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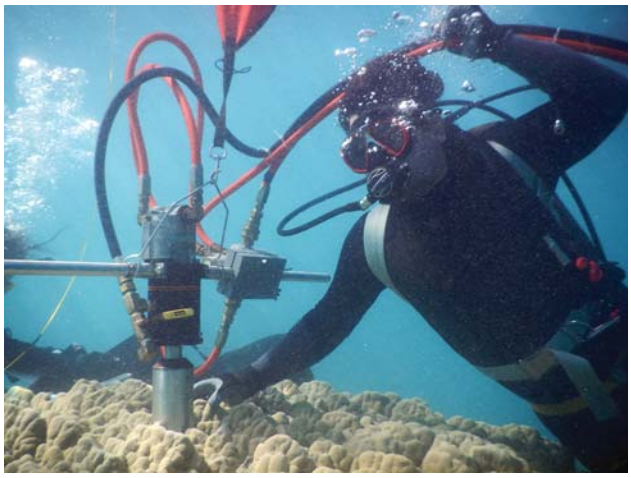
Fieldwork

USGS and Hawai‘i Researchers Collaborate to Better Understand Changing Coral Reef Ecosystems Along West Maui, Hawai‘i

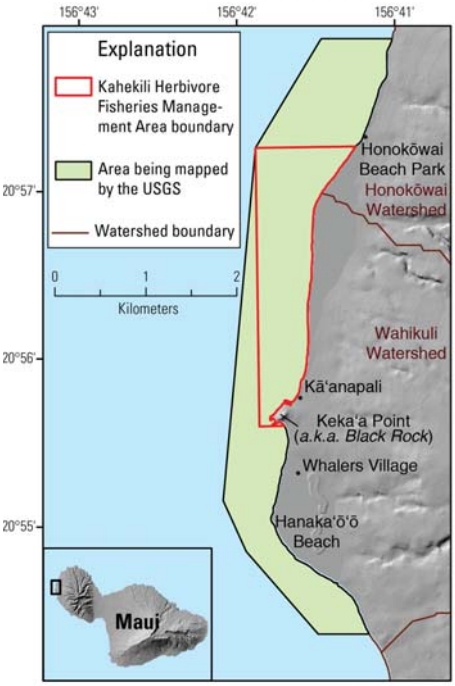
By Curt Storlazzi and Susan Cochran

Over the past decade, there has been a notable change in seafloor-bottom type along west Maui, Hawai‘i. Nearshore areas, once dominated by corals, are now mostly overgrown by algae, suggesting a local nutrient imbalance that warrants further investigation. Previous studies by the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), State of Hawai‘i, and University of Hawai‘i have documented the magnitude of change along this section of the coast and have investigated the causes driving these changes.



*USGS engineering technician **Pete Dal Ferro** checks the status of the hydraulic drill during the coring of a head of* Porites lobata*, 4 meters (13 feet) in diameter, off Olowalu, west Maui. The resulting core may document environmental conditions as far back as pre-European times. The water depth is approximately 3 meters (10 feet). USGS photograph by **Curt Storlazzi**.*

In 2009, the Hawai‘i Department of Land and Natural Resources’ Division of Aquatic Resources (HI-DAR, <**http://state.hi.us/dlnr/dar/**>) established the Kahekili Herbivore Fisheries Management Area (KHFMA), designated to improve the health of the coral reef ecosystem by increasing the number of herbivores (plant eaters) to help reduce the turf algae and macroalgae that have overgrown the corals at the site.



West coast of Maui, showing the boundary of the State of Hawai‘i Kahekili Herbivore Fisheries Management Area and the extent of the area being mapped by the USGS, which covers the U.S. Coral Reef Task Force Watershed Partnership Initiative Kā‘anapali priority study area.

In early 2011, the U.S. Coral Reef Task Force (USCRTF, <**http://www.coralreef.gov/**>) Watershed Partnership Initiative selected the Kā‘anapali area of west Maui as the second of three national priority study areas on which to focus its research and restoration efforts. Driven by this national support, the Hawai‘i Coral Reef Strategy (<**http://www.hawaiicoralreefstrategy.com/**>) identified the coral reef ecosystem of west Maui as a priority management area. Likewise, the West Maui Ridge to Reef (R2R) Initiative published the Wahikuli-Honokāwai Watershed Management Plan (<**http://www.westmauir2r.com/watershed-management-plan.html**>), which provides a framework for reducing the generation and transport of land-based pollutants (generally sediment, but also nutrients, such as nitrogen from agricultural fertilizers) to improve water quality and the health of west Maui’s coral reef ecosystems.

In cooperation with HI-DAR, the USGS Coastal and Marine Geology Program (<**http://marine.usgs.gov/**>) initiated a multidisciplinary effort in 2012 to provide scientific information in support of both USCRTF and HI-DAR priorities in west Maui. This effort includes the following:

- Constructing a high-resolution map of the underwater environment along the west coast of Maui.
- Recovering coral cores to provide historical records of sediment and nutrient inputs to the reefs along west Maui, in order to put recent instrument measurements into longer-term context.
- Making time-series measurements (measuring the same variable at regular time intervals) of nutrient and contaminant inputs to coastal waters from the submarine discharge of fresh groundwater (flowing seaward in un-

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Sound Waves

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Deadline: The deadline for news items and publication lists for the January/February issue of *Sound Waves* is Tuesday,December 3.
Publications: When new publications or products are released, please notify the editor with a full reference and a bulleted summary or description.
Images: Please submit all images at publication size (column, 2-column, or page width). Resolution of 200 to 300 dpi (dots per inch) is best. Adobe Illustrator© files or EPS files work well with vector files (such as graphs or diagrams). TIFF and JPEG files work well with raster files (photographs or rasterized vector files).

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Fieldwork, continued

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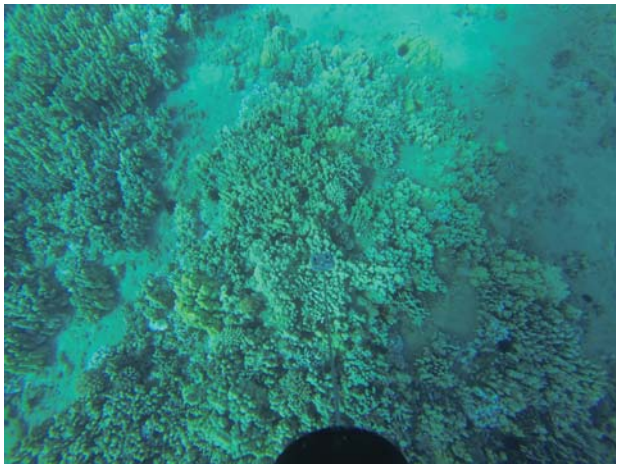
derground aquifers and discharging from the seafloor either by diffuse flow from sediment pores or through discrete submarine vents).
- Deploying satellite-trackable drifters from key reefs to measure near-surface currents that transport coral larvae, in order to better understand the connectivity between different reefs and islands.



*Ground-truth still image of coral on the seafloor, captured from digital video collected off the west coast of Maui. A 2-pound lead diving weight (small gray object near center of image) was suspended 1 meter (3 feet) below the camera to maintain a vertical orientation in the current and to provide a safety buffer for the camera. HI-DAR photograph by **Darla White**.*

Susan Cochran and **Ann Gibbs** (USGS Pacific Coastal and Marine Science Center [PCMSC], Santa Cruz, California) worked with **Darla White** (HI-DAR) in winter 2012–2013 to begin constructing high-resolution maps of the underwater environment along the west coast of Maui (see map on page 1). They used existing satellite imagery, bathymetric data from airborne lidar (light detection and ranging), sidescan-sonar data, and georeferenced underwater video. Maps of dominant structure (such as mud, sand, reef) and major biological cover (such as coral, macroalgae, coralline algae) were created using methodology and a classification scheme used by the National Oceanic and Atmospheric Administration (NOAA) but at much finer spatial resolution. (The NOAA methodology is described in NOAA Technical Memorandum NOS NCCOS 19, available at <**http://ccma.nos.noaa.gov/publications/biogeography/floridatm19.pdf**> [2 MB].)

A minimum mapping unit (MMU) of 100 square meters was used (as opposed to the NOAA MMU of 1 acre [4,047 square meters]), and smaller features were mapped if they carried habitat significance (for example, an individual coral colony 2 meters in diameter located in an otherwise uncolonized area). During a multifaceted interagency effort in July 2013, the USGS Pacific Coral Reefs Project (<**http://coralreefs.wr.usgs.gov/**>), along with HI-DAR personnel, collected seafloor photographs and video for the ground-truth survey.

Also in July 2013, **Nancy Prouty**, **Josh Logan**, **Tom Reiss**, **Pete Dal Ferro**, and **Curt Storlazzi** (USGS-PCMSC) collected several cores along the west Maui coast. Given the length of the cores, it may be possible to document environmental conditions as far back as pre-European times. Prouty and Storlazzi instrumented the coral head from which one of these cores was collected with temperature, salinity, turbidity, and chlorophyll sensors in October 2012. Comparing the measurements from these sensors with the chemistry of recently formed layers of the coral skeleton will help scientists quantify relationships between coral chemistry and seawater chemistry. This calibration will enable them to use ancient coral layers to learn about the chemistry of the seawater in which those layers formed.

Processes related to the sustained discharge of coastal groundwater at a site off west Maui were studied by **Peter Swarzenski**, **Pamela Campbell**, **Cordell Johnson**, **Randy Russell**, and Storlazzi (USGS-PCMSC); **Kevin Kroeger** (USGS Woods Hole Coastal and Marine Science Center [WHCMSC], Woods Hole, Massachusetts); and **Joe Fackrell** and **Meghan Dailer** (University of Hawai'i, Honolulu). Their diverse list of analyses included time-series measurements of two

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radioactive isotopes that occur naturally in groundwater and so serve as groundwater "tracers": radon (^{222}Rn, half-life = 3.8 days) and thoron (^{220}Rn, half-life = 55.6 sec). These measurements were complemented with data from strategically placed thermistor arrays (for measuring temperature), wave- and pressure-sensors, and an acoustic Doppler current profiler (ADCP, for measuring current velocities at different heights above the seafloor). The scientists also deployed an acoustic Doppler velocimeter (ADV) capable of accurately measuring wave-induced pumping of focused coastal groundwater discharge.

A suite of water samples were collected from both nearby and distant groundwater wells, surface and bottom water, and sites of submarine groundwater discharge to better understand the geochemical character and composition of the discharging groundwater. Additionally, a thermal-infrared (TIR) camera installed in a building near the beach collected time-series images to record variations in submarine groundwater discharge as revealed by temperature contrasts between the discharging groundwater plume and ambient surface

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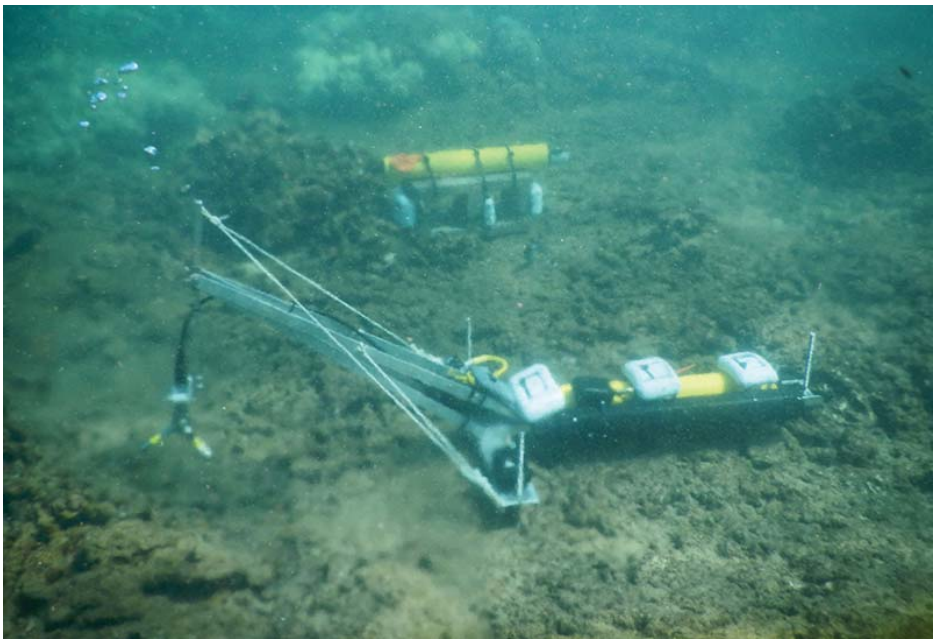
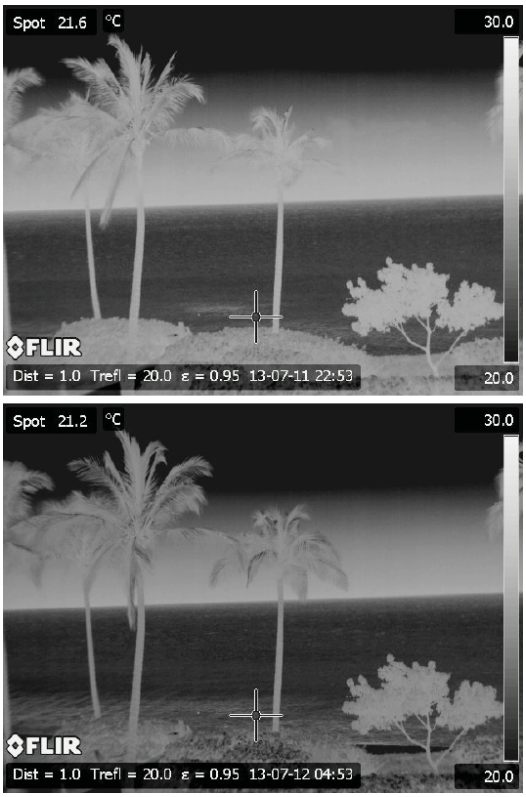


*Instruments deployed on the seafloor to understand oceanographic controls on submarine groundwater fluxes off west Maui. The blurriness of the photograph is caused by fresh submarine groundwater (with a different index of refraction than seawater) discharging from the seafloor. The instrument in the foreground is a high-resolution acoustic Doppler velocimeter (ADV) measuring wave-induced pumping of groundwater discharge from a specific vent (below the three-pronged sensor). The instrument in the background is an acoustic Doppler current profiler (ADCP), measuring current velocities throughout the water column as well as wave height (as indicated by fluctuations in water pressure) to better predict the movement of the groundwater away from the vent site and determine potential zones of impact. Water depth is approximately 1.7 meters (5 feet). USGS photograph by **Curt Storlazzi**.*

*An inflatable boat floating above a submarine groundwater vent was used as a multiday mooring platform for making time-series measurements of the naturally occurring groundwater tracers radon (^{222}Rn) and thoron (^{220}Rn). Gray surface buoys closer to the beach mark locations of thermistor arrays and wave/tide gauges. The hotel directly behind the boat housed a thermal-infrared (TIR) camera making time-series measurements of sea-surface temperature to document variations related to groundwater discharge (TIR images at right). USGS photograph by **Cordell Johnson**.*



Two thermal infrared (TIR) images of a submarine groundwater vent site off west Maui showing the influence of tides on the spatial extent of submarine groundwater discharge. Top, Image taken at high tide. Bottom, Image taken a low tide. The thermal range (20–30°C) on the right displays warmer temperatures as lighter shades of gray and cooler temperatures as darker shades of gray. Note that the extent of warm submarine groundwater discharge close to shore is greater at low tide than at high tide.

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water. Essential logistical support was most ably provided by White of HI-DAR and **Sulinn Aipa** and **Ryan Nobriga** of the Westin Ka'anapali Ocean Resort (in which the TIR camera was installed).

Lastly, Storlazzi, Logan, Reiss, Cochran, and Russell partnered with HI-DAR staff to deploy a series of satellite-tracked, near-surface current drifters during the nighttime spawning of the reef-building coral *Montipora capitata*. (Read about a similar study in "Tracking Coral Larvae to Understand Hawai'i Reef Health," *Sound Waves*, August/September 2010 <**http://soundwaves.usgs.gov/2010/08/fieldwork3.html**>.) The drifters were released on two nights during the July 2013 spawning event, from one reef off south-central Moloka'i and three reefs off west Maui, two of which are also State of Hawai'i marine managed areas (Honolua-Mokule'ia Bay Marine Life Conservation District and Āhihi Kīna'u Natural Area Reserve). These drifters were tracked for six days and elucidated the interconnected nature of the coral reefs in the main Hawaiian Islands, as drifters from Maui reached the reefs of O'ahu and Kaho'olawe during the time frame when the developing larvae were still in their positively buoyant, planktonic stage.

In order to better communicate the recent findings and goals of our ongoing studies to Federal, State, and local partners, Storlazzi briefed the USCRTF, HI-DAR, and the Maui Nui Marine Resource Council one evening after field operations, and both he and Prouty gave invited lectures at the University of Hawai'i Maui College at the end of field operations. All in all, a wide range of multidisciplinary data was acquired, and interaction with partners occurred in support of National, State, and local needs.

Learn more about USGS coral reef studies in the Pacific at <**http://coralreefs.wr.usgs.gov/**>.

Learn more about USGS coastal groundwater studies in the Pacific at <**http://walrus.wr.usgs.gov/sgd/**>.❁

Underwater view of satellite-tracked drifter following near-surface currents off Guam in 2012. Similar drifters were used to track coral larvae in the Hawaiian Islands during the July 2013 spawning of the reef-building coral Montipora capitata. *USGS photograph by* ***Tom Reiss****.*

California's Sea Otter Numbers Continue Slow Climb

By Ben Young Landis

California sea otter numbers are up, according to the latest population survey led by Federal, State and university scientists. The reasons: more pups and the addition of San Nicolas Island sea otters to the population count.

Since the 1980s, U.S. Geological Survey (USGS) scientists have calculated an averaged population index each year for the southern sea otter—*Enhydra lutris nereis*—a federally listed threatened species found in California (<**http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=A0A7**>). For the 2013 report, the USGS lists the population index as 2,941 (see <**http://www.werc.usgs.gov/seaottercount**>). For southern sea otters to be considered for removal from threatened species listing, the population index would have to exceed 3,090 for three consecutive years, according to the threshold established under the Southern Sea Otter Recovery Plan (<**http://www.fws.gov/ventura/species_information/so_sea_otter/**>) by the U.S. Fish and Wildlife Service (USFWS).

Sea otter with pup in her arms, Morro Bay, California, March 23, 2007. Photograph by ***"Mike" Michael L. Baird*** *(<**http://bairdphotos.com/**>).*

"Population growth in central California has faltered recently, so the fact that we're seeing a slightly positive trend is a basis for cautious optimism," says **Tim Tinker** (<**http://www.werc.usgs.gov/tinker**>), a biologist with the USGS Western Ecological Research Center (<**http://www.werc.usgs.gov/**>) who supervises the annual survey. "Certainly, sea otters have made an impressive recovery in California since their rediscovery here in the 1930s. But as their numbers expand along California's coast, they are facing different 'growing pains' in different locales. Our research partnership is investigating the factors responsible for these local trends."

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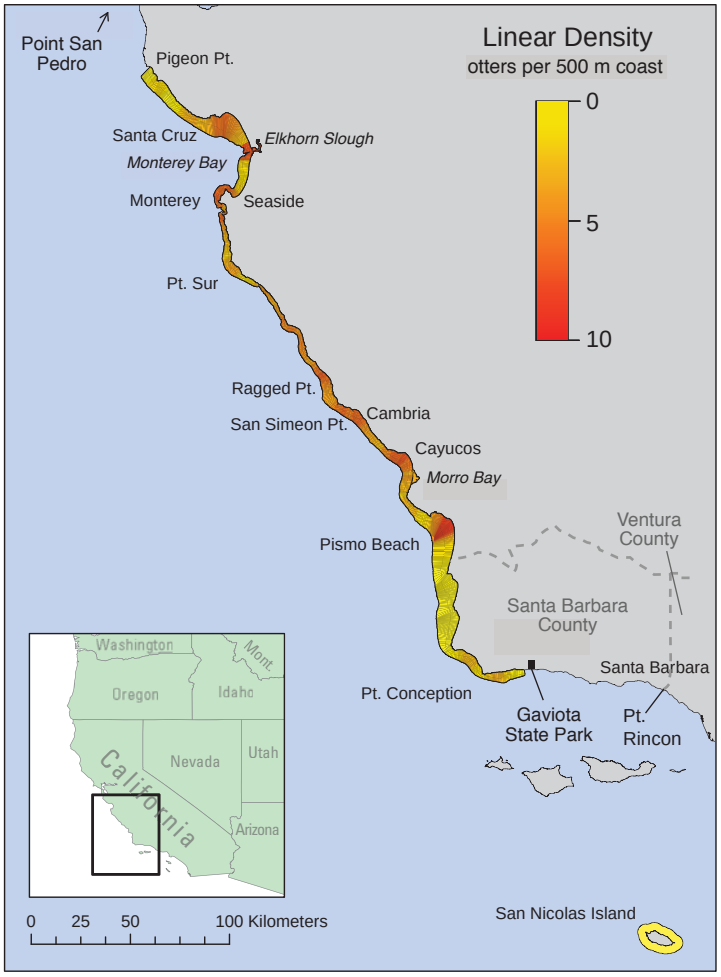
Researchers from the USGS, the California Department of Fish and Wildlife (CDFW) Office of Spill Prevention and Response (<**http://www.dfg.ca.gov/ospr**>), the Monterey Bay Aquarium (<**http://www.montereybayaquarium.org/cr/sorac.aspx**>), the University of California, Santa Cruz (<**http://www.ucsc.edu/**>), and other institutions collaborate annually to conduct the sea otter survey. To compensate for year-to-year variability in observation conditions and to give scientists a more reliable picture of sea otter abundance trends, the population index reported to USFWS is calculated as 3-year averages of raw data from annual surveys. (As an example, the population index for 2009 is the average of data from 2007, 2008, and 2009.)

"We counted a record number of pups this year, which led to the uptick in the 3-year average," says USGS biologist **Brian Hatfield**, coordinator of the annual survey. "A high pup count is always encouraging, although the number of adult otters counted along the mainland was almost identical to last year's count, so we'll have to wait and see if the positive trend continues."

There is a second reason for the higher population index reported this year. In 2013, the equation for this population index was amended to add sea otters living at San Nicolas Island. In the 1980s, 140 sea otters were introduced to the island as part of a USFWS recovery experiment, but most of them returned to the mainland, died, or simply disappeared. USFWS completed an extensive review of the translocation program in December 2012, resulting in termination of the program (<**http://www.fws.gov/ventura/docs/frnotices/77%20FR%2075266.pdf**>, 600 KB). As a consequence, sea otters at San Nicolas Island are no longer considered to be an "experimental" population and will now be included as part of the California-wide population index for southern sea otter recovery. The population at the island is currently at 59 individuals, a mix of original translocated animals and their offspring.



*Map of central California showing the sea otter's habitat in near-shore coastal waters (colored strip along coast) with color shading indicating the relative abundance of otters at each point along the coast (yellow to red = low to high densities, measured as otters per 500 meters of coastline). From "Annual Survey - 2013 Summary"; link at <**http://www.werc.usgs.gov/seaottercount**>.*

Statewide Trends and Local Questions

USGS scientists also annually update a database of sea otter strandings—the number of dead, sick, or injured sea otters recovered along California's coast each year. In 2012, scientists from CDFW, USGS, Monterey Bay Aquarium and other institutions came across a total of 368 stranded sea otters. (<**http://www.werc.usgs.gov/seaotterstranding**>).

This stranding number accounts only for sea otters that people find (see "Report a Stranding" link at <**http://www.werc.usgs.gov/seaotterstranding**>), and past research indicates that possibly less than 50 percent of sea otters that die in the wild end up on the beach. But efforts are made to examine each reported sea otter carcass, and a subset of fresh carcasses are sent to the CDFW Marine Wildlife Veterinary Care and Research Center (<**http://www.dfg.ca.gov/ospr/Science/marine-wildlife-vetcare/**>), where scientists conduct necropsies to determine the primary causes of death (<**http://www.dfg.ca.gov/ospr/Science/marine-wildlife-vetcare/seaotternecropsy.aspx**>) and identify factors that may have contributed to the death of each animal.

Data from both living and deceased sea otters continues to shed light on sea otter population ecology in different parts of the California coast. For example, a high proportion of sea otter carcasses recovered between Cayucos and Pismo Beach in recent years have white shark bite wounds (see "2012 Stranding Summary" link at <**http://www.werc.usgs.gov/seaotterstranding**>), a potential explanation for the downward trend in sea otter numbers in that area. In Elkhorn Slough, a new study suggests that sea otter appetites for crabs can improve the health of seagrass beds (see "Sea Otters Promote Recovery of Seagrass Beds," this issue, <**http://soundwaves.usgs.gov/2013/10/research3.html**>). And at the southern end of California sea otters' mainland range, researchers are observing sea otter feeding

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and movement behavior to understand their slow southward expansion.

"Overall trends are important, but they can mask problems that may be affecting only a portion of the population," says **Lilian Carswell**, Southern Sea Otter Recovery Coordinator for USFWS. "These regional research projects help us understand the effects of local influences, whether human-caused or natural, and inform the overall southern sea otter recovery strategy."

Survey Methodology

The annual population index is calculated from visual surveys conducted along the California coastline by researchers, students, and volunteers from the USGS, CDFW's Office of Spill Prevention and Response, Monterey Bay Aquarium, UC Santa Cruz, USFWS, the U.S. Bureau of Ocean Energy Management, and the Santa Barbara Zoo.

Surveys are conducted via telescope observations from shore and via low-flying aircraft, typically from April through June. This year, the surveyed coastline spanned Point San Pedro in San Mateo County south to Rincon Point near the Santa Barbara/Ventura County line, and also San Nicolas Island.

The annual survey was interrupted in 2011, when weather conditions prevented completion of the mainland survey.

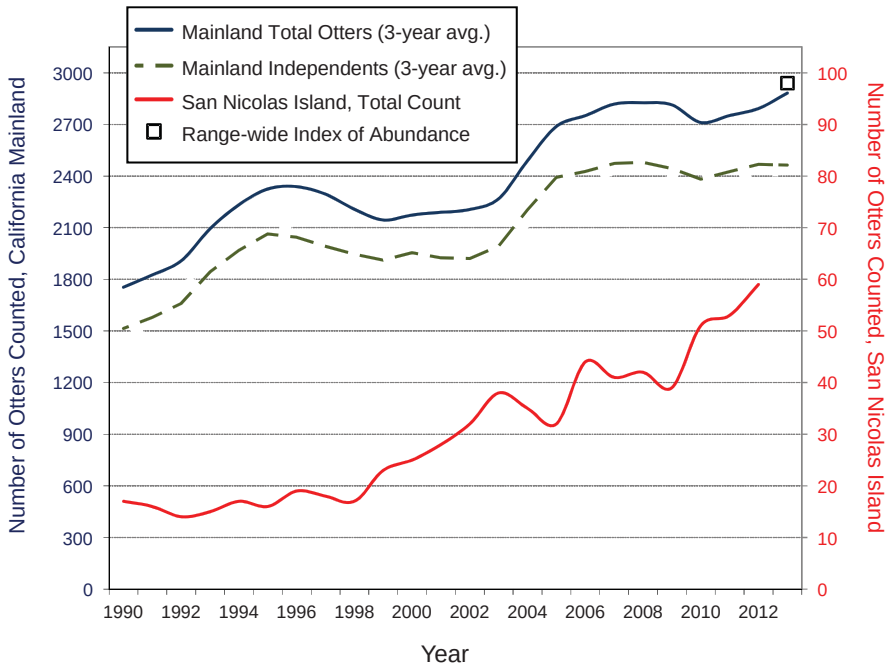
Sea Otter Facts

Sea otters were presumed extinct in California after the fur-trade years but were rediscovered in the 1930s by the public, when as few as 50 animals were documented in nearshore areas off the coast of Big Sur.

Sea otters are considered a keystone species of the kelp ecosystem because they prey on herbivorous invertebrates—such as sea urchins—that, if left unchecked, can decimate kelp beds and the fish habitat they provide.

Scientists also study sea otters as an indicator of nearshore ecosystem health (<**http://on.doi.gov/nearshore**>), since sea otters feed and live near the coast and often are the first predators exposed to pollutants and pathogens washed down from coastlands, such as the microbial toxin microcystin (<**http://news.ucsc.edu/2010/09/otter-toxin.html**>).

The public can report sightings of stranded sea otters to institutions listed on the "Report a Stranding" link at <**http://www.werc.usgs.gov/seaotterstranding**>.



*Plot of southern sea otter population trends along the mainland coast of California and at San Nicolas Island over the period 1990–2013. Trend lines for the mainland (left vertical axis) are shown as "3-year running averages" of independents (dashed green line) and total otters (solid blue line). For example, the 3-year average of total otters for 1998 is the average of the total counts for 1996, 1997, and 1998. For San Nicolas Island (right vertical axis, note scale difference) the trend line (lowest line, in red) represents the annual high counts. The range-wide index of abundance (left vertical axis) is also shown for 2013. From "Annual Survey - 2013 Summary"; link at <**http://www.werc.usgs.gov/seaottercount**>.*

Experts Team Up on Tsunami Resilience in California

By Erin Burkett, John Bwarie, Lucy Jones, Justin Pressfield, Jessica Robertson, and Stephanie Ross

Scientists cannot predict when a great earthquake producing a trans-Pacific tsunami will occur, but thanks to new tools being developed by Federal and State agencies, scientists can now offer more accurate insight into the likely impacts of such tsunamis. This knowledge can lead officials and the public to reduce the risk of future tsunamis that hit California.

What are the potential economic impacts? Which marinas could be destroyed? Who needs to be prepared for evacuations? A recently published report looks at these questions and more (<**http://www.usgs.gov/natural_hazards/safrr/projects/tsunamiscenario.asp**>).

A hypothetical yet plausible scenario was developed in which a magnitude-9.1 earthquake offshore of the Alaskan Peninsula triggers a tsunami that reaches the California coast. This scenario is detailed in the new report, *The SAFRR (Science Application for Risk Reduction) Tsunami Scenario* (<**http://pubs.usgs.gov/of/2013/1170/a/**>), released September 4, 2013.

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Some of the issues highlighted in the scenario include public safety and economic loss. In this scenario, approximately 750,000 people—about a third of them tourists and visitors—would need to be evacuated in just a few hours. Additionally, one-third of the boats and more than half of the docks in California's marinas could be damaged or destroyed, resulting in $700 million in losses. Total economic losses in California due to physical damage and business interruption would range from $5–10 billion, depending on resilience strategies adopted by businesses (such as using existing inventories and working extra shifts after the tsunami). It was concluded that neither of California's nuclear power plants would likely be damaged by this particular event.

Looking back to 2011, not only was Japan devastated by the magnitude-9.1 Tohoku earthquake and resulting tsunami, but the tsunami also swept through California and caused $50–100 million of damage. This event shows that tsunamis near and far can lead to severe economic losses in California.

The SAFRR Tsunami Scenario is a collaborative effort between the U.S. Geological Survey (USGS), the California Geological Survey, the California Governor's Office of Emergency Services, the National Oceanic and Atmospheric Administration, other agencies, and academic and other institutions.

"The good news is that three-quarters of California's coastline is cliffs and thus immune to the harsher and more devastating impacts tsunamis could pose," said **Lucy Jones**, who is the USGS Science Advisor for Risk Reduction and leads the SAFRR Project. "The bad news is that the one-quarter at risk is some of the most economically valuable property in California."

"In order to effectively protect communities from tsunamis, we must first know what to plan for," continued Jones. "By starting with science, there is a clearer understanding on how tsunamis function and their potential impacts. The scenario will serve as a long-lasting resource to raise awareness and provide scientifically sound and unbiased information to decision makers in California and beyond."

*The March 11, 2011, Tohoku tsunami caused significant damage to ships and docks in Crescent City Harbor in California. A number of ships were sunk within the harbor. Because of extensive sedimentation and potential contaminated debris within the harbor, recovery efforts took more than a year to complete. Photograph by **Rick Wilson**, California Geological Survey.*

In the SAFRR scenario, scientists specifically outline the likely inundation areas, current velocities in key ports and harbors, physical damage and repair costs, economic consequences, environmental impacts, social vulnerability, emergency management, and policy implications for California.

Collaboration on the tsunami scenario was coordinated over 2 years by USGS marine geophysicist and SAFRR Tsunami Scenario project lead **Stephanie Ross**, who also edited and contributed to the resulting multichapter report and wrote a 4-page USGS Fact Sheet summariz-

(Tsunami Resilience continued on page 8)

*Some areas that would be inundated (in red) during the SAFRR tsunami scenario. Top, in Oakland and Alameda, in the eastern San Francisco Bay area, large parts of the Oakland Airport would be flooded. Bottom, in Newport Beach, Orange County, there would be complete or partial flooding of all islands and near overtopping of the Balboa Peninsula neighborhood, possibly creating evacuation challenges. From USGS Fact Sheet 2013–3081, <**http://pubs.usgs.gov/fs/2013/3081/**>.*

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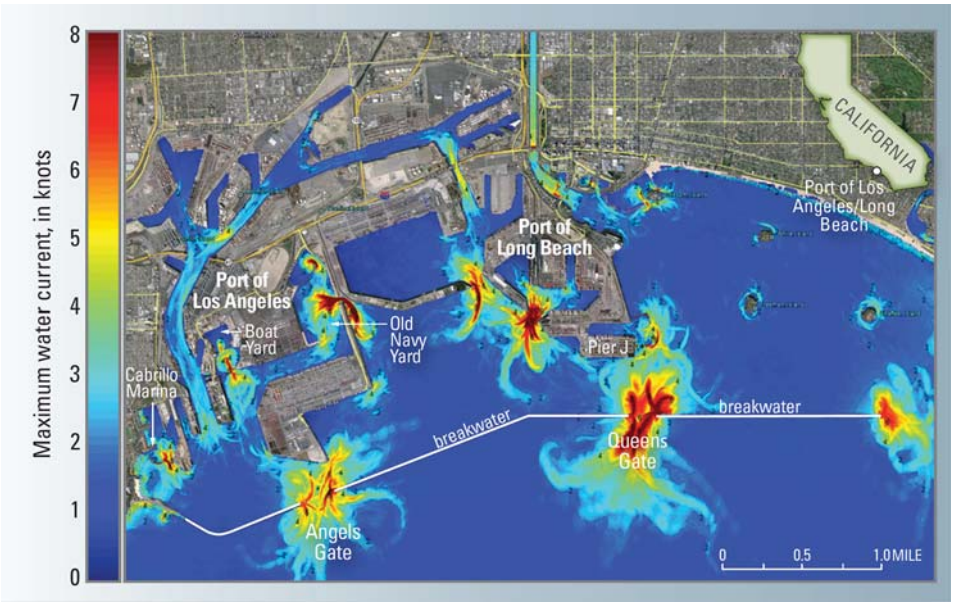
ing its findings (<**http://pubs.usgs.gov/fs/2013/3081/**>).

On the day that the report and Fact Sheet were released, Jones and Ross launched a series of workshops convened in partnership with the California Geological Survey and the California Governor's Office of Emergency Services and focused on discussion of the tsunami scenario. USGS scientists and partners explained the scenario and its implications to stakeholders in California coastal communities. Participants included emergency managers, maritime managers, first responders (for example, police and fire agencies), representatives of elected officials, and others. The workshops aimed to establish a community of experts while fostering the use of science in decision-making. They were hosted by the Cabrillo Marine Aquarium in Los Angeles (September 4), the Santa Barbara County Office of Emergency Management (September 5), the San Diego County Office of Emergency Management (September 6), the Santa Cruz County Office of Emergency Management (September 9), and the Port of San Francisco (September 10).

The SAFRR Project is the same USGS research project that produced the ShakeOut Scenario in 2008, examining the consequences of a probable major earthquake on the southern San Andreas Fault (<**http://pubs.usgs.gov/of/2008/1150/**>), and the ARkStorm Scenario in 2011, examining the risks associated with extreme rain events caused by "atmospheric rivers" moving large quantities of moisture from the equatorial Pacific Ocean to the U.S. West Coast (<**http://soundwaves.usgs.gov/2011/01/research2.html**>).



Maximum current speeds for the Port of Los Angeles (POLA) and the Port of Long Beach (POLB) generated during the SAFRR tsunami scenario. The ports are protected by a breakwater, but during the tsunami there would be dangerously fast currents around the port entrances in the wall, locally referred to as "Angels Gate" (at POLA) and "Queens Gate" (at POLB). In the POLA, powerful currents are also expected at Cabrillo Marina and the Boat Yard, where they could break apart floating docks, damage pilings, and pull small vessels from their mooring lines. The strongest currents would be expected in the Old Navy Yard; however, there are no exposed floating assets in that immediate area. In the POLB, jet-like currents would be likely at the entrance to the main cargo container area (Pier J) and may be sufficient to damage, and possibly break, mooring lines. Image from The SAFRR Tsunami Scenario—Improving Resilience for California *(USGS Fact Sheet 2013–3081, <**http://pubs.usgs.gov/fs/2013/3081/**>).*

Tsunami on the Delaware River? Study of Historical Quake and Early East Coast Seismicity

By Susan Hough and Barbara Wilcox

Imagine the Delaware River abruptly rising toward Philadelphia in a tsunami-like wave of water. Scientists now propose that this might not be a hypothetical scenario. A newly published paper concludes that a modest (1 foot) tsunami-like event on the East Coast was generated in the early 19th century by a large offshore earthquake. This result may have potential ramifications for emergency-management professionals, government officials, businesses, and the general public.

Early in the morning of January 8, 1817, earthquake shaking was felt along the Atlantic seaboard as far north as Baltimore, Maryland, and at least as far south as Charleston, South Carolina. Later that morning, a keen observer saw a "sudden agitation of the river Delaware" near Philadelphia, Pennsylvania, as reported in an article published January 20, 1817, in the *Philadelphia Gazette*. According to the eyewitness, "vessels at the wharves were violently tossed about, and the tide swelled upwards of 12 inches." The observer commented on the earthquake felt earlier to the south and remarked that the tidal swell was most likely "the reverberation or concussion of the earth operating on the watery element."

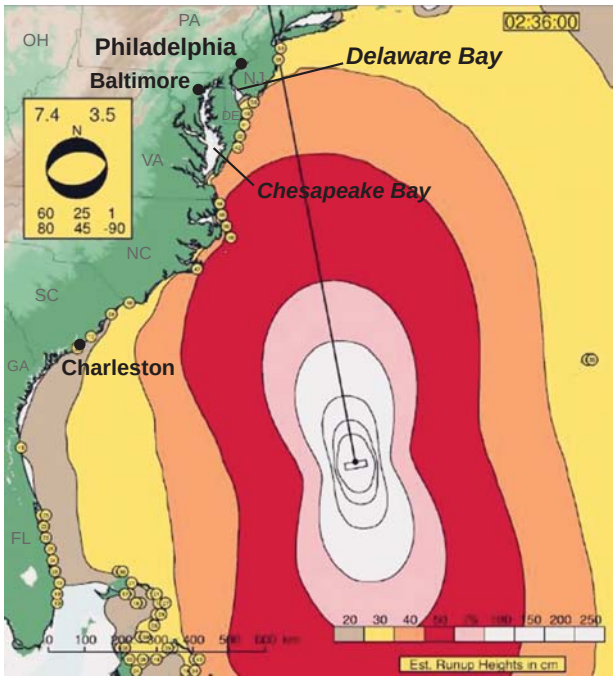
Scientists have previously interpreted this earthquake to have a magnitude around 6 and a location somewhere in the Carolinas or slightly offshore. In a new study, U.S. Geological Survey (USGS) research geophysicist **Susan Hough** and colleagues reconsider the accounts of

(Tsunami on the Delaware continued on page 9)

(Tsunami on the Delaware continued from page 8)

shaking and, for the first time, consider in detail the Delaware River account. They show that the combined observations point to a larger magnitude and a location farther offshore than previously believed. In particular, they show that a magnitude-7.4 earthquake located 400–500 miles off South Carolina or Georgia could have generated a tsunami wave large enough to account for the tidal swell on the Delaware. Using searchable electronic archives of historical newspapers, they uncovered firsthand accounts from ships' logs and news stories—such as the *Philadelphia Gazette* article quoted above—that give a wider perspective on the 1817 event. Notably, the predicted timing of such a tsunami wave from this location matches the documented timing in the eyewitness account.

The USGS monitors offshore earthquakes and, in recent years, has undertaken research to better understand shaking and tsunami hazards from offshore earthquakes and landslides. Scientific understanding of faults and geological processes in this part of the Atlantic is limited. Still, it has long been understood that large, infrequent offshore earthquakes may pose a tsunami hazard to the Atlantic coast. In 1929, the magnitude-7.2 Grand Banks, Newfoundland, earthquake triggered a submarine landslide that generated a large tsunami. Waves 10 to 13 feet high struck the Newfoundland coast, killing 29 people and leaving 10,000 temporarily homeless.



Tsunami radiation pattern for the preferred earthquake parameters shown in inset panel. Note the efficiency of wave propagation toward Delaware Bay and the relative inefficiency of propagation toward the northeast and the west-northwest. Estimated runup (height of tsunami above sea level when it reaches land) at the mouth of Delaware Bay is approximately 50 centimeters (20 inches). Numbers at top of inset panel show preferred earthquake magnitude (7.4) and mean slip (3.5 meters [11 feet]); numbers at bottom show preferred fault length (60 kilometers [40 miles]), width (25 kilometers [15 miles]) and depth to top edge (1 kilometer [0.6 mile]), and strike/dip/rake of assumed rupture plane. Slightly modified from figure 4 of Seismological Research Letters *paper at <**http://dx.doi.org/10.1785/0220120152**>.*

The inferred 1817 tsunami was significantly smaller than the Newfoundland disaster. However, the new interpretation by Hough and colleagues highlights the potential earthquake and tsunami hazard along the Atlantic seaboard from the still poorly understood offshore earthquake faults. The new study shows that there is still work to be done to characterize this hazard in the southeastern United States.

Hough and her coauthors—seismologists **Jeffrey Munsey** of the Tennessee Valley Authority and **Steven N. Ward** of the University of California, Santa Cruz—published their results in the September/October issue of *Seismological Research Letters*. The full citation is:

Hough, S.E., Munsey, J., and Ward, S.N., 2013, Reverberations on the watery element—A significant, tsunamigenic historical earthquake offshore the Carolina coast: Seismological Research Letters, v. 84, no., 5, p. 891–898, doi:10.1785/0220120152 <**http://dx.doi.org/10.1785/0220120152**>.

Sea Otters Promote Recovery of Seagrass Beds

Recolonization of Elkhorn Slough by sea otters led to recovery and expansion of seagrass beds due to cascading effects on the food web, study finds

By Tim Stephens, University of California, Santa Cruz

*[Reprinted from University of California, Santa Cruz NewsCenter story at <**http://news.ucsc.edu/2013/08/sea-otters-seagrass.html**>]*

Scientists studying the decline and recovery of seagrass beds in one of California's largest estuaries have found that recolonization of the estuary by sea otters was a crucial factor in the seagrass comeback. Led by researchers at the University of California, Santa Cruz, the study was published in the *Proceedings of the National Academy of Sciences* the week of August 26.

Seagrass meadows, which provide coastal protection and important habitat for fish, are declining worldwide, partly because of excessive nutrients entering coastal waters in runoff from farms and urban areas. The nutrients spur the growth of algae on seagrass leaves, which then don't get enough sunlight. In Elkhorn Slough, a major estuary on California's central coast, algal blooms caused by high nutrient levels are a recurring problem. Yet the seagrass beds there have been expanding in recent years.

"When we see seagrass beds recovering, especially in a degraded environment like Elkhorn Slough, people want to know why," said **Brent Hughes**, a Ph.D. candidate in ecology and evolutionary biology at UC Santa Cruz and first author of the *PNAS* study. His coauthors include **Tim Tinker**, a wildlife biologist with the U.S. Geological Survey (<**http://www.werc.usgs.gov/tinker**>), and **Kerstin Wasson**, research

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coordinator for the Elkhorn Slough National Estuarine Research Reserve (<**http://www.elkhornslough.org/esnerr**/>), who are both adjunct professors of ecology and evolutionary biology at UCSC (<**http://www.eeb.ucsc.edu**/>).

Hughes and his colleagues documented a remarkable chain reaction that began when sea otters started moving back into Elkhorn Slough in 1984. The sea otters don't directly affect the seagrass, but they do eat enormous amounts of crabs, dramatically reducing the number and size of crabs in the slough. With fewer crabs to prey on them, grazing invertebrates like sea slugs become more abundant and larger. Sea slugs feed on the algae growing on the seagrass leaves, keeping the leaves clean and healthy.

"The seagrass is really green and thriving where there are lots of sea otters, even compared to seagrass in more pristine systems without excess nutrients," Hughes said.

In addition to the sea slugs, small crustaceans known as *Idotea* are also important grazers on the algae, and they too increase in number when sea otters control the crab population.

This kind of chain reaction in a food web is known to ecologists as a "trophic cascade." Scientists have long known that sea otters have a big impact on coastal ecosystems. Their importance in maintaining kelp forests by preying on animals that graze on kelp is especially well documented. The new study shows sea otters play a slightly different but equally important role in estuarine ecosystems like Elkhorn Slough, according to Tinker.

"This provides us with another example of how the strong interactions exerted by sea otters on their invertebrate prey can have cascading effects, leading to unexpected but profound changes at the base of the food web," he said. "It's also a great reminder that the apex predators that have largely disappeared from so many ecosystems may play vitally important functions."

The sea otter population in Elkhorn Slough has had its ups and downs, reflecting trends in the ongoing recovery of California's sea otters. The slough's initial recolonizing population of about 15 declined in the late 1980s, then grew to nearly 100 in the 1990s before declining again, followed by a recovery over the past decade. These fluctuations in the otter population were matched by corresponding fluctuations in the seagrass beds, Hughes said. Even within the slough, he said, sea otter density varies among the different seagrass beds, and those with more otters have fewer and smaller crabs and healthier seagrass.

*Eelgrass beds in Elkhorn Slough benefit from the presence of sea otters. Photograph by **Ron Eby**, Elkhorn Slough National Estuarine Research Reserve.*

*Crabs are a favorite prey item for sea otters in Elkhorn Slough. Photograph by **Ron Eby**, Elkhorn Slough National Estuarine Research Reserve.*

The researchers used a combination of field experiments and data from long-term monitoring of Elkhorn Slough to study these interactions. "We used multiple approaches, and they all came up with the same answer," Hughes said.

Eelgrass (*Zostera marina*) is the dominant seagrass in Elkhorn Slough and elsewhere in the northern hemisphere. Seagrasses in general provide important nursery habitat for juvenile fish, and eelgrass beds along the west coast are especially important for species such as Pacific herring, halibut, and salmon. In addition, seagrass beds protect shorelines from storms and waves, and they soak up carbon dioxide from seawater and from the atmosphere.

"These are important coastal ecosystems that we're losing, and mostly that's been associated with bottom-up effects like nutrient loading. This study shows that these ecosystems are also being hit by top-down forces due to the loss of top predators," Hughes said.

The findings in Elkhorn Slough suggest that expansion of the sea otter population in California and recolonization of other estuaries will likely be good for seagrass habitat throughout the state, he added.

According to Wasson, the study has important management implications, suggesting that to restore valued coastal habitats, it may be necessary to restore entire food webs. "That is a new perspective for us,"

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Both sea slugs and Idotea *(the crustacean between the two sea slugs above) feed on algae and increase in numbers when the crab population is controlled by sea otters. Photograph by **Brent Hughes**, University of California, Santa Cruz.*

(Sea Otters and Seagrass continued from page 10)

she said. "Most estuarine managers focus on the bottom-up approach, bringing back marshes and eelgrass and hoping the rest comes along with it. But in this case, it's clear you need to focus on the top and bottom of the food web at the same time."

In addition to Hughes, Tinker, and Wasson, study coauthors include **Ron Eby** and **Eric Van Dyke** at the Elkhorn Slough National Estuarine Research Reserve; **Corina Marks** at California State University Monterey Bay; and **Kenneth Johnson** at the Monterey Bay Aquarium Research Institute. This work was supported by the National Estuarine Research Reserve System, the California Department of Fish and Wildlife, and the U.S. Geological Survey's Western Ecological Research Center.

The full citation for the recent publication is:

Hughes, B.B., Eby, R., Van Dyke, E., Tinker, M.T., Marks, C.I., Johnson, K.S., and Wasson, K.W., 2013, Recovery of a top predator mediates negative eutrophic effects on seagrass: Proceedings of the National Academy of Sciences, published online before print August 27, 2013, 6 p., doi:10.1073/pnas.1302805110 <**http://dx.doi.org/10.1073/pnas.1302805110**>.

About the author: *Article author* ***Tim Stephens****, who holds degrees from the University of California, Santa Barbara (B.A., botany), and Cornell University (M.S., plant pathology), is a science writer in the UCSC Public Information Office.*

Sea slug Phyllaplysia taylori*, also known as the "eelgrass sea hare," feeds on algae growing on eelgrass leaves. Photograph by* ***Brent Hughes****, University of California, Santa Cruz.*

USGS Hosts the 2013 Meeting of the Curators of Marine and Lacustrine Geological Samples Group

By Brian Buczkowski

As ocean-exploration technology continues to improve, our window onto the seafloor is becoming clearer and our understanding of its resources, ecosystems, and landforms continually grows. Bathymetric and sonar data provide us with remote views of the seafloor using physics, but samples plucked from the seabed give us tangible evidence of what is actually down there. These samples—usually collected as mud-filled cores, dredged rocks, and shallow surface grab samples—provide scientists with a wealth of information, ranging from grain size and composition to potential anthropogenic contamination and its effects. If properly preserved and curated, these cores, dredge hauls, and grab samples can be useful to generations of researchers.

Facilities storing these samples are scattered throughout the country and around the globe. They vary in size and the scope of their collections as well as in capabilities and resources dedicated to curation. The Curators of Marine and Lacustrine Geological Samples Group is a community formed out of the need to develop common preservation standards throughout these facilities and to share ideas and collections-management strategies. This group provides a forum for sharing information through mailing lists, meetings, and a website (<**http://seabedsamples.org/**>) hosted by the National Geophysical Data Center (NGDC).

From June 11–13, 2013, the U.S. Geological Survey (USGS) Woods Hole Coastal and Marine Science Center (WHCMSC), in cooperation with the Woods Hole Oceanographic Institution (WHOI), hosted the 2013 meeting of the Curators of Marine and Lacustrine Geological Samples Group (hereinafter Curators Group) in Woods Hole, Massachusetts. This meeting, normally held every 2 years, brings together professionals in the fields of marine geology collections management, database design, and marine policy with the purpose of sharing collections-management strategies and fostering collaboration among universities, Federal repositories, and international organizations dedicated to the preservation and curation of marine geological samples.

Fourteen members of the Curators Group gathered in the WHCMSC's Tilley Conference Room, and several other members joined via teleconference technology. The 3-day meeting included reports from repositories at academic institutions (University of Rhode Island, Oregon State University, and—new to the group—the University of Hawai'i and the Polar Rock Repository at the Ohio State University); U.S. research institutions (Lamont-Doherty Earth Observatory [LDEO], Scripps Institution of Oceanography, the Antarctic Marine Geology Research Facility, and WHOI); governmental organizations (WHCMSC, the USGS St. Petersburg Coastal and Marine Science Center, the British Ocean Sediment Core Research Facility, and Canada's Bedford Institute of Oceanography); and an international marine research program (Integrated Ocean Drilling Program [IODP]).

(Not all repositories were able to send representatives to the 2013 meeting; visit <**http://www.ngdc.noaa.gov/mgg/curator/participants.html**> to see a

(Curators Group continued on page 12)

(Curators Group continued from page 11)

complete list of member repositories and contact information.)

On Tuesday afternoon, **Carla Moore** (NGDC), database administrator for the Curators Group's Index to Marine and Lacustrine Geological Samples (IMLGS), telephoned into the meeting with a report on the status of the IMLGS and new additions to the database since the last Curators Group meeting in 2011. Next, **Candace Major**, a program director for marine geology and geophysics in the National Science Foundation (NSF) Division of Ocean Sciences, presented an overview of NSF ocean-science activities and curation practices.

On Wednesday, **Kerstin Lehnert**, director of Integrated Earth Data Applications (IEDA) at LDEO, introduced the group to IEDA's services (<**http://www.iedadata.org/**>), including EarthChem, a website for access to geochemical data systems and services, and SESAR (System for Earth Sample Registration), an international registry that provides unique identifiers for geologic samples. **Bob Arko**, lead systems analyst at LDEO's Division of Marine Geology and Geophysics, then telephoned in to discuss "linked" data and collaborative work between the IMLGS and the Rolling Deck to Repository (R2R), an initiative for collecting, transmitting, and archiving "underway" data from U.S. academic oceanographic expeditions.

Research presentations included a Tuesday afternoon talk on ice cores and climate research by **Alison Criscitiello**, a graduate student in the Massachusetts Institute of Technology/WHOI Joint Program, and a Thursday morning talk on paleoclimate research at LDEO by **Maureen Raymo**, director of the Lamont-Doherty Core Repository.

*Meeting participants on a walking tour of the Woods Hole Oceanographic Institution (WHOI) core repository. Left to right: **Ellen Roosen** (WHOI), **George Heimerdinger** (WHOI), **Suzanne MacLachlan** (British Ocean Sediment Core Research Facility), **Brian Buczkowski** (USGS), **Maziet Cheseby** (Oregon State University), **Phil Rumford** (Integrated Ocean Drilling Program), **Alex Hangsterfer** (Scripps Institution of Oceanography), **Jim Broda** (WHOI), **Nichole Anest** (Lamont-Doherty Earth Observatory), **Steve Petrushak** (Antarctic Marine Geology Research Facility), and **Kevin Johnson** (University of Hawai'i). Additional meeting participants are not shown. Photograph courtesy of **Brian Buczkowski**, USGS.*

The meeting attendees also enjoyed two afternoon outings: on Tuesday, a guided tour of local conservation land Beebe Woods, featuring the geology and wildlife of Cape Cod; and on Wednesday, walking tours of the WHCMSC and WHOI core repositories, as well as a tour of the National Ocean Sciences Accelerator Mass Spectrometry Facility (NOSAMS) on WHOI's Quissett campus.

The full meeting agenda, a list of participants, PowerPoint presentations, and meeting information are posted online at <**http://www.ngdc.noaa.gov/mgg/curator/meetings/2013/**>.

The next Curators Group meeting will be hosted by the IODP Gulf Coast Repository in Texas. Details will be announced as they become available on the IMLGS website, <**http://seabedsamples.org/**>. For questions about the Curators Group or the IMLGS, please contact **Carla Moore** at **carla.j.moore@noaa.gov** or **Brian Buczkowski** at **bbuczkowski@usgs.gov**.

California Seafloor Mapping Reveals Hidden Treasures

By Leslie Gordon

Science and technology have peeled back a veil of water just offshore of California, revealing the hidden seafloor in unprecedented detail. New imagery, specialized undersea maps, and a wealth of data from along the California coast are now available. Three new products in an ongoing series were released on August 9, 2013, by the U.S. Geological Survey—a map set for the area offshore of Carpinteria (about 120 kilometers [75 miles] northwest of Los Angeles), a catalog of data layers for geographic information systems, and a collection of videos and photos of the seafloor in State waters along the entire California coast,

"A program of this vast scope can't be accomplished by any one organization. By working with other government agencies, universities, and private industry, the USGS could fully leverage all its resources," said USGS Pacific Region Director **Mark Sogge**. "Each organization brings to the table a unique and complementary set of resources, skills, and know-how."

The USGS is a key partner in the California Seafloor Mapping Program (<**http://walrus.wr.usgs.gov/mapping/csmp/**>): a large, unique, and historically

(California Seafloor Mapping continued on page 13)

(California Seafloor Mapping continued from page 12)

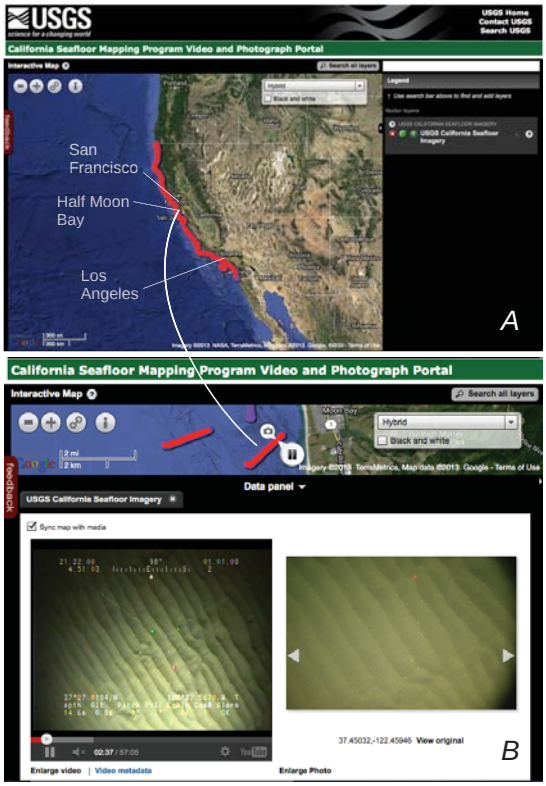
ambitious collaboration between State and Federal agencies, academia, and the private sector to create a comprehensive base-map series for all of California's ocean waters. Scientists are collecting sonar data, video and photographic imagery, seismic surveys, and bottom-sediment data to create a series of maps (<**http://walrus.wr.usgs.gov/mapping/csmp/sheets.html**>) of seafloor bathymetry, habitats, geology, and more, in order to inform coastal managers and planners, government entities, and researchers. With the new maps, decision makers and elected officials can better design and monitor marine reserves, evaluate ocean energy potential, understand ecosystem dynamics, recognize earthquake and tsunami hazards, regulate offshore development, and improve maritime safety.

"The Ocean Protection Council recognized early on that seafloor habitats and geology were a fundamental data gap in ocean management," said California's Secretary for Natural Resources and Ocean Protection Council Chair **John Laird**. "After an impressive effort by many partners to collect and interpret the data, the maps being produced now are providing pioneering science that's changing the way we manage our oceans."

"Our collaboration with the State and more than 15 other partners is critical to the success of this program. We've come together to make the maps, and then to use them. We all like to say that you can't manage it, monitor it, or model it if you don't know what the 'it' is, and our seafloor mapping gives that important 'it' to the entire coastal management and research community," said the USGS' lead researcher on this project, **Sam Johnson**.

USGS California Seafloor Mapping Program Map Series

The heart of the USGS California Seafloor Mapping Program effort is a series of map sets. To date, three sets have been published, including the most recent one released in August covering the area "Offshore of Carpinteria," USGS Scientific Investigations Map 3261 (<**http://pubs.usgs.gov/sim/3261/**>). Each of the map sets includes 10 or more sheets illustrating different features of the seafloor, including geology, bathymetry, and habitats within the 3-nautical-mile limit of California's State waters. The maps are created through the collection, integration, interpretation, and visualization of swath sonar data, acoustic backscatter, seafloor video, seafloor photography, high-resolution seismic-reflection profiles, and bottom-sediment sampling data. Fourteen other map sets are being formatted for publication; the California State Waters Map Series (<**http://walrus.wr.usgs.gov/mapping/csmp/sheets.html**>) is planned to comprise 83 such seafloor map sets spanning the entire coast of California.



*Explore the seafloor through the California Seafloor Mapping Program Video and Photograph Portal (<**http://dx.doi.org/10.5066/F7J1015K**>). **A**, Interactive map (here with added labels) allows viewers to zoom into areas of interest; video tracklines appear in purple and photograph locations (dots) in red. (At scales shown here, red dots are too closely spaced to distinguish.) **B**, Clicking on a trackline starts video in left window and associated photographs in right window. This example—sand ripples at a depth of approximately 15 meters (49 feet)—is from a trackline just offshore of Half Moon Bay, California. Two green dots in the video window (from lasers mounted on the camera and used as reference points) are 15 centimeters (6 inches) apart; likewise the red dots in both windows. (Dots are easier to see in online images.) High-resolution versions of the photographs can be viewed by clicking "View original" below photograph window.*

USGS California Seafloor Mapping Program Data Catalog

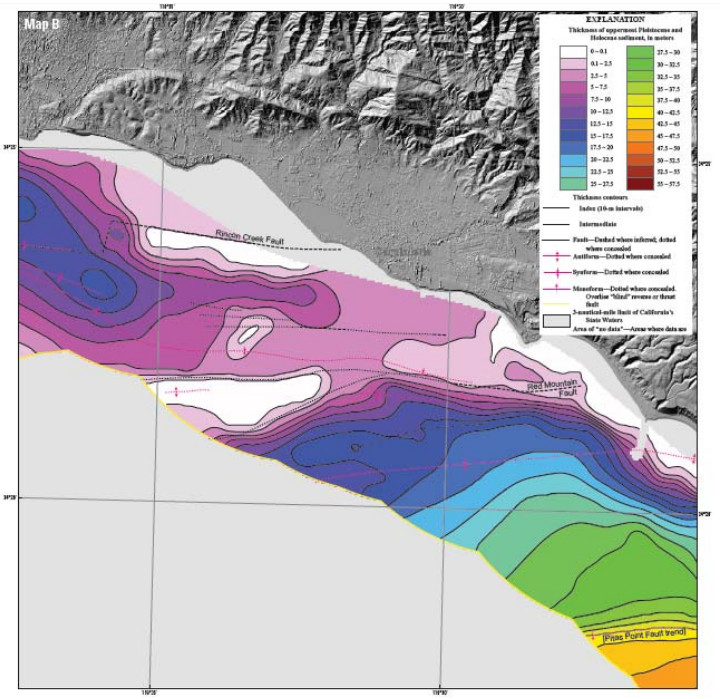
Underlying the series of published seafloor map sets are large geospatial digital files, including bathymetry, acoustic backscatter, offshore geology and geomorphology, faults, folds, potential marine habitats, seafloor character, sediment thickness, visual observations of bottom habitat from video, and more. These

(California Seafloor Mapping continued on page 14)

Kelp greenling fish swimming above a seafloor of mixed gravel, cobble, and rock outcrop with scattered shell. Fish is approximately 20 centimeters (8 inches) long. Photograph acquired 1 kilometer (0.62 miles) offshore of Half Moon Bay, California (on same trackline as images above), at a depth of 14 meters (46 feet). Also in the photograph are encrusting sponges, red algae (seaweed), and orange cup corals.

(California Seafloor Mapping continued from page 13)

data sets are now available through a new California State Waters Map Series Data Catalog for users to create their own maps or engage in further investigations of the seafloor. The catalog, USGS Data Series 781 (<**http://pubs.usgs.gov/ds/781/**>), provides all geographic-information-system (GIS) data layers associated with the map sets published by the California Seafloor Mapping Program. Data will be continually added to the data series catalog as new seafloor map sets are published.



*Map B from Sheet 9 of USGS Scientific Investigations Map 3261 (*California State Waters Map Series—Offshore of Carpinteria, California*), showing thickness of uppermost Pleistocene and Holocene sediment, from (in this view) white (0–0.1 meters [0–0.3 feet]) to orange (45–47.5 meters [154–156 feet]). Additional information, plus links to pamphlet and all 10 sheets, at <**http://pubs.usgs.gov/sim/3261/**>.*

USGS California Seafloor Mapping Program Video and Photograph Portal

The unique set of seafloor images (video and still photography) collected by the USGS from the U.S.-Mexico border to the Oregon State line is now available via a new California Seafloor Mapping Program Video and Photograph Portal (<**http:/dx.doi.org/10.5066/f7j1015k**>). More than 500 hours of video and 87,000 photographs were collected (<**http://walrus.wr.usgs.gov/mapping/csmp/data_collection.html**>) and are now posted in the online portal for viewing. Scientists are using these data to ground-truth their interpretations of sonar data, to provide a framework for understanding seafloor ecosystems, and to create maps of seafloor materials and habitats. The video and photo portal is based on an interactive map that allows users to zoom into a particular area and see the imagery available (see example at top of page 13). The video and still photographs of the same locations are displayed simultaneously, just as they were acquired along the trackline.

The California Seafloor Mapping Program (<**http://walrus.wr.usgs.gov/mapping/csmp/**>) is a collaborative effort supported by the USGS, the California Ocean Protection Council (<**http://www.opc.ca.gov/2010/03/mapping-californias-seafloor-2/**>), NOAA, California State University Monterey Bay, and many other academic, government, and industry partners.❁

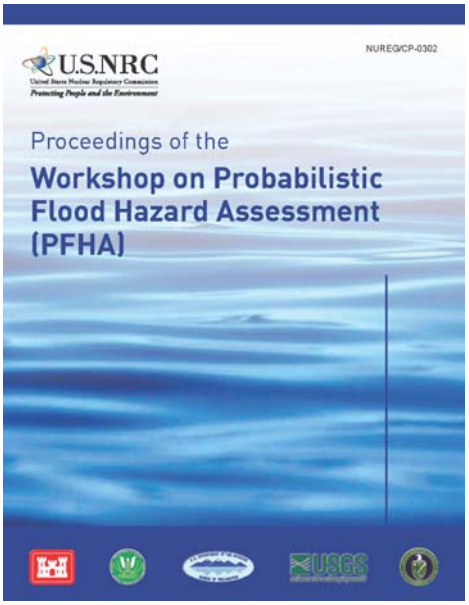
Assessing the Probabilities of Extreme Flood Hazards—Workshop Proceedings Released

By Helen Gibbons

The results of a workshop prompted by extreme flooding during the 2011 Japanese tsunami have been published. *Proceedings of the Workshop on Probabilistic Flood Hazard Assessment (PFHA)* was released in September 2013 by the U.S. Nuclear Regulatory Commission (NRC) at <**http://www.nrc.gov/reading-rm/doc-collections/nuregs/conference/cp0302/**>.

The tsunami triggered by the Tohoku earthquake of March 11, 2011 (see "Japan Lashed by Powerful Earthquake, Devastating Tsunami," *Sound Waves*, March 2011, <**http://soundwaves.usgs.gov/2011/03/**>) caused widespread damage and many thousands of deaths. It also flooded Japan's Fukushima Dai-ichi nuclear power plant, knocking out backup power systems needed to cool the plant's reactors. Several of the reactors underwent fuel melting, hydrogen explosions, and the most extensive release of radioactivity since the Chernobyl accident in 1986.

(Flood Hazards continued on page 15)



Cover of new report, Proceedings of the Workshop on Probabilistic Flood Hazard Assessment (PFHA) *(<**http://www.nrc.gov/reading-rm/doc-collections/nuregs/conference/cp0302/**>). Logos along the bottom represent the Federal agencies that cooperated with the U.S. Nuclear Regulatory Commission (NRC) to plan and conduct the workshop (left to right): U.S. Army Corps of Engineers, Federal Energy Regulatory Commission, U.S. Bureau of Reclamation, USGS, and U.S. Department of Energy.*

(Flood Hazards continued from page 14)

Radioactive contamination from the plant forced the evacuation of communities as far as 25 miles away and affected as many as 100,000 residents. (Congressional Research Service, 2012, R41694 <**www.fas.org/sgp/crs/nuke/R41694.pdf**>, approx. 1 MB)

To address flooding events such as this one, with extremely low probabilities but extremely severe consequences, the NRC held a "Workshop on Probabilistic Flood Hazard Assessment (PFHA)," January 29–31, 2013, at NRC headquarters in Rockville, Maryland. Participants from Federal agencies and other organizations examined numerous flood-causing mechanisms—including extreme rainfall, flood-induced dam and levee failures, tsunami flooding, river flooding, extreme storm surge, and combined-events flooding—and shared information about the probabilistic assessment of these hazards.

Probabilistic hazard assessment entails creating and testing mathematical models of many possible sets of conditions that might cause or influence a hazard. In the case of earthquake-generated tsunamis, for example, a probabilistic assessment might model thousands of possible sets of earthquake parameters, generate thousands of possible tsunami scenarios, and report each of their probabilities. Probabilistic techniques have been used for many years in weather forecasting and now are coming into favor for assessing other hazards, such as tsunamis, dam failures, and extreme storm surge.

An earlier, complementary technique—deterministic hazard analysis—entails modeling an event with a specific set of parameters (commonly a "worst-case" event) and determining one or a few scenarios that will result. Deterministic assessments typically produce a single, vivid story that can capture public attention and assist agencies and communities in developing emergency-response plans; an example is the USGS SAFRR Tsunami Scenario described in "Experts Team Up on Tsunami Resilience in California," this issue, <**http://soundwaves.usgs.gov/2013/10/research.html**>.

Probabilistic assessments produce numerous possible scenarios, reporting the probabilities not only of each scenario but also of each factor considered to affect the scenario—such as the tidal stage at the time a hurricane storm surge reaches land, the direction of the storm's approach, the strength of its winds, and many additional variables. Probabilistic assessments are used by FEMA's National Flood Insurance Program to set flood-insurance rates and by engineers to weigh the costs and benefits of designs for such structures as bridges, dams, seawalls, coastal highways, and nuclear power plants.

Altus Dam, Oklahoma. Image from a case study presented at the workshop by hydrologic engineer ***Nicole Novembre*** *(Bureau of Reclamation) titled "Use of Stochastic Event Flood Model and Paleoflood Information to Develop Probabilistic Flood Hazard Assessment for Altus Dam, Oklahoma."*

"Cooperation and collaboration among Federal and local agencies and stakeholders in the sharing of flood risk information is very important to leverage limited resources and to serve the American public."

—**K. Steven West**, Deputy Director, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, in foreword to the new report.

The workshop was organized and conducted by the NRC in cooperation with the U.S. Department of Energy (DOE), the U.S. Bureau of Reclamation, the U.S. Army Corps of Engineers, the U.S. Geological Survey (USGS), and the Federal Energy Regulatory Commission. Other contributors were the National Weather Service of the National Oceanic and Atmospheric Administration, the Federal Emergency Management Agency (FEMA), and invited industry, academic, and DOE national laboratory experts. Significant technical support was also provided by Deltares, an independent institute in the Netherlands for applied research in the field of water, subsurface, and infrastructure.

U.S. Geological Survey (USGS) researchers were involved in the workshop at all levels. Hydrologist **Timothy Cohn** (Reston, Virginia) and geophysicist **Eric Geist** (Menlo Park, California) served on the organizing committee and co-chaired panels on Tsunami Flooding (Geist) and State-of-the-Practice in Identifying and Quantifying Extreme Flood Hazards (Cohn). Hydrologist **Robert Mason** (Deputy Chief, USGS Office of Surface Water, Reston) was the USGS management liaison for the workshop. Geophysicist **Uri ten Brink** (Woods Hole, Massachusetts) and hydrologist **Jim O'Connor** (Oregon Water Science Center, Portland) gave presentations. Additional USGS contributors were geophysicist **Daniel Brothers** (Woods Hole), geologist **Jason Chaytor** (Woods Hole), geologist **Thomas Cronin** (Reston), hydrologist **Julie Kiang** (Reston), hydrologist **Thomas Over** (Urbana, Illinois), and geophysicist **Tom Parsons** (Menlo Park).

The full citation for the new report is:

Nicholson, T.J., and Reed, W.A., 2013, Proceedings of the Workshop on Probabilistic Flood Hazard Assessment (PFHA): U.S. Nuclear Regulatory Commission, NUREG/CP-0302, 241 p. <**http://www.nrc.gov/reading-rm/doc-collections/nuregs/conference/cp0302/**>.

All of the workshop presentation slides, a video of the workshop, the webcast, and the public meeting summary can be viewed at the NRC webpage at <**http://www.nrc.gov/public-involve/public-meetings/meeting-archives/research-wkshps.html**>.

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