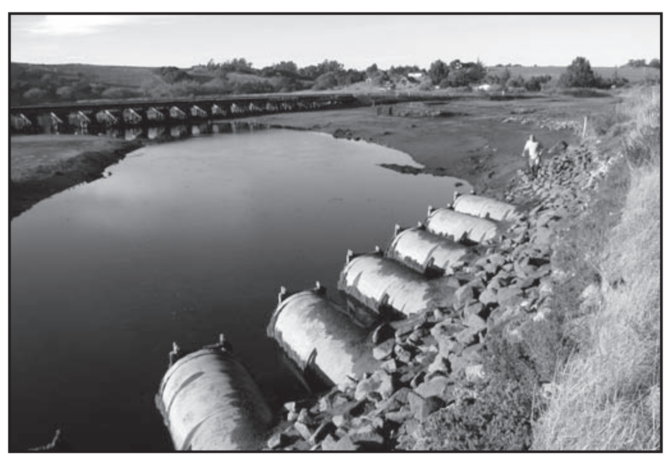
Ecological Impacts of Artificially Restricted Tidal Exchange at Elkhorn Slough

One of the most pervasive anthropogenic (human-related) disturbances to estuaries worldwide is the restriction of tidal exchange through the construction of water-control structures. Elkhorn Slough is no exception: dikes, tide gates and culverts currently restrict tidal exchange to more than a third of former tidal areas. These structures were built for many purposes, including facilitating agricultural uses, impounding freshwater for waterfowl hunting, preventing flooding of roads and protecting the passage of the railroad. Some of the former estuarine habitats behind water-control structures have been totally converted to freshwater or upland function. However, many still retain estuarine function.

How do the biological communities of these estuarine habitats with restricted tidal exchange differ from those with full tidal exchange? Our team of eight regional researchers recently answered this question, supported by funding from the Sanctuary Integrated Monitoring Network (SIMoN) and the Elkhorn Slough National Estuarine Research Reserve. We employed a variety of field approaches to rapidly assess community composition of algae, plants, invertebrates, fishes, birds and marine mammals in estuarine habitats around Elkhorn Slough with varying levels of tidal exchange.

Overall, we found that animal communities at sites with extremely restricted tidal exchange were markedly different from those with full tidal exchange. Not surprisingly, freshwater species were better represented in the former and marine species at the latter. However, animal communities at sites with moderately restricted tidal exchange were fairly similar to those with full tidal exchange.

For plants, the story was different. Tidal restriction is the single greatest cause of salt marsh loss at Elkhorn Slough, but effects on plant communities are more pronounced at sites with moderate tidal exchange than at those with extremely restricted tidal exchange. Most sites with moderate tidal exchange are managed as lagoonal habitats and have very little marsh cover or species diversity because the former marsh plain is submerged.



Tide gates at Hudson's Landing. Ecological communities were surveyed on either side of these structures, which restrict tidal exchange to the uppermost portion of Elkhorn Slough.

The results of our study suggest that tidal restriction has very different effects depending on the amount of exchange. So coastal managers should choose water-control structures and management strategies carefully, given that the resulting effects on communities are substantial.

We analyzed our results according to contrasting conservation targets and found that management recommendations varied. For instance, full exchange appears to favor native oysters, commercially valuable flatfishes, migratory shorebirds and site-level biodiversity. So to optimize these targets, existing water-control structures should be removed or enhanced to allow for more tidal exchange. On the other hand, minimal tidal exchange resulting from water-control structures supports a suite of estuarine endemics (including the endangered tidewater goby and California brackish snail) not represented elsewhere and minimizes invasions by non-native marine species. So for these targets, at least some water-control structures should be maintained. In summary, contrasting ecological indicators provided different perspectives on restoration strategies required to enhance estuarine ecosystem health, and total estuary-wide biodiversity may be enhanced with a mosaic of tidal-exchange regimes.

– Kerstin Wasson[1,2], Amy F. Ritter[1,2], Steve I. Lonhart[3], Rikke K. Preisler[1,2], Andrea Woolfolk[1], Katie A. Griffith[4], Sarah Connors[5] and Kimberly Heiman[6]

[1] Elkhorn Slough National Estuarine Research Reserve
[2] Ecology and Evolutionary Biology, University of California Santa Cruz
[3] Monterey Bay National Marine Sanctuary
[4] Ocean Sciences, University of California Santa Cruz
[5] Moss Landing Marine Laboratories
[6] Hopkins Marine Station, Stanford University

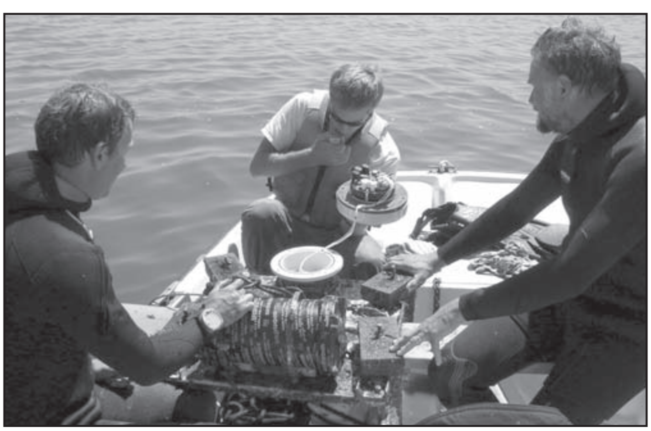
Hydrodynamics Research in Elkhorn Slough

Flows in Elkhorn Slough play an important role in shaping a wide variety of ecological and geomorphological processes operating in the slough. Starting in late 2002, Land Ocean Biogeochemical Observatory (LOBO) hydrodynamic research at Stanford has emphasized a dual approach of making field measurements and carrying out numerical modeling of flows, sediments and (most recently) nutrients.

Our field work has been focused on obtaining several-month to year-long time series of water velocities, sea level, temperature and salinity at several stations. These data make clear several important features of the flow:

1. Because differences in tidal phase along the slough are much smaller than the tidal period, the water surface rises and falls nearly uniformly along the length of the slough. As a result, tidal currents are strongly correlated with the rate of change of tidally varying water level in Monterey Bay.
2. Currents in most of the slough are ebb-dominant, meaning that outgoing tides are more intense than incoming ones. This stems from the nature of the tides in Monterey Bay rather than being an effect of the geometry of the slough itself. From a sediment standpoint, ebb dominance can lead to a net export of sediments from the system, although the actual loss of sediments may depend on the fact that ebb flows from the slough tend to bypass the harbor and exit directly into the ocean.
3. Curvature of the channel in Seal Bend and several other locations means that there are significant variations across the channel in flow. These significantly alter the fluxes of materials both up and down the slough and may be important determinants of residence time in different parts of the system.
4. During the rainy season in wet years, salinity variations are complicated by the fact that there are two freshwater sources: Carneros Creek at the head of the estuary and, via the southern half of Moss Landing Harbor, the old Salinas River channel, which enters the system at the mouth of the estuary. Subsequent mixing and transport of water from the old Salinas River is particularly important because this water can be very high in nitrate.
5. During the summer, Elkhorn Slough can become an inverse estuary with hyper-saline waters found at Kirby Park and upstream, although it appears that co-occurring variations in temperature can eliminate some or all of the density difference associated with these salinity variations. These seasonal density changes alter the residual circulation patterns in the estuary, affecting the net transport of sediment and nutrients.
6. Sediment erosion and transport events may be highly episodic and variable throughout the year and may not be easily modeled by the standard models used to represent cohesive sediment erosion and deposition in estuaries.

In addition to field work, we have carried out a simultaneous program of modeling using the three-dimensional, free-surface circulation model. Despite the challenges associated with properly modeling the significant wetting and drying of intertidal mudflats, the current



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Nick Nidzieko prepares an acoustic Doppler current profiler for deployment at LOBO2 with the help of his assistants Jim Hench (left) and Stephen Monismith (right).

model, which has a grid spacing of 10 meters in the horizontal and 1 meter in the vertical, reproduces many of the main features of the slough's flow. While the model's accuracy is continually improving, in its present incarnation it shows how water entering the slough initially retains its identity as it is carried up the slough but is largely mixed over the lower slough (i.e., below the confluence with Parson's Slough) in a single tidal cycle.

Overall, the picture gained to date of the physics of Elkhorn Slough points to the importance of the slough's geometry in determining how it responds to tidal forcing from Monterey Bay and buoyancy forcing from Carneros Creek and the Salinas River.

This research has been supported in part by the Sanctuary Integrated Monitoring Network (SIMoN) and, more recently, by the National Science Foundation through the Monterey Bay Aquarium Research Institute.

–Nicholas Nidzieko, Jim Hench and Stephen Monismith
Stanford University

Ocean Ecosystems and the Carbon Dioxide Invasion

The world ocean, once considered a vast and unchangeable resource, has been influenced in many ways by human activities, from fishing to resource mining and pollution. Perhaps one of the least widely known and understood processes by which we are altering the oceans is the rise in ocean carbon levels due to the influx of carbon dioxide (CO_2) from the atmosphere, or 'ocean acidification.' Carbon dioxide levels in the atmosphere have increased due to human activities since the expansion of agriculture across the globe and have risen abruptly during the past 150 years from fossil fuel emissions.

Roughly one third of the CO_2 emitted to the atmosphere each year (now more than 26 billion metric tons) is absorbed by the surface waters of the ocean. This is an important process: without it, atmospheric CO_2 levels would now be much higher, with far stronger warming consequences. In addition to passive CO_2 uptake, direct injection of liquid CO_2 into the deep sea is one of several strategies now under consideration to reduce atmospheric CO_2 emissions. The potentially large impact on ocean ecosystems of increasing ocean carbon levels is now an important research priority.

Once absorbed by ocean waters, CO_2 reacts with seawater to produce carbonic acid (H_2CO_3), thereby increasing the acidity (measured as a reduction in pH) of the ocean. In just the past 150 years, humans have released more than 1.1 trillion tons of CO_2 to the atmosphere, more than half of this during the past 30 years. This has increased the acidity of ocean surface waters by roughly 25 percent (an approximately 0.1 unit decrease in pH) since around 1750. By 2100, ocean pH is expected to drop by up to 0.4 units, reaching more than -0.7 units (a 900 percent increase in acidity) by around 2300 due to the increasing burden of anthropogenic (human-released) carbon. Fossil-fuel carbon is now detectable to deeper than 1,500 meters in much of the world ocean, and the deep sea will continue to acidify as the surface CO_2 invasion mixes to deep water – or by direct CO_2 injection via ocean carbon sequestration.

The scale of these changes in ocean carbon and acidity is large in the context of the natural variation that occurs among ocean basins and with depth. The upper ocean experiences the greatest CO_2 variability, particularly in seasonally productive regions such as the central California coast, where pH can vary by nearly 1 unit in the upper 1,000 meters (*Figure 1*). In contrast, the pH of deep-sea waters (depths greater than 2,000 meters) varies in all ocean basins only mildly (<0.05 – 0.2 pH units), even over thousands of years.

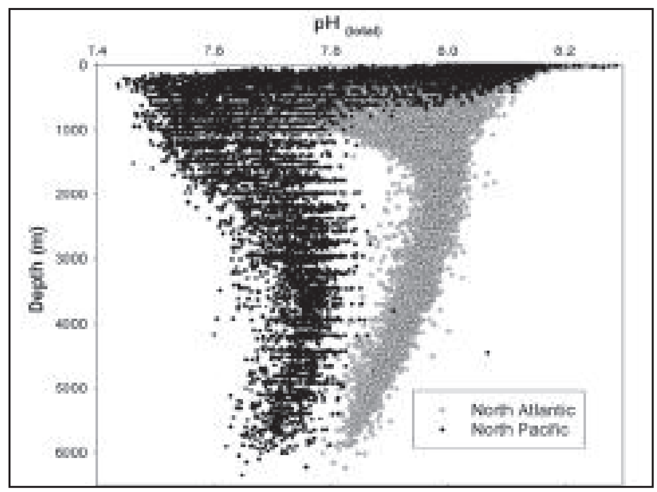


Figure 1. pH versus depth in the Atlantic and Pacific oceans. Note the less acidic (higher pH) waters of the North Atlantic compared to the colder waters of the North Pacific.

Is ocean acidification benign for ocean ecosystems? The physiological challenges associated with seawater acidity are similar for all animals but are more severe for deep-sea animals with very low metabolic rates. Oxygen-binding by respiratory proteins used by many marine animals (such as hemoglobin in our blood) is impaired by a reduction in pH, leading to respiratory stress and limited aerobic scope. Acidosis (high acid and low bicarbonate levels) of internal fluids by immersion in acidic seawater impairs metabolic processes and requires energy for restoration of normal internal pH. Higher ocean CO_2 levels also decrease the 'carbonate saturation state' of seawater, increasing the difficulty for animals to build calcium carbonate skeletons or shells. These issues, if not lethal, will generally increase the energetic costs of day-to-day life in the ocean – energy that would otherwise be used for growth or reproduction.

Although CO_2-related stresses will likely occur throughout the oceans, they are expected to be most severe for deep-sea organisms that have evolved in habitats with minimal environmental variation and limited food resources. The physiological literature on deep-sea animals supports this notion, but little research has focused specifically on the consequences of ocean acidification. It appears that

Figure 2. World map indicating the aragonite saturation depth (ASD, or Omega-A), the depth below which aragonite, a form of calcium carbonate, will dissolve. Aragonite is a primary carbonate compound used in deep-sea coral skeletons. The ASD off California is only around 500 meters, shallower than the peak of Davidson Seamount. Hatching indicates areas with no data.

shallow-living species may be more tolerant of pH changes *per se* but could suffer from reduced calcification. Deep-sea species appear intolerant of even minor changes in pH, and species with calcium-carbonate skeletons, such as many deep-sea corals, may be doubly impacted.

Our recent research has focused on the potential impacts of passive ocean acidification or direct ocean carbon sequestration on deep-sea animals. Using field experiments performed at depths near 3,600 meters off central California, we have simulated ocean carbon sequestration by releasing liquid CO_2 into containers placed on the seabed and evaluated the tolerance of animals placed nearby to elevated CO_2 levels (hypercapnia) in the dissolution plume emanating from these pools. Our results indicate that a reduction in pH near 0.2 units may cause significant mortality for a wide variety of organisms living on the seabed. Most small infaunal animals (e.g., crustaceans, meiofaunal protists) and invertebrate megafauna (e.g., urchins, sea cucumbers) found in or on the sediment succumbed during month-long exposure to the mildly acidic dissolution plume. Some deep-sea fishes, however, were surprisingly tolerant of short-term, but relatively severe, hypercapnia. Microbial communities appeared to respond positively following hypercapnic events, perhaps due to tolerance and growth by some of these microbial species.

In the lab, we have compared the physiological responses of a deep-sea crab (Tanner crab, *Chionoecetes tanneri*) to a shallow-living crab (Dungeness crab, *Cancer magister*). These experiments show clearly that the Dungeness crab is quite capable of coping with relatively severe hypercapnia for short periods. The deep-sea crab, however, exhibited little ability to recover from similar internal acidosis.

Considering the ominous climate projections for the next few centuries, there is a distinct possibility that ocean acidification will increase in prominence as a significant threat to deep-sea species and ecosystems. Deep-sea corals, for example, are now known to be very long-lived and highly vulnerable to bottom trawling, which can destroy centuries-old coral colonies and require centuries to recover. Such corals have aragonite (a form of calcium carbonate) skeletons that are vulnerable to acidic conditions. Off California, the aragonite saturation depth (ASD; *Figure 2*) is quite shallow (depths less than 500 meters), forcing deeper-living corals to protect carbonate elements of their skeleton from dissolution. Increased acidity in the ocean of the future will raise the depth of the ASD and will likely increase the physiological costs of calcification for deep-sea corals. Ocean acidification, just a new kid on the block among concerns for ocean health, is almost certain to become, in our children's lives, a major threat for ocean ecosystems.

–James P. Barry, Eric F. Pane and Peter G. Brewer
Monterey Bay Aquarium Research Institute

Surface Current Mapping with High-Frequency Radar: Building the Tools for Hazardous Spill Response

Technology is helping to create new and expanded options to monitor the marine ecosystem. This fact alone is one of the reasons that there is a renewed focus on ocean observing at all levels of government as well as within the marine science community. Observing the ocean through various methods of direct and remote sensing makes it possible to connect processes, to track events and, in some cases, to predict future actions.

One of the major new observing system technologies that is helping in this regard is the use of radio-wave backscatter to map surface currents over wide swaths of the coastal ocean. The instruments themselves are commonly referred to as high-frequency (HF) radars. They exploit the fact that radio waves propagate large distances out and back over the surface of the conducting sea water, and they have resonant interactions with ocean surface waves (i.e., the ones that can make people seasick). Back at the shoreline, a measurement of the frequency offset (i.e., Doppler shift) of the reflected radio waves provides a remotely sensed measurement of the speed of the ocean waves and surface currents. Since the instruments themselves are on the shoreline, they can be easily maintained, making them perfect candidate instruments for ocean-observing systems. (*See photo.*)

The area around the Monterey Bay National Marine Sanctuary has long been a testing ground for surface current mapping by HF radar. Recently, the State of California invested significantly in this capability as part of its Coastal Ocean Currents Monitoring Program (COCMP; www.cocmp.org). That program is funding the installation and initial operation of HF radars throughout the state, which is being undertaken by members of two academic consortia. The northern consortia recently expanded the monitoring area around central California to extend from Gerstle Cove (north of San Francisco) down to Point Sur with coverage out to about 60 kilometers from shore (*Figure 1*). These types of map are updated every hour based on input from 14 individual stations along the open coastline and three stations within San Francisco Bay. They contain a wealth of detailed information about the changing coastal current patterns (which are directly related to a wide range of ecosystem processes) and the direct movement of materials delivered to the coastal ocean from terrestrial sources.

Areas of direct application of this type of mapping data include responding to oil spills or search and rescue efforts. Knowing how the surface currents vary both spatially and temporally is critical to the prediction of surface particle trajectories (i.e., movements). It is usually not sufficient to use a single velocity measurement to predict such movements because of the complex spatial and temporal nature of coastal circulation patterns. For these reasons, the continuous, real-time, two-dimensional nature of the HF radar-derived surface current maps is extremely helpful.

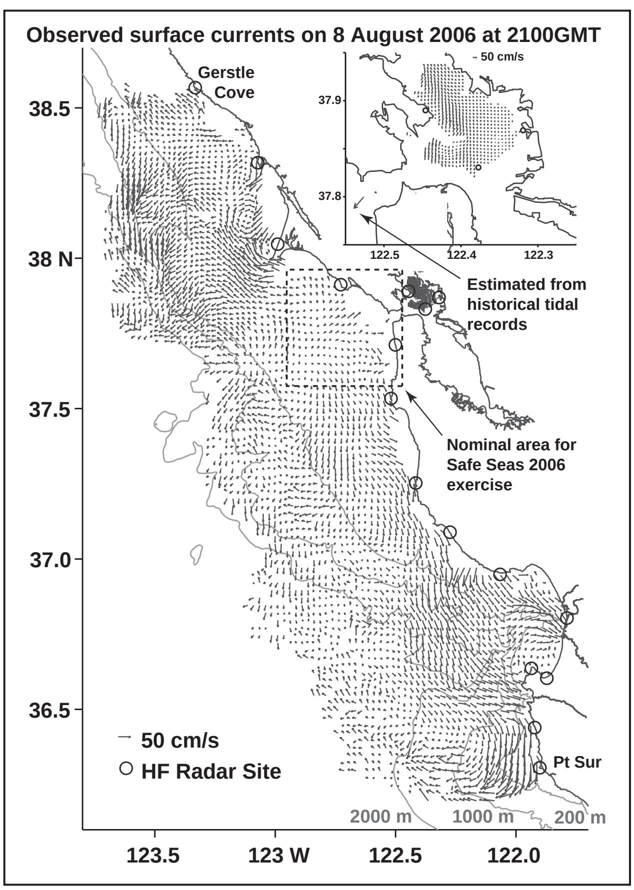


Figure 1. HF radar-derived ocean surface currents along the central California coast and inside San Francisco Bay (inset). The length of individual arrows indicates the speed of the surface currents.

CODAR-type HF radar antenna deployed along the coast south of Monterey

A direct test of the benefits of surface current mapping was made as part of the 'Safe Seas 2006' oil-spill response drill (http://sanctuaries.noaa.gov/safeseas/), which took place offshore of San Francisco in August. Although this exercise was initiated by the National Marine Sanctuaries Program, it included a large number of participants from the U.S. Coast Guard and other state and federal agencies.

To be most useful in a response scenario, surface current mapping products must include forecasts of where floating objects will be one or two days later. The COCMP team has developed such a capability, which was used successfully during Safe Seas 2006 and is undergoing continual testing and refinement. The real-time forecasting product involves many steps, including (1) downloading data from the individual radar sites, (2) combining those data to make maps of the surface currents, (3) spatially smoothing those typically gappy maps, (4) computing the average and tidal-period flow characteristics for the past several days at each point in the maps and (5) predicting the future flow at each point, based on those characteristics. In the 'Safe Seas 2006' area, an additional step was added that involves inserting an estimate of the tidal flow at the mouth of the Golden Gate, which is an area of very strong currents that is not measured by the present HF radar network geometry. (*See Figure 1.*)

The prediction system was able to distinguish the oppositely directed paths taken by simulated oil spills (drift card releases) north and south of the Golden Gate during Safe Seas 2006. Examples of today's observed and predicted particle trajectories are hosted on the web site for the Central and Northern California Ocean Observing System (CeNCOOS; www.cencoos.org/currents), while additional information and archival data can be found at cencalcurrents.org. In terms of wide-area ocean current monitoring, this represents just the beginning. Through the collaborative efforts of the State of California and federal observing programs, marine sanctuaries along the California coast have a new tool for monitoring the ecosystems they were created to protect.

–Jeffrey D. Paduan[1], David Kaplan[2], Newell Garfield[3] and John Largier[4]

[1]Naval Postgraduate School
[2]University of California Santa Cruz
[3]San Francisco State University
[4]University of California Davis

Marine Mammals off Our Coast: A Summary of CSCAPE 2005

Marine mammals are among the most visible and charismatic animals along our coastline. The rich, productive waters of the California Current System are home to more than 30 whale, dolphin and porpoise species (collectively known as cetaceans), six seal and sea lion species (pinnipeds) and one sea otter species. Although historical whaling and hunting decimated several populations, and some species remain listed as threatened or endangered under the Endangered Species Act, all marine mammals have been protected since 1972 by the Marine Mammal Protection Act. Most U.S. West Coast marine mammal populations are now recovering or stable.

To manage human impacts on marine mammals, NOAA Fisheries is periodically required to assess the abundance, distribution and status of all marine mammals in U.S. waters. While pinnipeds can effectively be counted when they are on land to breed, the primary means of estimating the abundance of most whale and dolphin species is via large oceanographic research vessels that remain at sea for many months at a time, covering extensive areas (*Figure 1*). Teams of experienced observers search for mammals during daylight hours, using high-powered binoculars from the flying bridge of the vessel. When animals are encountered, the ship is directed towards their location to allow species identification and group size estimation. With groups numbering from a few to thousands of individuals, and often containing two to four different species, this can be a formidable challenge. At the end of the field survey, data are checked, compiled and statistically analyzed to estimate the abundance of all species seen. Such broad-scale surveys have been conducted previously along the U.S. West Coast in 1991, 1993, 1996 and 2001.

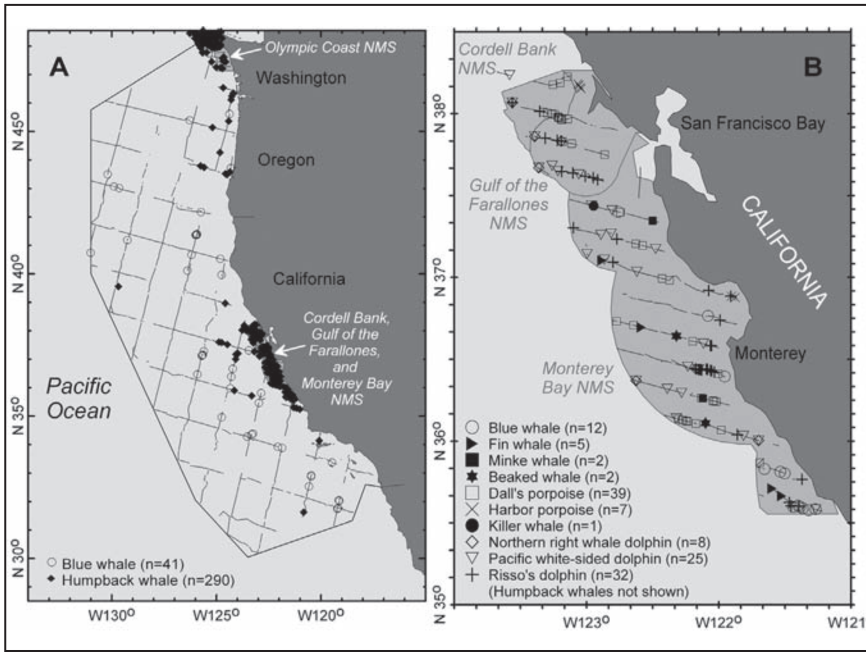


Figure 1. (A) Survey transects (gray lines), national marine sanctuaries (light shading) and sightings of blue and humpback whales during the June-December 2005 CSCAPE project (B) Survey transects (gray lines) and sightings of cetaceans within the central California sanctuaries during July 2005

Cetacean Species Encountered during CSCAPE

SPECIES COMMON AND SCIENTIFIC NAME	Central California NMS	Entire West Coast Study Area
Dall's Porpoise, *Phocoenoides dalli*	2,000	55,700
Pacific White-Sided Dolphin, *Lagenorhynchus obliquidens*	3,500	21,000
Risso's Dolphin, *Grampus griseus*	2,100	6,800
Northern Right-Whale Dolphin, *Lissodelphis borealis*	2,600	6,500
Bottlenose Dolphin (offshore stock), *Tursiops truncatus*	—	1,500
Striped Dolphin, *Stenella coeruleoalba*	—	16,400
Short-Beaked Common Dolphin, *Delphinus delphis*	—	311,000
Long-Beaked Common Dolphin, *Delphinus capensis*	—	7,800
Killer Whale, *Orcinus orca*	35	790
Short-Finned Pilot Whale, *Globicephala macrorhynchus*	—	500
Baird's Beaked Whale, *Berardius bairdii*	—	430
Mesoplodont Beaked Whales, *Mesoplodon spp.*	—	1,800
Cuvier's Beaked Whale, *Ziphius cavirostris*	—	2,700
Sperm Whale, *Physeter macrocephalus*	—	2,400
Humpback Whale, *Megaptera novaeangliae*	960	1,700
Blue Whale, *Balaenoptera musculus*	90	680
Fin Whale, *Balaenoptera physalus*	30	2,900
Sei Whale, *Balaenoptera borealis*	—	80
Minke Whale, *Balaenoptera acutorostrata*	15	940

Table 1. Cetacean species encountered during CSCAPE, with preliminary abundance estimates for waters within the central California national marine sanctuaries and for the entire study area extending 555 kilometers (300 nautical miles) from shore ('—' indicates no sightings were made). No estimates were made for harbor porpoise, gray whales or pinnipeds because these species are monitored via separate surveys.

During 2005, the broad-scale assessment survey was coordinated with additional fine-scale surveys conducted within four of the five West Coast national marine sanctuaries. This joint effort, termed CSCAPE (Collaborative Survey of Cetacean Abundance and the Pelagic Ecosystem) began in June off Washington state aboard the NOAA ship *McArthur II* and continued aboard the NOAA ship *David Starr Jordan* from August through December. Although marine mammals were the primary species of interest, the project also obtained systematic data on seabirds, zooplankton and the physical oceanographic environmentalong the survey track. The results of this extensive research cruise will provide a broad ecological context for patterns of marine mammal occurrence within sanctuary waters relative to the entire California Current. Following and in Table 1 we present some preliminary findings and interesting patterns observed for marine mammals during the survey. The data are currently being processed for more comprehensive analyses in the future.

Many marine researchers off California reported that patterns in 2005 were strikingly different than in the past. The usual spring and early summer upwelling pattern off central California was disrupted, resulting in poor recruitment of zooplankton prey and causing breeding failures for some seabirds. During CSCAPE, we also noted a conspicuous scarcity of some zooplankton feeders, most notably the blue whale, *Balaenoptera musculus*. Blue whales are commonly observed within waters of the Monterey Bay, Gulf of the Farallones and Cordell Bank National Marine Sanctuaries during the summer, when they feed on dense swarms of krill (*euphausiids*). But during CSCAPE, blue whales were encountered infrequently within the sanctuaries, with the only concentration found at the southern edge of the Monterey Bay sanctuary during July (*Figure 1B*). Most blue whale sightings were in waters well offshore and to the north and south of sanctuary waters (*Figure 1A*).

The lack of adequate zooplankton prey did not, however, mean that all marine mammals were absent or scarce within sanctuary waters. Many other marine mammal species forage primarily on fish prey or can switch between prey types as availability changes. For example, humpback whales, *Megaptera novaeangliae*, are known to feed on both zooplankton (krill) and small schooling fishes. During our study, we observed hundreds of humpback whales within the three sanctuaries' waters, feeding on dense aggregations of schooling fishes. Our preliminary abundance estimates suggest that more than half the U.S. West Coast population of humpback whales was feeding within the boundaries of the three central California sanctuaries during July (*Table 1*). Thus, although the ecosystem and some species distributions were different during 2005, we still observed an abundance of marine life.

Our preliminary cruise results make it clear that the West Coast national marine sanctuaries are important habitat for marine mammals, supporting a wide diversity of species (*Figure 1B*) and a substantial proportion of the estimated population of some species, including humpback whales and some dolphins. It is important to remember, however, that this region is oceanographically dynamic, and the distribution of animals varies considerably from year to year. An interesting illustration of this was the 2005 distribution of northern fur seals, *Callorhinus ursinus*, a species that is generally found tens or hundreds of kilometers from shore. We were surprised to find many individuals within 10 to 20 kilometers of the central California coast during July 2005. Although the reasons for this observation are presently not known, it is possible that their prey was less available in offshore waters, leading them to move closer to shore in search of food. Similar patterns have been observed in the past for some whale species, which were found to concentrate in Monterey Bay when offshore productivity was low, such as during the 1997-1998 El Niño event.

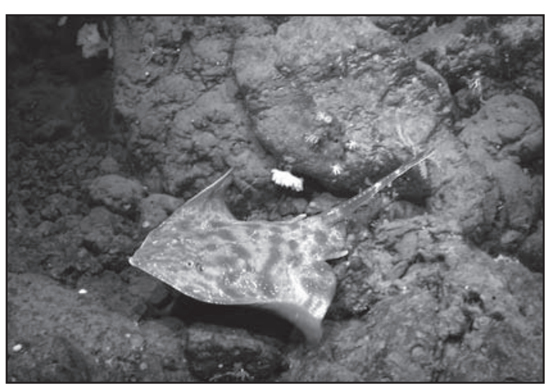
CSCAPE has provided a foundation for continued joint assessments of marine mammal populations along the U.S. West Coast and within the national marine sanctuaries. Preliminary results illustrate the importance of the sanctuaries to many species. Future collaborative studies of marine mammals and their habitat, coordinated among NOAA Fisheries, the National Marine Sanctuary Program and other partners in this region, will improve our understanding of this unique ecosystem and increase our ability to manage and protect the living marine resources off our coast effectively.

– Karin Forney
Southwest Fisheries Science Center

Sharks, Rays and Chimaeras of the Sanctuary

Shark! The word conjures up images of a large, fearsome, torpedo-shaped, toothy predator, cunningly stalking its victim from below. Although this image may make terrific Hollywood fare, most of these mysterious creatures are far different. Some shark species, such as the white shark, *Carcharodon carcharias*, do occasionally attack people. However, of the nearly 500 shark species known worldwide, fewer than 50 have been reported to attack people. (For skates, rays and chimaeras, virtually none does.) Most of the shark species that inhabit the waters of the Monterey Bay National Marine Sanctuary are, in fact, quite timid.

Sharks, rays and chimaeras (ratfishes) form a distinctive group of fishes collectively referred to as chondrichthyans. As their name implies, they are distinguished by a cartilaginous ('chondro') skeleton from most other bony fishes ('ichthy') like rockfishes (*Sebastes* spp). They live in a world that is often difficult to study, about which we know very little.



Broad skate, Amblyraja badia, on Davidson Seamount

This is slowly changing, however, due to a federally-funded program at Moss Landing Marine Laboratories (MLML) to help improve the management and conservation of sharks and rays in U.S. waters. The Pacific Shark Research Center (PSRC) is the West Coast representative of the National Shark Research Consortium (NSRC), one of four major shark research organizations working in cooperation with NOAA Fisheries.

We know that there are at least 22 shark, 18 ray and 3 chimaera species in sanctuary waters. Four of these have only been seen from video footage taken by the Monterey Bay Aquarium Research Institute (MBARI) using its ROVs *Ventana* and *Tiburon* and are new to science.

Why should we care about sharks and rays? Global shark and ray catches have been increasing at an alarming rate in recent years, prompting concern over the depletion or collapse of impacted populations. Increased U.S. shark landings and declines of some large,

COMMON NAME	SCIENTIFIC NAME
SHARKS	
Sixgill shark	*Hexanchus griseus*
Sevengill shark	*Notorynchus cepedianus*
Prickly shark	*Echinorhinus cookei*
Sleeper shark	*Somniosus pacificus*
Spiny dogfish	*Squalus acanthias*
Angel shark	*Squatina californica*
Horn shark	*Heterondontus francisci*
Whale shark	*Rhincodon typus*
Common thresher	*Alopias vulpinus*
Basking shark	*Cetorhinus maximus*
White shark	*Carcharodon carcharias*
Shortfin mako	*Isurus oxyrinchus*
Salmon shark	*Lamna ditropis*
Brown catshark	*Apristurus brunneus*
Longnose catshark	*Apristurus kampae*
Swell shark	*Cephaloscyllium ventriosum*
Filetail catshark	*Parmaturus xaniurus*
Soupfin shark	*Galeorhinus galeus*
Gray smoothhound	*Mustelus californica*
Brown smoothhound	*Mustelus henlei*
Leopard shark	*Triakis semifasciata*
Blue shark	*Prionace glauca*

COMMON NAME	SCIENTIFIC NAME
RAYS AND SKATES	
Shovelnose guitarfish	*Rhinobatos productus*
Thornback ray	*Platyrhinoidis triseriata*
Pacific torpedo ray	*Torpedo californica*
Broad skate	*Amblyraja badia*
Deep-sea skate	*Bathyraja abyssicola*
Sandpaper skate	*Bathyraja kincaidii*
Fine-spined skate	*Bathyraja microtrachys*
Pacific white skate	*Bathyraja spinosissima*
Roughtail skate	*Bathyraja trachura*
Unidentified deep-sea skate "A"	*Bathyraja sp. "A"*
Unidentified deep-sea skate "B"	*Bathyraja sp. "B"*
Big skate	*Raja binoculata*
California skate	*Raja inornata*
Longnose skate	*Raja rhina*
Pacific starry skate	*Raja stellulata*
Round stingray	*Urobatis halleri*
Pelagic stingray	*Pteroplatytrygon violacea*
Bat ray	*Myliobatis californicus*
CHIMAERAS	
White-spotted chimaera	Hydrolagus colliei
Black chimaera	Hydrolagus sp. "A"
Davidson Seamount chimaera	Hydrolagus sp. "B"

Shark, ray and chimaera species occurring within sanctuary boundaries

coastal shark populations by as much as 85 percent prompted NOAA Fisheries to develop Fisheries Management Plans (FMPs) for the Atlantic Ocean and the Gulf of Mexico.

PSRC is addressing the lack of critical life history information that has hindered the development of sustainable management strategies for eastern North Pacific (ENP) sharks and rays by working with NOAA Fisheries and state agencies. We mainly study the life histories (age, growth, reproduction, demography and feeding ecology) and population structure of cartilaginous fishes. To date, we have studied the ecology of 23 chondrichthyan species in sanctuary waters. Several of our current sanctuary research projects are collaborative efforts with the NOAA Fisheries Santa Cruz Laboratory, which provides specimens for our studies from its surveys.

In the past three decades, fish ecologists at MLML have completed age, growth and reproduction studies of sharks (14 species), skates (5 species) and rays (1 species), and we are continuing studies on other skate species, both in the sanctuary and other parts of the ENP. Lately, PSRC scientists have been conducting life history studies on skates – mainly because of their susceptibility to bycatch from trawl fisheries; the lack of knowledge about their life histories; and their tendency to grow slowly, mature late in life and have few offspring. Our studies on sanctuary species indicate that the skates studied range in longevity from around 13 to 26 years of age, with first age-at-maturity between around 7 and 14 years of age. Their fecundity (number of offspring) ranges from one to a few offspring per egg case. So far, these skates appear to differ from sharks in that they do not seem to have a seasonal reproductive cycle, and they produce eggs all year round.

We have studied the feeding habits of four skate species (big, *Raja binoculata*; California, *R. inornata*; longnose, *R. rhina*; and sandpaper, *Bathyraja kincaidii*), all of which are common, soft-bottom, continental shelf and upper slope species. The skates in this assemblage are primarily generalist crustacean and fish predators that exhibit high dietary overlap at similar sizes and depths. Small (less than 60 centimeters total length) skates of all four species ate mainly crustaceans, especially shrimp, krill and crabs, whereas larger specimens were largely piscivorous (fish-eaters). Skates thus appear to play important roles in benthic food web dynamics in sanctuary waters.

To date, we have only examined the population genetics of the three thresher shark species. In the sanctuary, the more coastal, common thresher (*Alopias vulpinus*) is genetically more diverse than the more widely distributed pelagic (*A. pelagicus*) and big eye (*A. superciliosus*) threshers.

We also study the habitat associations, distribution and abundance of sharks and rays in the sanctuary and ENP, hoping to identify critically important nursery areas. Overfishing and disturbance of their critical habitats could endanger these populations. Therefore, knowing where these areas are will be extremely important in developing management decisions, such as development of regional marine protected areas.

PSRC and MLML use several ways to inform the general public, scientists, and state and federal agencies about sharks and rays along our coast. This information is published in refereed, scientific journals and is presented at national and international scientific meetings and on the PSRC web site. We hope that our results will help develop effective fishery management plans for these vulnerable fishes.

Please visit http://psrc.mlml.calstate.edu to access PSRC's life history data matrix (summarizing existing knowledge on 105 species of chondrichthyan) and its 'Featured Elasmobranch' series, which highlights a different species each month.

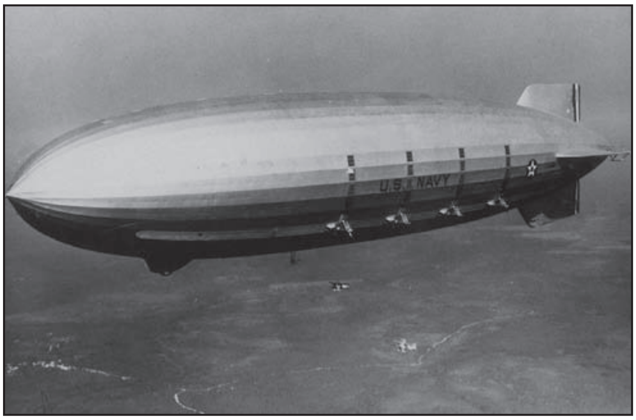
–David A. Ebert, Gregor M. Cailliet, Joseph J. Bizzarro and Wade D. Smith
Pacific Shark Research Center/Moss Landing Marine Laboratories

USS Macon Expedition 2006

A five-day archeological investigation was conducted by researchers from the Monterey Bay National Marine Sanctuary, the National Marine Sanctuary Program (NMSP), the Monterey Bay Aquarium Research Institute (MBARI) and Stanford University to document two major debris fields associated with the submerged wreck site of the rigid airship USS *Macon*, a U.S. Navy dirigible lost off California's Big Sur coast on February 12, 1935.

The National Marine Sanctuary Act mandates the NMSP to manage and protect submerged archaeological resources within the sanctuaries, including those owned by the U.S. Navy. The sanctuaries are also responsible for the development of education and outreach initiatives for those resources.

The Monterey Bay National Marine Sanctuary's draft Maritime Heritage Action Plan (2006) emphasizes the characterization and assessment of archaeological resources as a sanctuary priority. Since the discovery of the submerged remains of the Navy dirigible in 1990, NOAA and the sanctuary have designated personnel to develop a program to document archaeological resources and assess their eligibility for the National Register of Historic Places.



The Macon is in flight over land, conducting launch and recovery maneuvers of its Sparrowhawk F9C-2 biplanes.

The 785-foot USS *Macon* (ZRS-5) and its four Curtiss F9C-2 Sparrowhawk aircraft were lost during severe weather offshore of Point Sur on a routine flight from the Channel Islands to its home base at Moffett Field (south of San Francisco). The dirigible was the nation's largest and the last American-built rigid lighter-than-air (LTA) craft. *Macon* was completed in 1933 as part of the U.S. Navy's LTA aviation program and championed by Navy Chief of Aeronautics Admiral William A. Moffett. The airship was constructed with a built-in aircraft hanger and a trapeze launch and recovery system to facilitate the Sparrowhawk biplanes.

The wreckage of the *Macon* provides an opportunity to study the relatively undisturbed archaeological remnants of a unique period of U.S. aviation history. The project was designed in two phases: a side scan sonar survey to map the distribution of the wreck site (May 1-5, 2005 onboard the NOAA R/V *McArthur II*); and the archaeological survey phase (September 17-22, 2006).

The 2006 expedition encompassed several objectives. The technical component involved video and photo documentation of the physical remains of the airship and four aircraft using a remotely operated vehicle (ROV) tethered to MBARI's R/V *Western Flyer*. An outreach component included the hosting of a live web uplink during the operations to educate students and the community about the deep-water technology used to conduct an archaeological survey as well as a 'teacher at sea' who provided daily updates posted to the Internet.

The mission's primary goal was to conduct a comprehensive survey of the wreck site that can be used to evaluate the archaeological context of the craft's remains. This will allow NOAA/NMSP and the U.S. Naval Historical Center to determine the condition of the site, the level of preservation of the archaeological remains and the potential for future research at the site. It also provided an opportunity to identify the remaining elements of the aircraft.

During the research cruise, more than 40 hours of deep-water surveys were completed using MBARI's ROV *Tiburon*. The surveys recorded the visual wreckage through high-definition videotape and still imagery that will be used to create a photo-mosaic of the two debris fields and for further site assessment.

Two debris fields, designated A and B, measure 60 meters in diameter and are elevated several meters above the seafloor. The fields are separated by a distance of 250 meters and show an accumulation of several centimeters of sediment since the initial 1990 surveys. Scientists have concluded that sections of the aluminum girder show signs of degradation after 71 years in the marine environment.

Some of the distinguishable features in Debris Field A include the airship's hangar bay containing four Sparrowhawk biplanes; two were identified by individual color striping on their wings. Five of the *Macon*'s eight German-built Maybach 12-cylinder gasoline engines were identified. Objects from the ship's galley were recorded, including two sections of the stove with propane tanks and the enlisted men's dining table and bench. Debris Field B contained the *Macon*'s bow section, including the mooring mast receptacle assembly. This field also contains aluminum chairs and desks that may have been from the officers' or meteorologist's office.

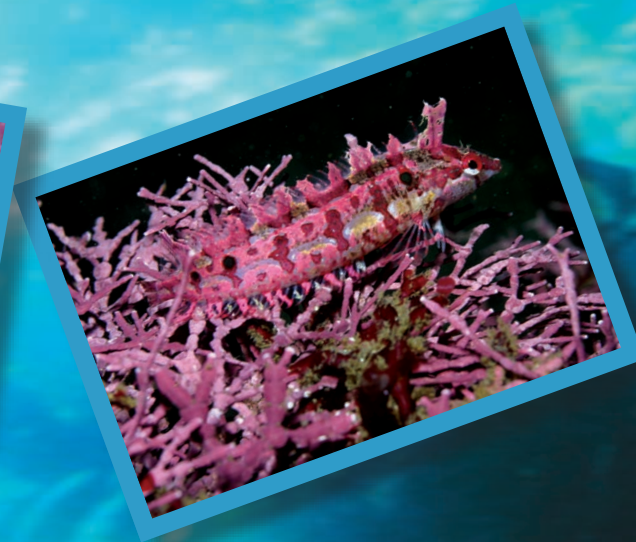
Our next steps are to process 10,000 high-definition video stills into a seamless photo-mosaic (to assist in identifying and assessing artifacts and their distribution) and to create a poster for public outreach. We also plan to prepare a final report and work towards nominating the USS *Macon* and the four Sparrowhawk biplanes to the National Register of Historic Places.

Submerged view of the sky-hook located at the center of the Curtiss Sparrowhawk F9C-2 biplane. During flight, the pilot positioned the aircraft below the Macon's hangar, where a trapeze was lowered; the pilot positioned the hook onto the trapeze. Sparrowhawk pilots were nicknamed the 'men on the flying trapeze.'

This expedition provides a good model for future deep-water archaeological surveys. Not only did it meet Federal Archaeological Program standards and the Sanctuary Act mandate, the results of this mission will aid the Monterey Bay sanctuary in managing and protecting the wreck site of the USS *Macon*.

For more information on the USS *Macon* expeditions, visit http://www.montereybay.noaa.gov/research/macon/welcome.html and http://sanctuaries.noaa.gov/missions/2006macon/welcome.html.

– *Robert V. Schwemmer*
National Marine Sanctuaries West Coast Regional Maritime Heritage Program



Credits

Editor – **Jenny Carless**

Graphic designer – **Judy Anderson**

Reviewers – **Andrew DeVogelaere, Dawn Hayes, Liz Love, Holly Price**

Photographers – as noted, and:

Front cover, clockwise from the top: vermillion rockfish: **Steve Lonhart**; kelp greenlng, coraline sculpin and snubnose sculpin: **Chad King**; black and yellow rockfish: **Josh Pederson** Background photo: **Kip Evans, courtesy of NOAA**

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National Oceanic and Atmospheric Administration

Monterey Bay National Marine Sanctuary
299 Foam Street
Monterey, CA 93940
(831) 647-4201
http://www.mbnms.nos.noaa.gov/

We welcome comments, which should be sent to Dawn Hayes, education coordinator, at the address above.

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Josh Adams, Moss Landing Marine Laboratories

Patrick Barnard, United States Geological Survey

James P. Barry, Monterey Bay Aquarium Research Institute

Joseph J. Bizzarro, Pacific Shark Research Center/Moss Landing Marine Laboratories

Peter G. Brewer, Monterey Bay Aquarium Research Institute

Jennifer Brown, Sanctuary Integrated Monitoring Network (SIMoN)

Gregor M. Cailliet, Pacific Shark Research Center/Moss Landing Marine Laboratories

Mark H. Carr, Dept. of Ecology and Evolutionary Biology, University of California Santa Cruz

Jennifer Caselle, Dept. of Ecology and Evolutionary Biology, University of California Santa Cruz

Sarah Connors, Moss Landing Marine Laboratories

Andrew DeVogelaere, Monterey Bay National Marine Sanctuary

David A. Ebert, Pacific Shark Research Center/ Moss Landing Marine Laboratories

Karin Forney, Southwest Fisheries Science Center

Newell Garfield, San Francisco State University

Katie A. Griffith, Dept. of Ocean Sciences, University of California Santa Cruz

Karen Grimmer, Monterey Bay National Marine Sanctuary

James T. Harvey, Moss Landing Marine Laboratories

Dawn Hayes, Monterey Bay National Marine Sanctuary

Kimberly Heiman, Hopkins Marine Station, Stanford University

Jim Hench, Stanford University

David Kaplan, University of California Santa Cruz

John Largier, University of California Davis

Steve Lonhart, Monterey Bay National Marine Sanctuary

Liz Love, Monterey Bay National Marine Sanctuary

Dan Malone, Dept. of Ecology and Evolutionary Biology, University of California Santa Cruz

Stephen Monismith, Stanford University

Nicholas Nidzieko, Stanford University

Jeffrey D. Paduan, Naval Postgraduate School

Eric F. Pane, Monterey Bay Aquarium Research Institute

Rikke K. Preisler, Elkhorn Slough National Estuarine Research Reserve

Holly Price, Monterey Bay National Marine Sanctuary

Josh Pederson, Sanctuary Integrated Monitoring Network (SIMoN)

Mark Readdie, Dept. of Ecology and Evolutionary Biology, University of California Santa Cruz

Amy F. Ritter, Elkhorn Slough National Estuarine Research Reserve

Robert V. Schwemmer, West Coast Regional Maritime Heritage Program

Wade D. Smith, Pacific Shark Research Center/ Moss Landing Marine Laboratories

Kerstin Wasson, Elkhorn Slough National Estuarine Research Reserve

Andrea Woolfolk, Elkhorn Slough National Estuarine Research Reserve