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Research

Virus Calculated as Culprit Killing Sea Stars

By Ben Young Landis

[Reprinted from USGS Science Features: Top Story, November 17, 2014, <**http://www.usgs.gov/blogs/features/usgs_top_story/virus-calculated-as-culprit-killing-sea-stars/**>.]

Apart from SpongeBob's pal Patrick, it's hard to think of sea stars as living creatures. They're sold in beachcombing shops as rock-hard, dried specimens for home décor, and artists use their symmetric shapes as motifs for ocean-inspired patterns. But sea stars are actually soft-bodied, colorful, mobile animals that hunt and feed on the ocean bottom, and since 2013, a mysterious disease (<**http://www.seastarwasting.org**>) has been killing them in droves along the U.S. and Canadian Pacific Coast—causing their arms to fall off and spilling their innards (<**https://www.youtube.com/watch?v=SOgOe3pH5Qc**>), and wasting away their bodies as if a heat gun were melting them from the inside.

The "Sea Star Wasting Disease" behind this deadly epidemic has been intensely studied by marine scientists in recent months, and now, a prime suspect has finally been identified as a probable cause of the disease.

Researchers from Cornell University, the U.S. Geological Survey (USGS), and other institutions managed to isolate and analyze the genome of a previously unidentified virus in the sick sea stars. They published their findings on this "sea star associated densovirus (SSaDV)" in the December 2, 2014, issue of the *Proceedings of the National Academy of Sciences* (<**http://dx.doi.org/10.1073/pnas.1416625111**>). (Read the Cornell University press release at <**http://mediarelations.cornell.edu/2014/11/17/densovirus-named-top-suspect-in-devastating-sea-star-wasting-disease/**>.)

Led by Cornell University microbiologist **Ian Hewson** (<**http://hewsonlab.micro.cornell.edu/**>) with Cornell disease ecologist **Drew Harvell** (<**http://www.eeb.cornell.edu/harvell/Welcome.html**>), the study team comprises researchers from a who's who of science institutions: Western Washington University, Wildlife Conservation Society, University of California-Davis, California Science Center, Los Angeles County Museum of Natural History, Monterey Bay Aquarium, National Park Service, University of South

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*Unlike their smiling cartoon brethren on television, real-life sea stars are suffering from a wasting disease epidemic in which they lose limbs and literally disintegrate in a matter of days. USGS photograph by **Kevin Lafferty**.*

*In contrast to pale, sick specimens, healthy sea stars are vibrantly colored, active predators, like this giant sea star (*Pisaster giganteus*) capturing a cowrie snail. USGS photograph by **Kevin Lafferty**.*

Sound Waves

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Florida, USGS, University of California-Santa Cruz, Seattle Aquarium, University of Washington, University of Connecticut, and Vancouver Aquarium.

The sea star mortality was so sudden and unprecedented that biologists were unprepared and short on resources, says study coauthor **Kevin Lafferty** (<**http://www.werc.usgs.gov/person.aspx?personid=166**>), a marine ecologist and parasite specialist with the USGS Western Ecological Research Center (<**http://www.werc.usgs.gov/**>). "Lots of people were scrambling to learn what was going on. Ian started having interesting findings with densovirus, so he and Drew helped pull together a team of interested scientists to donate time to the effort." The USGS Western Fisheries Research Center also provided aquarium space at their Marrowstone Field Station (<**http://wfrc.usgs.gov/fieldstations/marrowstone/about.html**>) in the course of the research.

Clues to an Outbreak

Lafferty is based at the University of California-Santa Barbara's Institute of Marine Sciences (<**http://parasitology.msi.ucsb.edu/**>) as adjunct faculty (<**http://www.msi.ucsb.edu/people/faculty/kevin-lafferty**>). He used to see sea stars all the time when diving in his local kelp forest. "Now I can't find any," he says. "That level of destruction close to home piqued my interest in the cause of the disease. It became personal."

Kevin Lafferty

Sea star die-offs have been observed in past decades, but none were at this geographic scale (<**http://data.piscoweb.org/**

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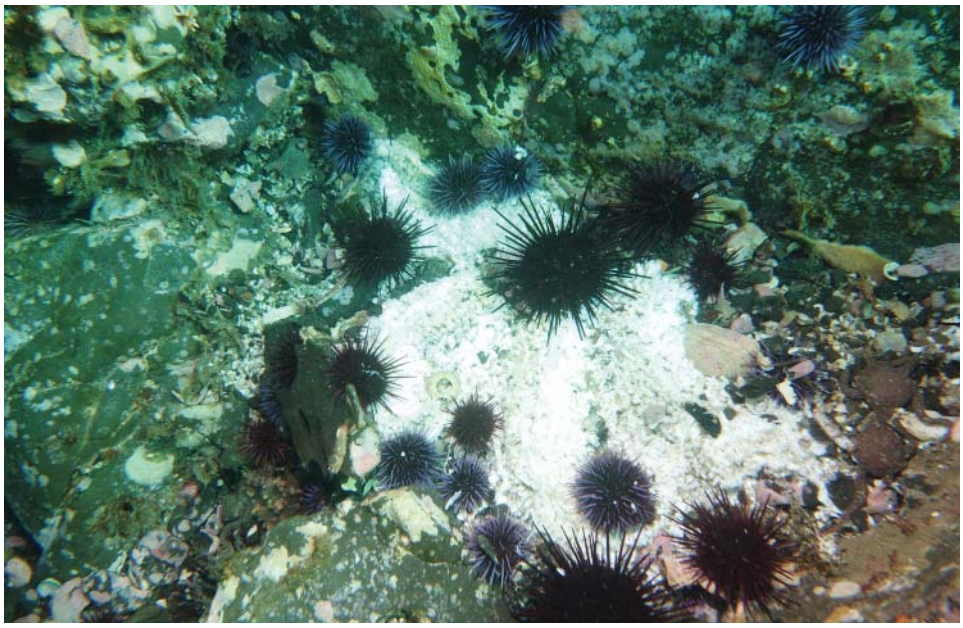

*Sea urchins crawl upon the disintegrated corpse of a sea star that succumbed to Sea Star Wasting Disease—a smattering of unrecognizable white matter. USGS photograph by **Kevin Lafferty**.*

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marine1/seastardisease.html>). Since June 2013, Sea Star Wasting Disease cases have been reported from Baja California in Mexico, southern California, northern California, Oregon, and all the way to southern Alaska. Worse, as many as 20 sea star species have been affected.

"Because it's happening underwater, this devastation may be difficult for many people to picture," says Lafferty. "But imagine if all the songbirds from Alaska to Mexico started falling out of the sky, dropping their wings, and disintegrating into a pile of feathers. You'd wonder if you were in an Old Testament-style plague."

Scientists raced to find a cause, ranging from pollution to storm surge damage. But when Sea Star Wasting Disease began to hit an aquarium that used natural seawater from the ocean, new clues emerged.

The disease did not spread into tanks where incoming seawater was treated with ultraviolet light, but it did spread into tanks with untreated water—suggesting that a living pathogen was in play instead of a chemical pollutant. Furthermore, trapping mechanisms like sand filters did not halt the spread of the disease from tank to tank, suggesting that the pathogen was microscopic and transferrable by water, rather than only via direct contact between infected sea stars.

Minced Tissue and Crunched Numbers

With that in mind, Cornell researchers devised a laboratory experiment using sunflower sea stars (*Pycnopodia helianthoides*) that showed symptoms of Sea Star Wasting Disease, removing tissue samples from these sick animals. The tissue was minced and blended in seawater, then passed through super-fine filters designed to remove bacteria but allow smaller materials—including viruses—to pass through.

This filtered blend was then injected into healthy sea stars, which all began to show wasting symptoms after two weeks. Researchers then took tissue from this set of newly diseased sea stars to create a second blend, injecting this into yet another group of healthy sea stars. Sure enough, these sea stars also showed wasting symptoms after two weeks.

*The sunflower sea star (*Pycnopodium helianthoides*) can be found in a variety of colors in the wild, like this healthy specimen with a lavender hue. USGS photograph by* ***Kevin Lafferty****.*

Meanwhile, another group of healthy sea stars was subjected to the same experiment, but they were injected with a boiled version of the blend intended to destroy any biologically active material. None of these sea stars developed wasting symptoms, and the experiments proved that some sort of virus-sized, biologically active entity could trigger wasting symptoms in one sea star, and continue to infect others.

"We went back to these sick and healthy sea stars to filter and extract virus particles from their tissue, and sequenced the genomes of these virus particles to uncover the types of viruses present," says Hewson, the Cornell microbiologist and the study's senior author. "The sick animals had higher prevalence of one viral group, the densoviruses. We were able to assemble a near-complete viral genome from the sick sea stars—a densovirus genome new to scientific record—and gave it a name: 'sea star associated densovirus,' or SSaDV."

But was SSaDV also related to wasting symptoms in sea stars in the wild? Drew Harvell, the marine disease specialist at Cornell, had been making field observations of the wasting disease and collected samples for the viral genome analysis. She rallied researchers at different institutions to gather tissue from more than 300 sick

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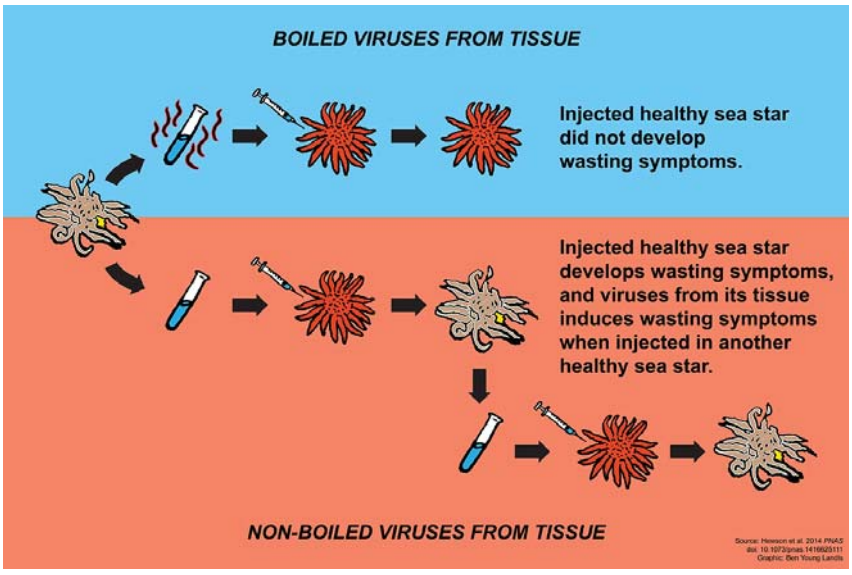

A simplified diagram of the Sea Star Wasting Disease experiment devised at Cornell University, used to prove that a virus-sized, biologically active entity was triggering wasting symptoms in sea stars. Graphic by ***Ben Young Landis****, USGS, based on the paper by Hewson and others, 2014, <****http://dx.doi.org/10.1073/pnas.1416625111****>.*

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and healthy sea stars from the wild, across 14 different species. Kevin Lafferty at USGS then performed statistical analyses on the results. "We confirmed that wild sea stars were more likely to be diseased if they carried a high viral load of SSaDV," says Lafferty.

Many-Armed Mystery

If SSaDV is indeed the culprit behind the current Sea Star Wasting Disease epidemic, that would leave researchers with even more mysteries. During the study, the team also analyzed preserved sea stars from past decades for viral traces, and found evidence of SSaDV or similar viruses in museum specimens dating back to the 1940s.

But if SSaDV has been in the wild all this time, and appears to be a virus that can be freely transmitted in the water column and in sediments, why is it all of sudden a problem now?

"There's a lot to untangle," according to Lafferty, whose USGS research often examines the role of disease organisms in natural food webs (for example, see <**https://www.youtube.com/watch?v=I3SzH_7QjIA#t=520**>) and their usefulness as indicators of ecosystem function (<**http://www.usgs.gov/envirohealth/geohealth/v09_n03.html#v09_n03_Land_Benj_010**>). "Parasites and pathogens are part of the natural food web, and just like wolves or sharks or any other organism, they can be affected by changes in the environment or their prey. So something has changed recently in Pacific waters—perhaps booms in sea star numbers, some stressor to sea star immune function, or some other environmental disturbance—to have set the stage for the current sea star wasting epidemic."

Late-Breaking News—Worries about Sea Urchins

In some areas along California's central coast, sea urchins are carpeting the seafloor as sea stars, their predators, disappear. In some southern California areas, however, the urchins themselves are losing their spines and dying, a wasting event that scientists do not yet understand.

*Screenshot from a video by **Robert Beck** of Brigham Young University and **Benjamin Miner** of Western Washington University that shows a healthy sea star gradually succumb to the mysterious symptoms of the Sea Star Wasting Disease—including an arm walking away from its deteriorating body. Video courtesy of Western Washington University, <**http://www.wwu.edu/mimsup/Robert/**>.*

*Tidepool scenes of vibrantly colored sea stars could become a rarity as the Sea Star Wasting Disease spreads. When asked recently to take photos of sea stars along his home coast of Santa Barbara, California, USGS ecologist **Kevin Lafferty** responded: "There are no sea stars now to photograph." USGS photograph of* Pisaster ochraceus *sea stars in San Juan Islands, Washington, by **Kevin Lafferty**.*

A recent article in *National Geographic* (<**http://news.nationalgeographic.com/2015/03/150401-urchins-sea-stars-monterey-bay-california-animals/**>) describes the complexities of how "effects of the sea star die-off seem to be reverberating along the California coast, altering the prey and predator relationships of urchins, sea otters, kelp, and even human anglers."

How You Can Help

As the investigation into Sea Star Wasting Disease continues, the public can still contribute citizen science data by reporting new cases of the disease that they observe while diving or exploring tidepools. Look for instructions at the UC Santa Cruz website at <**http://www.seastarwasting.org**>.

Scientific Portrait of the Largest Dam Removal in U.S. History

By Jonathan Warrick and Paul Laustsen

The effects of dam removal are better known as a result of several new studies released in February 2015 by government, tribal, and university researchers. The scientists worked together to examine and report the effects of removing two large dams from the Elwha River in Washington State, the largest dam-removal project in U.S. history (<**http://www.nps.gov/olym/learn/nature/elwha-ecosystem-restoration.htm**>). New findings suggest that dam removal can change landscape features of river and coasts, affecting ecosystems downstream of former dam sites.

"These studies not only give us a better understanding of the effects of dam removal, but show the importance of collaborative science across disciplines and institutions," said **Suzette Kimball**, Acting Director of the U.S. Geological Survey (USGS).

Five peer-reviewed papers, with authors from the USGS, the Bureau of Reclamation, the National Park Service, Washington Sea Grant, National Oceanic and Atmospheric Administration (NOAA) Fisheries, the Lower Elwha Klallam Tribe, and the University of Washington, provide detailed observations and insights about changes in the river's landforms, waters, and coastal zone during the first 2 years of dam removal. During this time, massive amounts of sediment were eroded from the drained reservoirs and transported downstream through the river and to the coast.

One finding that intrigued scientists was how efficiently the river eroded and moved sediment from the former reservoirs; more than a third of the 27 million cubic yards of reservoir sediment, equivalent to the volume of about 3,000 Olympic-size swimming pools, was eroded into the river during the first 2 years, even though the river's water discharge and peak flows were moderate compared with historical gaging records.

This sediment release altered the river's clarity and reshaped its channel while adding new habitats in the river and at the coast. In fact, the vast majority of the new sediment was discharged into the coastal waters of the Strait of Juan de Fuca, where the river mouth delta expanded seaward by hundreds of feet.

Aerial photographs of the Elwha River mouth before and during dam removal. A*, the river mouth wetlands before dam removal;* B*, the turbid coastal plume that was present during much of the dam removal project; and* C*, the expansion of the river mouth delta by sediment deposition. Photograph* A *by* ***Ian Miller*** *of Washington Sea Grant;* B *by* ***Jonathan Felis*** *of USGS; and* C *by* ***Neal*** *and* ***Linda Chism****, volunteers with LightHawk (<**http://www.lighthawk.org/**>).*

"The expansion of the river mouth delta is very exciting, because we are seeing the rebuilding of an estuary and coast that were rapidly eroding prior to dam removal," said USGS research scientist and lead author of the synthesis paper **Jonathan Warrick**.

Although the primary goal of the dam-removal project is to reintroduce spawning salmon runs to the pristine upper reaches of the Elwha River within Olympic National Park, the new studies suggest that dam removal can also have ecological effects downstream of the former dam sites. These effects include a renewal of sand, gravel, and wood supplies to the river and to the coast, restoring critical processes for maintaining salmon habitat to river, estuarine, and coastal ecosystems.

"These changes to sediment and wood supplies are important to understand because they affect the river channel form, and the channel form provides important habitat to numerous species of the region," stated USGS research scientist and river study lead author **Amy East**.

The final stages of dam removal occurred during the summer of 2014. Some erosion of sediment from the former reservoirs will likely continue. Research teams are continuing to monitor how quickly the river returns to its long-term restored condition.

"We look forward to seeing when the sediment supplies approach background levels," said Bureau of Reclamation engineer and co-author **Jennifer Bountry**, "because this will help us understand the length of time during which dam-removal effects will occur."

The five new papers have been published in Elsevier's peer-reviewed journal *Geomorphology* (<**http://www.journals.elsevier.com/geomorphology**>), and

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they focus on the following aspects of the large-scale dam removal on the Elwha River, Washington:

- Erosion of reservoir sediment (<**http://dx.doi.org/10.1016/j.geomorph.2014.12.045**>)
- Fluvial (river) sediment load (<**http://dx.doi.org/10.1016/j.geomorph.2014.12.032**>)
- River channel and floodplain geomorphic change (<**http://dx.doi.org/10.1016/j.geomorph.2014.08.028**>)
- Coastal geomorphic change (<**http://dx.doi.org/10.1016/j.geomorph.2015.01.002**>)
- Source-to-sink sediment budget and synthesis (<**http://dx.doi.org/10.1016/j.geomorph.2015.01.010**>)

A public lecture about some of these findings was presented in February 2015 at the USGS campus in Menlo Park, California, by USGS research geologist **Amy East**. Read about it in "Undamming Washington's Elwha River—Public Lecture on Largest Dam Removal in U.S. History," *Sound Waves*, this issue, <**http://soundwaves.usgs.gov/2015/02/outreach5.html**>; view an archived video of the lecture on the USGS Evening Public Lecture Series website, <**http://online.wr.usgs.gov/calendar/**> (click "Video Archives" in bar at top of page).❁

*Map of Elwha River watershed (darker shading), showing locations of the Elwha and Glines Canyon dams, the lakes they used to impound, USGS river-gaging stations (numbered triangles), the regional setting (inset), and other boundaries. Slightly modified from figure 1C of "Large-scale dam removal on the Elwha River, Washington, USA: Source-to-sink sediment budget and synthesis" by **Jonathan Warrick** and others, 2015 (<**http://dx.doi.org/10.1016/j.geomorph.2015.01.010**>)*

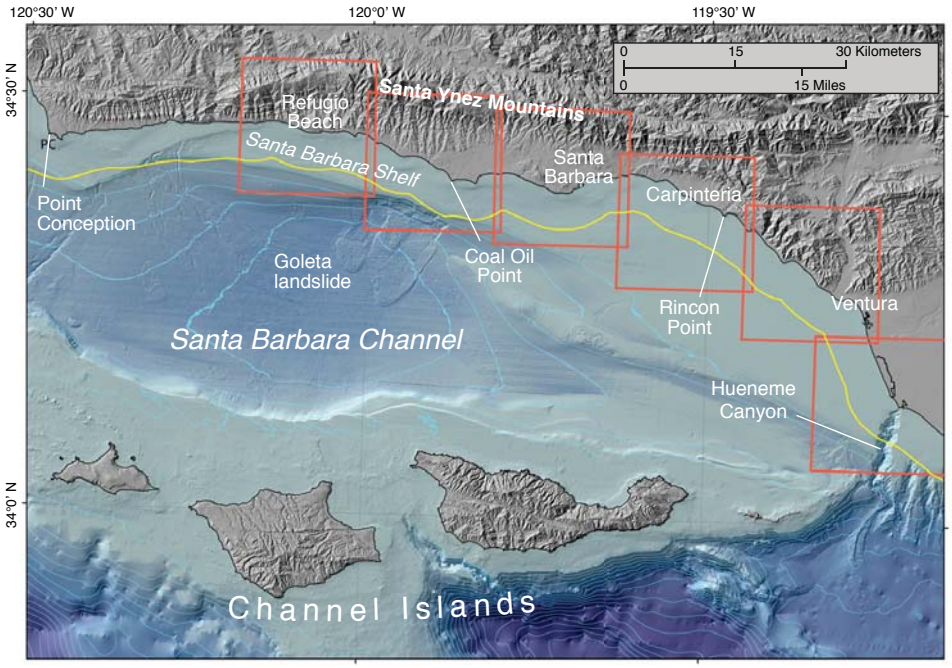
*USGS researchers **Raegan Huffman** (left) and **Chris Curran** retrieve instrumentation to measure sediment concentration from the Elwha River, Washington, on April 2, 2012, during the incremental removal of two large dams from 2011 to 2013. The USGS sampled sediment from the river during the dam-removal project to quantify the magnitude and timing of sediment released during the restoration project. More than a third of the 27 million cubic yards of reservoir sediment, equivalent to the volume of about 3,000 Olympic-size swimming pools, was eroded into the river during the first 2 years of dam removal. USGS photograph by **Jon Czuba**.*

California Seafloor Mapping Program Reaches Milestone

By Samuel Y. Johnson, Peter Dartnell, Guy R. Cochrane, Nadine E. Golden, and Susan A. Cochran

The California Seafloor Mapping Program (CSMP) has released its latest set of maps and data, "California State Waters Map Series—Offshore of Refugio Beach, California," U.S. Geological Survey (USGS) Scientific Investigations Map 3319 (<**http://pubs.usgs.gov/sim/3319/**>). The "Offshore of Refugio Beach" maps lie within the western Santa Barbara Channel in southern California, and their publication marks a CSMP milestone: the first phase of map and geospatial data publications, comprising six USGS Scientific Investigations Maps and associated data files centered on the Santa Barbara Channel, is now complete. The maps are part of an ambitious collaborative effort to develop comprehensive bathymetric (seafloor depth), habitat, and geologic maps for all of California's State Waters, which extend from the shoreline to 5.56 kilometers (3 nautical miles) offshore. These State Waters maps provide many types of information with a large range of applications. Examples include baselines for monitoring long-term change (from such factors as climate change and sea-level rise), geologic-framework data useful for assessing local earthquake and tsunami hazards, sediment distribution and thickness data that can serve as input to regional sediment management and sediment-transport modeling, physical and biologic habitat data that can provide a basis for ecosystem-based management, and data layers for use in decision-support tools for ocean planning.

CSMP began in November 2007, when the California Ocean Protection Council (COPC) allocated $15M for high-resolution bathymetric mapping, largely to support the California Marine Life Protection Act Initiative (<**http://www.msp.noaa.gov/examples/california.html**>). Subsequent support from the COPC, the National Oceanic and Atmospheric Administration (NOAA), the USGS Coastal and Marine Geology Program, and many other partners has led to development of one of the world's largest and most comprehensive seafloor-mapping datasets.



Santa Barbara Channel region, showing locations of six California Seafloor Mapping Program (CSMP) map sets (red rectangles) and the outer boundary of California's State Waters (yellow line).

More background information on CSMP is available at <**http://walrus.wr.usgs.gov/mapping/csmp/**>.

Development of map products, an effort led by the USGS Pacific Coastal and Marine Science Center (PCMSC), has been a CSMP focus. Each map set contains 10 downloadable pdf map sheets (most at 1:24,000 scale), an explanatory pamphlet, and digital geospatial data for a selected coastal "block." Map sheets and (or) data layers show bathymetry, backscatter (strength of sound energy reflected from the seafloor during sonar mapping, which reveals information about seafloor roughness and composition), perspective views, seafloor "character" (video-supervised automated classification of bathymetry and backscatter data into such categories as "fine- to medium-grained smooth sediment" or "rugged anthropogenic material"), ground-truth imagery (photographs and video footage collected to verify interpretations of the bathymetry and backscatter data), potential habitats, seismic-reflection profiles (cross-sectional views of sediment layers beneath the seafloor), seafloor sediment distribution and thickness, and onshore-offshore geology (distribution of rock and sediment types, faults, and folds). Some map sets include additional thematic sheets that highlight detailed geomorphology (shape of the seafloor), predicted distribution of benthic macro-invertebrates (animals living in seafloor sediment), and natural offshore hydrocarbon seepage. Each map set represents a large collaborative effort (for example, the 67 maps and data layers in the six Santa Barbara Channel map sets have 31 co-authors) representing federal, state, academic, and private-sector partners.

The Santa Barbara Channel area extends from the steep Santa Ynez Mountains on the north to the Channel Islands and adjacent continental shelf on the south, and from Point Conception east to the Hueneme submarine canyon (see map above). This dynamic landscape, characterized by diverse ecosystems and both urban and rural populations, faces

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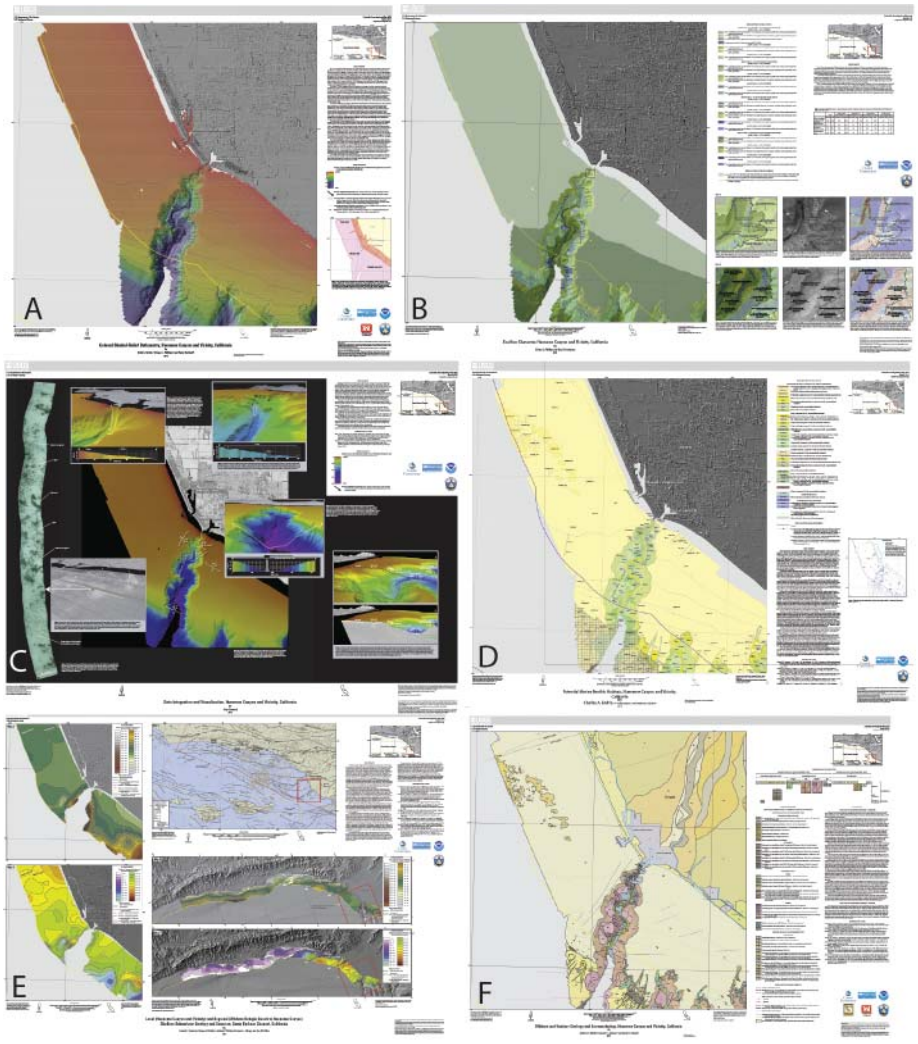
increasing environmental stress due to development, climate change, and natural hazards. The map publications provide essential information for coastal management while enabling coastal research and modeling. Highlights include:

1. Development of new methods and protocols for seamless onshore-offshore geologic mapping, and new strategies for geologic and geomorphic mapping of submarine canyons.
2. Detailed mapping of the Ventura-Pitas Point Fault, Red Mountain Fault, Rincon Creek Fault, and other active faults and folds from the onshore into the offshore, providing important constraints on earthquake-hazard assessments.
3. Maps that demonstrate the dramatic control of active faults on latest Pleistocene to Holocene sediment distribution and thickness.
4. Mapping of more than 60 potential habitats, revealing significant amounts of soft sediment and isolated areas of rocky habitat that support nearshore kelp-forest communities and deeper rocky reefs. These habitats can be quantified and modeled for ecosystem characterization.
5. Maps showing where common benthic macro-organisms—such as cup corals—are expected to occur based on real-time observations made by biologists watching video monitors during ground-truth surveys.
6. Observation of bedrock overlain by very thin sediment cover in many areas in water depths of active sediment transport. As the coast changes and evolves, these areas could be buried more deeply or exhumed to form new rocky habitat.
7. Recognition of submerged wave-cut platforms, keys to interpreting latest Pleistocene sea-level history.
8. Documentation of widespread hydrocarbon-seep-induced topography on the Santa Barbara shelf; the largest concentration of pockmarks occurs near the head of the large Goleta landslide.
9. Waves at Rincon, the world-famous surf spot, refract perfectly around a boulder delta that was deposited during a low stand of sea level and extends 1,500 meters offshore of Rincon Point.



*Six of 12 map sheets included in the USGS CSMP map-set publication "Hueneme Canyon and Vicinity" (<**http://pubs.usgs.gov/sim/3225/**>), the first CSMP Santa Barbara Channel map set to be published.* A, *bathymetry;* B, *seafloor character;* C, *perspective views;* D, *potential habitats;* E, *shallow subsurface geology and structure;* F, *offshore-onshore geology and geomorphology. Other sheets in this map set show gray-scale bathymetry, backscatter, ground-truth imagery, seismic-reflection profiles, detailed geology and geomorphology, and predicted distribution of benthic invertebrates.*

And much, much more.

The Santa Barbara Channel map sets are available at:

- <**http://pubs.usgs.gov/sim/3225/**> (Hueneme Canyon and vicinity)
- <**http://pubs.usgs.gov/sim/3254/**> (offshore of Ventura)
- <**http://pubs.usgs.gov/sim/3261/**> (offshore of Carpinteria)
- <**http://pubs.usgs.gov/sim/3281/**> (offshore of Santa Barbara)
- <**http://pubs.usgs.gov/sim/3302/**> (offshore of Coal Oil Point)
- <**http://pubs.usgs.gov/sim/3319/**> (offshore of Refugio Beach)

Three additional map sets for areas in central California are also available:

- <**http://pubs.usgs.gov/of/2014/1260/**> (offshore of Pacifica)
- <**http://pubs.usgs.gov/of/2014/1214/**> (offshore of Half Moon Bay)
- <**http://pubs.usgs.gov/sim/3306/**> (offshore of San Gregorio)

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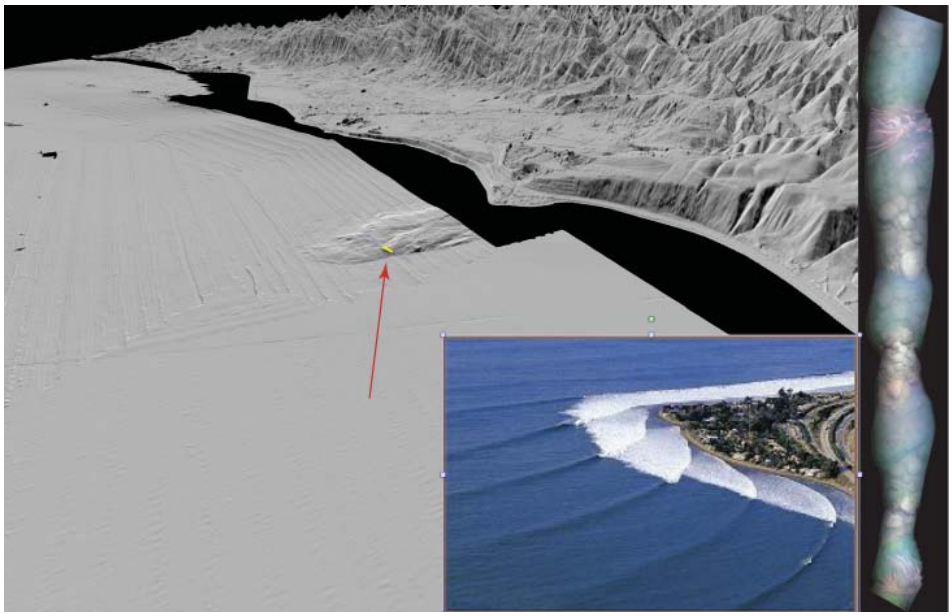
The data catalog for all CSMP is at <**http://pubs.usgs.gov/ds/781/**>. General information about CSMP is at <**http://walrus.wr.usgs.gov/mapping/csmp/**>.



*Gray-scale perspective view of Rincon Point, the subaerial part of a delta formed by boulders deposited at the mouth of Rincon Creek. A relict submerged boulder delta, formed by similar processes during lower stands of sea level, extends 1,500 meters offshore. Relief on this submerged delta causes wave refraction and a world-class surfbreak (inset image). Vertical panel on right is a video clip showing the pebble-boulder seafloor on the relict delta (clip's location shown by yellow line just above red arrow; easier to see at <**http://soundwaves.usgs.gov/2015/02/research3.html**>).*

Future Wave and Wind Effects on Pacific Islands—Projections Will Assist Planning for Climate Change

By Leslie Gordon and Curt Storlazzi

According to a report released in January 2015 by the U.S. Geological Survey (USGS), climate changes during the 21st century are expected to alter the highest waves and strongest winds across U.S. and U.S.-affiliated Pacific islands (see map, next page).

Information on changes in waves and winds under global climate change is crucial for understanding the sustainability of existing infrastructure and natural and cultural resources. It is also critical for planning future investments, such as renewable wind and wave energy for islands, and for understanding the viability of coastal economic activities, such as fishing and tourism. Wave- and wind-driven processes drive flooding of coastal land, potentially damaging islands' infrastructure, freshwater supplies, and natural resources, and harming federally protected species such as nesting seabirds. Such impacts may only be exacerbated in the future by projected trends in sea-level rise.

*Aerial photograph of waves breaking on the fringing reef off Ennuebing Island, Kwajalein Atoll, Republic of the Marshall Islands. From cover of "Future Wave and Wind Projections for United States and United States-Affiliated Pacific Islands," <**http://dx.doi.org/10.3133/ofr20151001**>.*

"With little to no publicly available historical wind and wave data for most of the U.S.-affiliated Pacific islands, and no future projections of waves and winds for different climate scenarios, there was a great science and management need to understand how waves and wind might change in future climates," said **Curt Storlazzi**, USGS oceanographer and lead author of the study.

Scientists from the USGS and the University of California, Santa Cruz (UCSC) ran four global climate models (developed for the Intergovernmental Panel on Climate Change, <**http://www.ipcc.ch/**>), using them to drive a global-wave model to look at projected changes in wave height,

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wave period, wave direction, wind speed, and wind direction. They focused on three Hawaiian Islands and 22 other locations on U.S.-affiliated islands in the Pacific Ocean. Modeling results project that wind and wave patterns will change over the years throughout the century, and also over certain months and seasons within each year.

"Natural-resource managers, communities, and engineers will all benefit by being able to prepare for the shifts in inundation risk shown by this study. This work shows that the degree of change we see will depend on how greenhouse-gas emissions change," said **Jeff Burgett**, science coordinator for the Pacific Islands Climate Change Cooperative (<**http://piccc.net/**>).

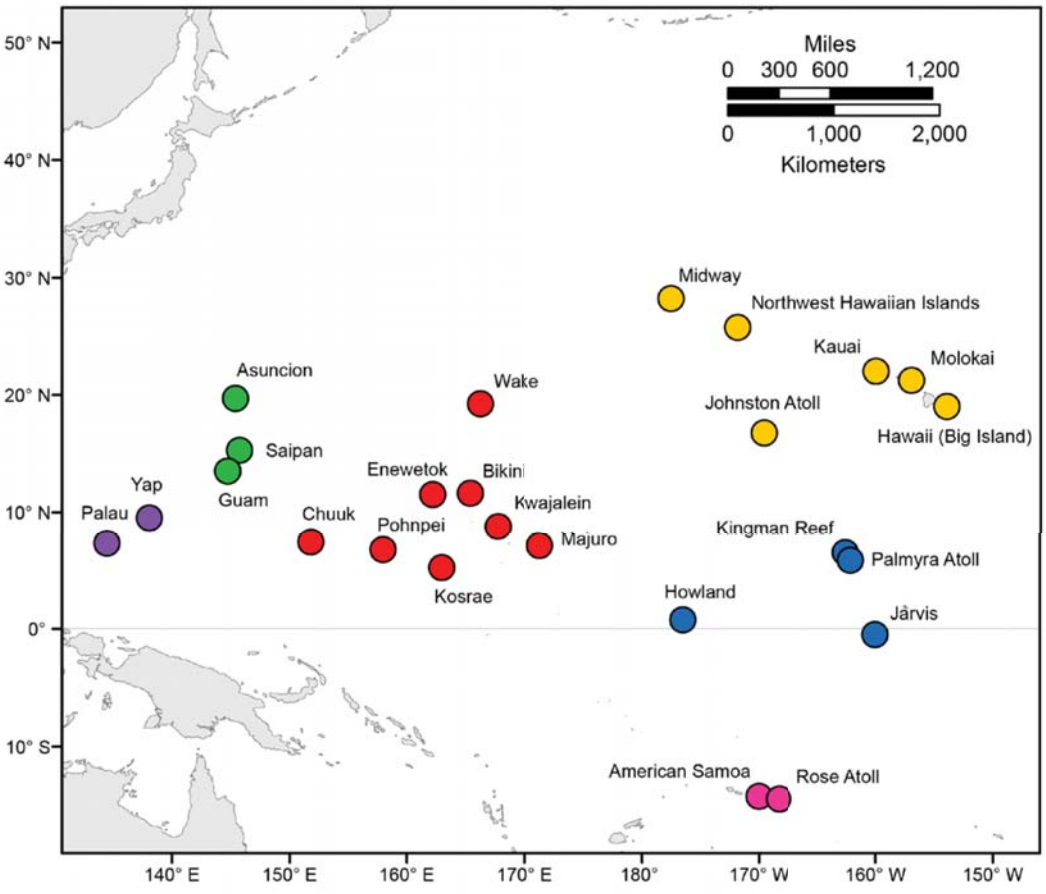
Scientists first ran the models for the years 1976–2005 and compared the results to the few available historical instrumental data in order to make sure the models were functioning properly. Then they ran the models for two future time spans—mid-21st century (2026–2045) and end-of-21st century (2085–2100)—under two different climatic scenarios: increasing greenhouse-gas concentrations until mid century, followed by reduced emissions (known as scenario RCP4.5), and unfettered growth of emissions (scenario RCP8.5). (These RCPs, or "representative concentration pathways," are two of four greenhouse-gas-concentration trajectories adopted by the Intergovernmental Panel on Climate Change for its Fifth Assessment Report [<**http://www.ipcc.ch/report/ar5/syr/**>].)

The spatial patterns and trends are mostly similar between the two different greenhouse gas concentration scenarios (scenario RCP4.5 and scenario RCP8.5), although the results of the study reveal some differences among islands. The magnitude and spatial extent of the trends are generally greater for the higher-emissions scenario (RCP8.5).

In general, extreme wave heights (the top 5 percent) are projected to increase from now until mid-21st century and then decrease toward the end of the 21st century. Peak wave periods (another measure of intensity) are forecast to increase east of the International Date Line and decrease west of the International Date Line. In equatorial Micronesia, extreme waves and winds are projected to undergo substantial (greater than 20 degrees) shifts in direction.

Detailed maps, graphs, and tables provided in the report will be useful to scientists, engineers, managers, community leaders, and others trying to understand and plan for the effects of climate change.

The full USGS Open-File Report 2015–1001, "Future Wave and Wind Projections for United States and United States-Affiliated Pacific Islands," by **Curt D. Storlazzi**, **James B. Shope**, **Li H. Erikson**, **Christie A. Hegermiller**, and **Patrick L. Barnard** is available online at <**http://dx.doi.org/10.3133/ofr20151001**>. This research was supported by the Pacific Islands Climate Change Cooperative (<**http://piccc.net/**>).



*Map of the tropical Pacific Ocean showing locations of the 25 modeled points used in the wave and wind study. Dots color-coded by study region: purple, western; green, Mariana Islands; red, central; blue, eastern equatorial; magenta, southern; yellow, northeastern. From figure 1 of "Future Wave and Wind Projections for United States and United States-Affiliated Pacific Islands," <**http://dx.doi.org/10.3133/ofr20151001**>.*

Slowly Swimming Towards Recovery, California's Sea Otter Numbers Holding Steady

By Ben Young Landis

[Reprinted from USGS Science Features: Top Story, September 22, 2014, <**http://www.usgs.gov/blogs/features/usgs_top_story/slowly-swimming-towards-recovery-californias-sea-otter-numbers-holding-steady/**>.]

When sea otters want to rest, they wrap a piece of kelp around their body to hold themselves steady among the rolling waves. Likewise, California's sea otter numbers are holding steady against the many forces pushing against their population recovery, according to the 2014 field survey led by federal, state, aquarium, and university scientists.

Since the 1980s, U.S. Geological Survey (USGS) scientists have calculated a population index each year for the southern sea otter—*Enhydra lutris nereis*—a species federally listed as Threatened (<**http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=A0A7**>). The annual range-wide field survey collects data on this protected marine mammal on behalf of the U.S. Fish and Wildlife Service (<**http://www.fws.gov/ventura/**>).

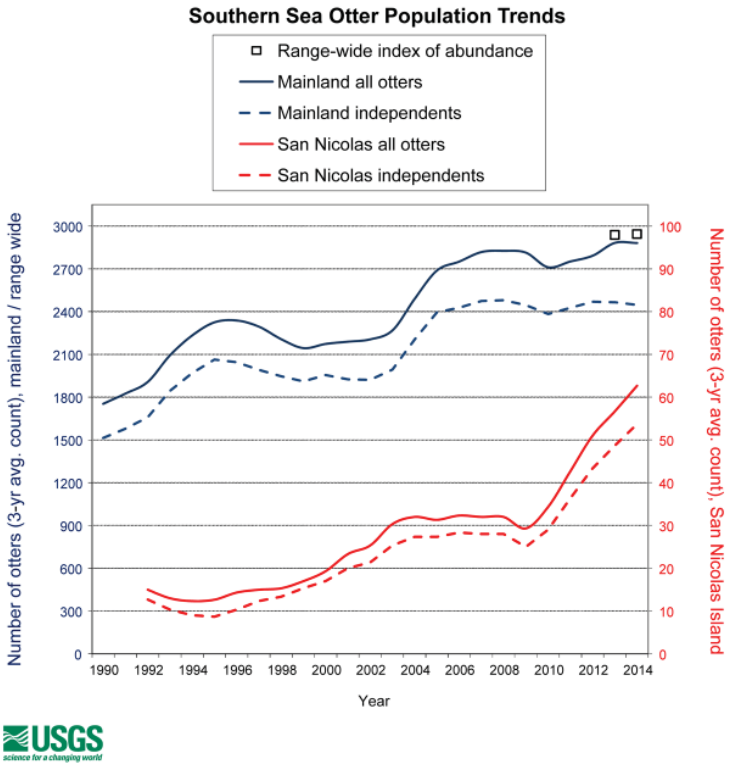
For 2014, USGS reported the population index as 2,944 (details available online; visit <**http://www.werc.usgs.gov/seaottercount**> and click on "Annual Survey – 2014 Summary"). It's a negligible bump from the 2013 report of 2,939 (read about the 2013 census in *Sound Waves*, <**http://soundwaves.usgs.gov/2013/10/fieldwork2.html**>).

For southern sea otters to be considered for removal from the "Threatened" species list, the population index would have to exceed 3,090 for three consecutive years, according to the Southern Sea Otter Recovery Plan (<**http://www.fws.gov/ventura/endangered/species/info/sso.html**>) established by the U.S. Fish and Wildlife Service.

"For an animal so few in number, sea otter population trends can be influenced by many local and range-wide factors," says biologist **Tim Tinker** (<**http://www.werc.usgs.gov/tinker**>) with the USGS Western Ecological Research Center (<**http://www.werc.usgs.gov/**>), who leads California sea otter

(Swimming Towards Recovery continued on page 12)

This southern sea otter is settling down to rest in a small patch of Egregia *feather boa kelp. Photograph by* ***Lilian Carswell****, U.S. Fish and Wildlife Service.*



Trends in population index reported by the USGS for southern sea otters in California in 2014. Data are shown for independent otters (non-pups) and all otters for mainland California (blue; left axis), San Nicolas Island (red; right axis), and range-wide (squares; left axis) from 2012 onward, when both indices were combined to calculate the population index.

(Swimming Towards Recovery continued from page 11)

research with co-investigators from the California Department of Fish and Wildlife's Office of Spill Prevention and Response (<**https://www.wildlife.ca.gov/OSPR/Science/MWVCRC**>), the Monterey Bay Aquarium (<**http://www.montereybayaquarium.org/conservation/research/southern-sea-otters**>), University of California, Santa Cruz (<**http://www.ucsc.edu/**>), and other institutions. "We are seeing elevated mortality suggestive of food-resource limitation in some parts of the range, and increasing mortality from white shark attacks in others. But our federal, state, aquarium, and university sea otter research alliance is making progress in understanding how all these trends relate to environmental factors along the California coast."

California sea otters feed and live in the "nearshore marine ecosystem"—the stretch of ocean that hugs a shoreline—making them a good indicator species for detecting pollutants and pathogens washed down from coastlands. And along many parts of Pacific North America, sea otters play critical roles in natural food webs, keeping important ecosystems like kelp forests and seagrass beds in balance.

Studying sea otters, then, not only helps us understand their population recovery, but it also uncovers clues on the health and rhythm of nearshore marine ecosystems—the same waters many people swim, fish, and make a living in every day.

Mothers and Pups

Sea otters were presumed extinct in California after the 19th-century fur trade years but were rediscovered in the 1930s by the public, when as few as 50 animals were documented persisting in nearshore areas off the coast of Big Sur.

In that context, the present state of sea otters in California isn't terrible. But population recovery has been slow. Part of the reason is the extreme, edge-of-the-knife life history of sea otters.

Not equipped with blubber like whales and seals, sea otters must rely on their fur coat and their super-high metabolic rate to stay warm. "The average adult sea otter has to actively hunt and eat 20 to 30 percent of its body mass in food each day just to meet its energy requirements," says Tinker.

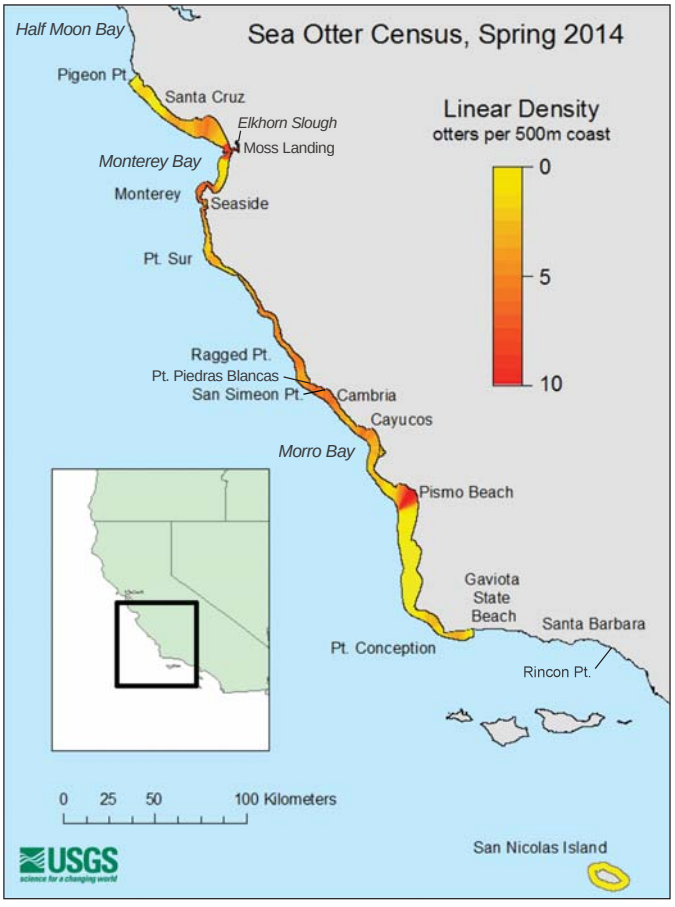
Research published in 2014 by UC Santa Cruz, USGS, and Monterey Bay Aquarium (<**http://dx.doi.org/10.1242/jeb.099739**>) addressed the question of how this energy demand changes for a nursing mother sea otter (<**http://news.ucsc.edu/2014/06/sea-otter-moms.html**>), who has to eat not only to keep herself alive but also to produce milk for her pup. Researchers calculated that a mother sea otter has to nearly double her energy intake to keep herself and her pup fed—she has to find enough groceries and eat for two, so to speak, for six months straight (<**http://www.werc.usgs.gov/outreach.aspx?RecordID=214**>).

Indeed, researchers have documented a high mortality rate in prime-breeding-age female sea otters in California from what they call "end-lactation syndrome"—where females are so underweight and energetically stressed after raising a pup that they are more vulnerable to life-threatening diseases and infections.

The new research offers an explanation for the high mortality in

(Swimming Towards Recovery continued on page 13)

Sea otters live at the edge of the land and sea environments, like these idyllic sun-lit waters in Big Sur, California—the same nearshore ocean waters that humans use and enjoy. USGS photograph by ***Ben Young Landis****.*



Map of central California showing variation in local population densities of southern sea otters along the mainland coast and San Nicolas Island in 2014.

(Swimming Towards Recovery continued from page 12)

breeding-age females in the center part of the sea otter's California range (Seaside to Cayucos, see map, previous page)—which is likely at or near "carrying capacity," the maximum population size that can be sustained over the long term by the resources available in the area.

"These fundamentally high energy demands are likely the underlying reason why we see so much mortality among prime-age females in the middle of their geographic range, where the density of the sea otter population is highest and resources are limited," explains study lead author **Nicole Thometz** of UC Santa Cruz. "In the center of the range, they appear to be up against their physiological limits."

But give even more credit to these sea otter moms: the 2014 population index also reported a record high for pups.

"The ratio of dependent pups to adult otters remains high overall, and together with data from tagging studies, that tells us that reproductive rates are within the normal range and not limiting recovery," says USGS biologist **Brian Hatfield**, who coordinates the annual population survey.

Of course, it remains to be seen whether more pups will translate into overall population growth.

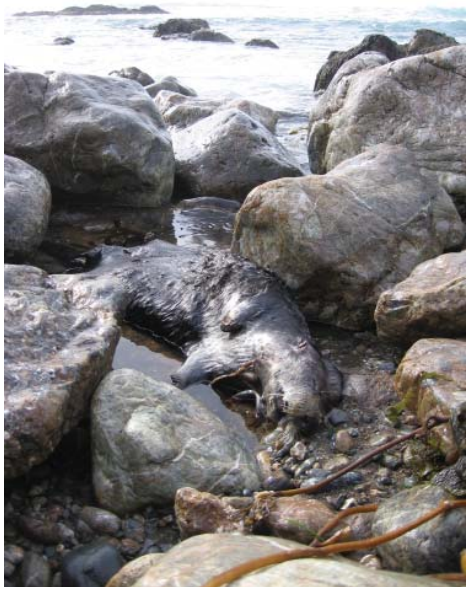
Le Morte d'Otter

Hatfield also coordinates a yearly review of sea otter strandings—the number of dead, sick, or injured sea otters recovered along California's coast each year (<**http://www.werc.usgs.gov/seaotterstranding**>), including those reported by the public to researchers (<**http://www.werc.usgs.gov/ProjectSubWebPage.aspx?SubWebPageID=5&ProjectID=232**>). In 2013, scientists came across a total of 340 stranded sea otters—a slight drop from 2012 but still remarkably high. However, Hatfield points out that the stranding number accounts only for sea otters that people find, and past research indicates that possibly fewer than 50 percent of sea otters that die in the wild wash ashore.

For the sea otter carcasses that do get reported, a subset is sent to the State of California's Marine Wildlife Veterinary Care and Research Center (<**https://www.wildlife.ca.gov/OSPR/Science/MWVCRC**>), where scientists conduct necropsies to determine the primary causes of death and to identify other factors that may have contributed to the death of each animal.

*Screenshot from video of a southern sea otter mother and pup at the Monterey Bay Aquarium (<**https://www.youtube.com/watch?v=UcHsEugpQrE**>), which collaborates on sea otter research with USGS and other institutions. Video courtesy of the Monterey Bay Aquarium.*

These necropsies are how scientists learned about the increase in bite wounds from great white sharks (<**http://www.montereybayaquarium.org/animal-guide/fishes/great-white-shark**>)—apparently the result of "exploratory bites" that do not lead to consumption of the otter by the shark, but that nonetheless often result in the death of the otter. This cause of death has been common at the north end of the range (from Pigeon Point to Seaside) for some time, but in recent years it has become most intense in the southern end of the range (from Cayucos to Gaviota)—to the point where the adult population now has a declining trend.



*The State of California studies dead sea otters, like this one found by USGS scientists in Piedras Blancas, California, to learn about their causes of death and to understand the variety of environmental stress factors that impact the nearshore marine environment. USGS photograph by **Brian Hatfield**.*

Not great news for the dense patch of sea otters stuck in the central range, trying to expand northward and southward.

In addition to end-lactation syndrome and shark bites, the state's "CSI: Sea Otter" laboratory (<**http://www.mercurynews.com/ci_22508871/**>) has revealed many other causes of death for sea otters across California. Over the years, California state veterinarians have found sea otters poisoned by the microbial toxin microcystin (<**http://news.ucsc.edu/2010/09/otter-toxin.html**>)—which can flow into the sea after blooming in warm lakes with an overabundance of nutrients—as well as sea otters infected with protozoan parasites that can cause fatal brain infections, including *Toxoplasma gondii*, which is transmitted in the feces of wild and domestic cats.

Other known sources of California sea otter mortality include bacterial infec-

(Swimming Towards Recovery continued on page 14)

(Swimming Towards Recovery continued from page 13)

tions, heart disease, mating trauma from aggressive male sea otters, boat strikes, and gunshots. Even today, the U.S. Fish and Wildlife Service (<**http://www.fws.gov/le/**>) has an unsolved case from 2013 of three sea otters found near Monterey, California, where gunshot was determined to be the cause of death.

Matters of Otter Importance

That's a lot of different factors determining the survival of a creature central to the survival of giant kelp forests—the underwater jungles teeming with marine life that stretch from California to Alaska.

"Sea otters are considered a keystone species of the kelp ecosystem because they are such voracious predators, and they are uniquely capable of limiting herbivorous invertebrates like sea urchins that, if left unchecked, can decimate kelp beds and the fish habitat they provide," says USGS biologist **Tim Tinker**, who with his mentor **Jim Estes** coauthored a 1998 study that described this epic circle of life in Alaskan waters (<**http://dx.doi.org/10.1126/science.282.5388.473**>).

[Editor's note: Read about changes that could affect the kelp ecosystem in "Virus Calculated as Culprit Killing Sea Stars," this issue (**http://soundwaves.usgs.gov/02/2015/**).]

The alliance of USGS, U.S. Fish and Wildlife Service, state, aquarium, and university researchers are continuing to study the ecological and environmental roles that sea otters can play, not only in kelp forests of the outer coast, but in protected tidal estuaries as well.

*Kelp forests provide refuge for sea otters, gamefish and other nearshore organisms—and in turn, sea otters help maintain the kelp ecosystem by keeping populations of herbivores, such as sea urchins, in check. USGS photograph by **Ben Young Landis**.*

*Screenshot from video of sea otter mother and newborn pup in Elkhorn Slough, near Moss Landing, California (<**https://www.youtube.com/watch?v=e42KCSxmq9k&list=PLLqsDvSH5x9eGr1fBKE0sEpYvLe_-khQg?rel=0#t=12**>). The Elkhorn Slough National Estuarine Research Reserve, Elkhorn Slough Foundation, and Friends of the Sea Otter operate a webcam that allows the public to view sea otters in the tidal wetlands of Elkhorn Slough, where USGS and other researchers are studying this Threatened species: <**http://www.elkhornslough.org/ottercam/**>.*

Over at the Elkhorn Slough National Estuarine Research Reserve (<**http://www.elkhornslough.org/esnerr/**>), which is owned and operated by the California Department of Fish and Wildlife in partnership with the National Oceanic and Atmospheric Administration (NOAA), alliance researchers have two ongoing studies. One study has revealed that sea otters help restore seagrass beds by keeping crab populations in balance (<**http://news.ucsc.edu/2013/08/sea-otters-seagrass.html**>), which in turn lets sea slugs thrive and munch on algae that would otherwise smother the seagrasses (<**http://dx.doi.org/10.1073/pnas.1302805110**>). Another study is investigating how sea otters utilize tidal wetland habitats (<**http://www.werc.usgs.gov/elkhornotters**>), where they may benefit from the rich food sources of estuaries and the ease of resting in warm shallows and sun-bathed marshes—helping us understand how sea otters might one day recolonize and balance similar habitats found elsewhere in California.

Farther down the coast in Big Sur, a recent analysis (<**http://dx.doi.org/10.1111/mms.12151**>) led by USGS geneticist **Liz Bowen** (<**http://www.werc.usgs.gov/bowen**>) reported that sea otters living near a 2008 wildfire showed a physiological response to chemicals generated by fire ash (<**http://radio.krcb.org/post/wildfires-cause-trouble-sea-otters**>)—uncovering another pathway through which land and sea environments can interact.

As for the sea otter numbers in California, USGS and alliance researchers are currently analyzing more than a decade of research to tease out the driving factors tempering their population recovery and spread—a recovery, as new findings continue to show, that should benefit California's nearshore marine ecosystem.

"We already knew that sea otters played a vital role in coastal ecosystems, but the exciting discoveries of the last several years suggest that we have really only begun to understand the far-reaching effects of this top predator," says **Lilian Carswell**, southern sea otter recovery coordinator for the U.S. Fish and Wildlife Service. "If sea otters can recolonize new areas of their historic range, we are almost certain to see an upswing in population growth. That will be good for sea otter recovery, good for the nearshore environment, good for all of us—because we all benefit from the services that intact ecosystems provide."

Can't Get Enough of Sea Otter Photos?

Click through this Flickr gallery created by the USFWS Ventura Fish and Wildlife Office: <**https://www.flickr.com/photos/usfws_pacificsw/sets/72157632298573498/**>.

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How Do Researchers Count Sea Otters?

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

Visual survey data from multiple years are averaged to calculate the annual population index, in order to compensate for year-to-year variability in observation conditions and to give scientists a more reliable picture of sea otter abundance trends.

Surveys are conducted via telescope observations from shore and via low-flying aircraft, typically from April through June. In 2014, the surveyed coastline spanned Point San Pedro in San Mateo County (about 10 miles north-northwest of Half Moon Bay), south to Rincon Point near the Santa Barbara/Ventura County line, and San Nicolas Island (<**http://www.werc.usgs.gov/ProjectSubWebPage.aspx?SubWebPageID=24&ProjectID=91**>).

In 2013, the equation for the population index was amended to add sea otters living at San Nicolas Island, in the Channel Islands offshore of Los Angeles. Sea otters were introduced to the island in the 1980s as part of a U.S. Fish and Wildlife Service recovery experiment, but most returned to the mainland or disappeared, and some are known to have died. The Service reassessed and ended the experimental program in December 2012 (<**http://www.fws.gov/ventura/docs/frnotices/77%20FR%2075266.pdf**>, 573 KB), and the remaining sea otters at San Nicolas Island are now counted as part of the California-wide population index.

Appreciating Sea Otters, Safely

Sea otters can be found in nearshore areas along the California coastline, including areas of high human activity, such as harbors. Like any other wild animals—especially carnivores—they should be appreciated from a distance. Here are some tips for watching sea otters, suggested by the Monterey Bay Aquarium and the U.S. Fish and Wildlife Service:

- Take caution in areas where sea otters are known to be present.
- Keep a safe distance from sea otters and other wildlife. If the otter notices you, you are likely too close and should back away.
- Keep pets on a leash on and around docks and harbors.
- Never feed sea otters or other wildlife. Wild animals that are fed can become aggressive.

New Research Vessel *Arcticus* Advancing USGS Fishery Science in the Great Lakes

By Andrea Miehls and Josh Miller

[Based on "Science Afloat: How a Research Vessel is Built, Part 5 (Jan 5)" <**http://www.glsc.usgs.gov/features#144361**>.]

The U.S. Geological Survey (USGS) Great Lakes Science Center (<**http://www.glsc.usgs.gov/**>) recently added a new vessel to its fleet: the 77-foot research vessel (R/V) *Arcticus*, which supports fishery research in Lakes Michigan and Huron.

The vessel's primary field-sampling capabilities include bottom trawling, plankton and benthic invertebrate sampling, hydroacoustics (use of sound waves to detect fish and assess their abundance), gill netting, and collection of environmental data, such as temperature, dissolved oxygen, and water transparency. The *Arcticus* offers greater research capabilities, increased fuel efficiency, improved health and safety features, and lower maintenance costs than its predecessor, the 75-foot R/V *Grayling*, a vessel that had served the USGS well since its construction in 1977 but was nearing the end of its effective service life.

(Arcticus *continued on page 15)*

The research vessel (R/V) Arcticus *at its homeport, the Cheboygan Vessel Base in Cheboygan, Michigan. USGS photograph by* ***Andrea Miehls****.*

(Arcticus *continued from page 15)*

In a nod to the legacy of the *Grayling*, which was instrumental in sampling deepwater ecosystems of Lakes Michigan and Huron, the name *Arcticus* was drawn from the species name for the arctic grayling, *Thymallus arcticus*, a cold-water fish once native to Michigan. The new vessel is a versatile platform with the capacity to continue historical lake-wide fishery surveys while also providing state-of-the-art scientific instrumentation to support USGS research. "The new vessel includes 21st-century technologies to advance the fishery science conducted by the USGS Great Lakes Science Center and its partners," said Center Director **Russell Strach** (<**http://www.glsc.usgs.gov/personnel/1122**>).

Research vessels are floating scientific laboratories that play a critical role in the mission of the Great Lakes Science Center. With a research vessel stationed on each of the five Great Lakes, USGS scientists are able to conduct cutting-edge research and track long-term trends in the ecology of these vast and valuable ecosystems.

The *Arcticus* was designed by JMS Naval Architects of Mystic, Connecticut, and built by the Burger Boat Company in Manitowoc, Wisconsin. The design-build process began in July 2013, and the new vessel was "splashed" and took its maiden voyage on September 29, 2014, off the shore of the city of Manitowoc. View a video of the vessel's launch at <**http://gallery.usgs.gov/videos/862**>.

The *Arcticus* plied the open waters of Lake Michigan for the very first time as part of its "sea trials." Sea trials for a new vessel take place when construction is complete but before final delivery to the owner in order to work out all the remaining bugs and ensure the vessel meets expectations. The vessel was evaluated based on a variety of criteria, including maneuverability, engine performance, and speed. The *Arcticus* passed its sea trials on October 14, 2014.

The Great Lakes Science Center took possession of the *Arcticus* on October 17, 2014, and the *Arcticus* arrived at her homeport, the Cheboygan Vessel Base in Cheboygan, Michigan, on October 20. She began her service to the USGS immediately, deployed to conduct a lake trout spawner survey in northern Lake Michigan on October 24. Her performance was outstanding.

It turns out that the best way to build a research vessel is to start from the bottom up, with the bottom, quite literally, up. For months the R/V Arcticus *hull took shape upside down on the floor of the Burger Boat Company construction bay. On March 10, 2014, the 67-ton hull module (more than the weight of 30 minivans) was rolled to its upright position, making it ready for the addition of the upper decks. USGS photograph by* ***Jean Adams****. View a video of this process at <****http://gallery.usgs.gov/videos/790****>.*

The final step for the *Arcticus* will be her christening and commissioning in summer 2015 at her base in Cheboygan, Michigan, when she will officially begin her service to the U.S. Government. (Read about the August 2014 christening and commissioning of the USGS R/V *Kaho* in Oswego, New York, at <**http://www.glsc.usgs.gov/features#143091**>).

The building of the *Arcticus* has been chronicled in a multipart video series filmed by Great Lakes Science Center scientist **Jean Adams** (<**https://profile.usgs.gov/jvadams**>). Major milestones include the arrival of materials (<**http://www.glsc.usgs.gov/05-11-2013/1905899627**>), construction and assembly of hull modules (<**http://www.glsc.usgs.gov/22-01-2014/245345928**>), rolling of the completed hull (<**http://www.glsc.usgs.gov/14-05-2014/1739362211**>), installation of the pilot house (<**http://www.glsc.usgs.gov/features#142961**>), sea trials and delivery to the vessel's homeport in Cheboygan, Michigan (<**http://www.glsc.usgs.gov/features#144361**>), and (still to come) the formal christening and commissioning. Look for short videos about these milestones in the "Science Afloat" series on the Great Lakes Science Center website (<**http://www.glsc.usgs.gov/search?search_api_views_fulltext=Science+Afloat&=Search**>).

The *Arcticus* at-a-glance:

- Length: 77.5 feet
- Breadth: 26 feet
- Draft: 8.9 feet
- Full load displacement: 205 tons
- Cruising speed: 9.5 knots
- Maximum speed: 10.2 knots
- Builder: Burger Boat Company (Manitowoc, Wisconsin)
- Designer: JMS Naval Architects (Mystic, Connecticut)
- Architect: Gregory C. Marshall, Naval Architect, Ltd. (Victoria, British Columbia, Canada)
- Design and construction cost: $5.6M ❁

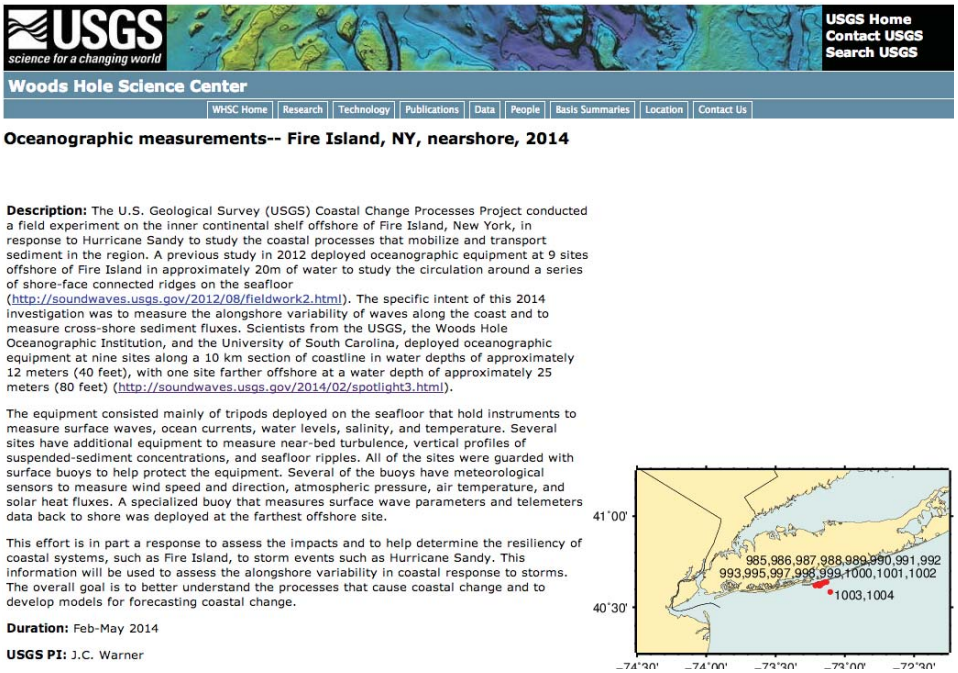
Five New USGS Oceanographic Datasets Published Online—Uses Include Assessing Coastal Resilience to Storms

By Ellyn Montgomery

Oceanographic data from U.S. Geological Survey (USGS) experiments off Fire Island, New York; in Barnegat Bay, New Jersey; in the Rachel Carson National Wildlife Refuge, Wells, Maine; on the Chandeleur Islands, Louisiana; and on Dauphin Island, Alabama, were published online in 2014 and early 2015 by the USGS Woods Hole Coastal and Marine Science Center in Woods Hole, Massachusetts. These are "time-series" data—measurements taken at regular intervals over a period of time—and include water temperature, pressure, current velocity, conductivity (salinity), suspended-sediment concentration, and more. These and the other datasets posted at <**http://stellwagen.er.usgs.gov/**> will help scientists better understand oceanographic and related sediment-transport processes. Knowing how much energy is required to move sediment, and how much energy is produced by storms of varying sizes, permits the development of more accurate planning tools.

Two of the datasets were collected off Fire Island, the first in January–April 2012 to study the effects of storms on coastal erosion and how bathymetry (depth and shape of the seafloor) may function to redirect wave energy. (Read more about this work in "Collecting Ocean-Circulation and Sediment-Transport Data Offshore of Fire Island, New York," *Sound Waves*, July/August 2012, <**http://soundwaves.usgs.gov/2012/08/fieldwork2.html**>, and "Coastal Change Processes Project Data Report for Observations Near Fire Island, New York, January to April 2012," USGS Open-File Report 2014–1159, <**http://pubs.usgs.gov/of/2014/1159/**>.) This experiment provided valuable information for comparison with data collected after Hurricane Sandy struck the region in October 2012.

The second experiment off Fire Island was conducted February–May 2014 to further study coastal processes that mobilize and transport sediment in the region. Data were collected in the same general area as the 2012 data but closer to shore. (See "Update on Oceanographic Study Offshore of Fire Island, New York," *Sound Waves*, March/April 2014, <**http://soundwaves.usgs.gov/2014/04/spotlight.html**>, and "Coastal Change Processes Project Data Report for Oceanographic Observations near Fire Island, New York, February through May 2014," USGS Open-File Report 2015–1033, <**http://pubs.usgs.gov/of/2015/1033/**>.) This data collection was part of a larger effort by the USGS, in cooperation with the U.S. Army Corps of Engineers and the National Park Service, to study coastal processes on Fire Island and assess coastal change during storms.



*Top of description page for experiment conducted off Fire Island, New York, in 2014 (<**http://stellwagen.er.usgs.gov/FIREISLAND14.html**>). Map shows locations of numbered sampling stations. Links to data are off the bottom of the image.*

The projects in Barnegat Bay and Rachel Carson National Wildlife Refuge were conducted to study circulation and light penetration in estuaries, and how these factors affect vegetation. The Chandeleur Islands and Dauphin Island experiments were conducted to measure wave heights and water levels during storms as part of the Barrier Island Evolution Research (BIER) project (<**http://coastal.er.usgs.gov/bier/**>).

Data from these experiments, and many more, are on the Woods Hole Coastal and Marine Science Center's "stellwagen" server in "U.S. Geological Survey Oceanographic Time-Series Data" (<**http://stellwagen.er.usgs.gov/**>), a USGS-approved online database of oceanographic time-series measurements recorded during scientific research projects conducted from 1975 to the present. Periods of data collection were typically one month to several years. The experiments commonly focused on observations near the seafloor, but most also obtained current-velocity data in the water column.

Exploring the Data

The main page of the database (<**http://stellwagen.er.usgs.gov/**>) presents a list of experiments with their dates, organized by region. Each experiment name links to a page with a description of the project, the principal investigator(s),

(Oceanographic Data continued on page 18)

(Oceanographic Data continued from page 17)

Tripods loaded on the deck of the research vessel Connecticut *in preparation for deployment at Fire Island in 2014. From title page of "Coastal Change Processes Project Data Report for Oceanographic Observations Near Fire Island, New York, February through May 2014" (<**http://dx.doi.org/10.3133/ofr20151033**>), a report based on one of the recently published datasets.*

the duration of the experiment, and a map detailing the location of each platform (for example, see <**http://stellwagen.er.usgs.gov/BARNEGAT.html**>). Also included on the experiment page are links to associated publications and field-activity entries (for example, see <**http://woodshole.er.usgs.gov/operations/ia/public_ds_info.php?fa=2013-050-FA**>).

Further details of the measurements collected at each site are available in a Google Earth .kml file or in links from a tabular catalog under the heading "Links to the Data." All experiments have a "basic sampling interval" link to a catalog page describing the observations. Basic-sampling-interval data files contain data reported in the intervals at which they were sampled. Some experiment pages also provide a link to a catalog of all the data files converted to a common time base: hourly averages.

The catalog pages display a table describing the contents of each file: time, location, sample depth, and type of data (for example, see <**http://stellwagen.er.usgs.gov/BARNEGAT-a.html**>). Clicking on the filename in the leftmost column initiates downloading of the data file. Viewers such as ncBrowse (<**http://www.epic.noaa.gov/java/ncBrowse/**>) allow easy viewing of the variables and structure of the files.

Nuts and Bolts

Data served on stellwagen go through a rigorous review and validation process before publication, as described in the database description document at <**http://woodshole.er.usgs.gov/pubs/of2007-1194/html/dataquality.html**>. The data are stored in Network Common Data Form (netCDF, <**http://www.unidata.ucar.edu/software/netcdf/**>) files using the Equatorial Pacific Information Collection (EPIC) conventions defined by the National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory (<**http://www.epic.noaa.gov/epic/**>). Details about how netCDF is used in the data files are provided at <**http://woodshole.er.usgs.gov/pubs/of2007-1194/html/netcdf.html**>. Select datasets have accompanying USGS Open-File Reports describing the research project.

Direct computer-to-computer access to the data files is provided via Unidata's Thematic Realtime Environmental Distributed Data Services (THREDDS, <**http://www.unidata.ucar.edu/software/thredds/current/tds/**>). THREDDS enables access via OPenDAP, WMS, SCS, and other methods.

Discovery by geoportals (webpages that collect information from different sources and provide a single point of access to the information) is enabled by using the attribute convention for dataset discovery (ACDD, <**http://wiki.esipfed.org/index.php?title=Category:Attribute_Conventions_Dataset_Discovery**>) in the ISO19115 metadata (<**http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?csnumber=53798**>) generated for each file. These records will also be harvested into the USGS Science Data Catalog (<**http://data.usgs.gov/datacatalog/**>) in the second part of 2015, to become part of the broader list of government-supplied ocean data.

Stay Tuned

Additional datasets are added to the server as they pass the necessary quality-review steps. Data from several more experiments are in the pipeline as this article goes to press, so check the website (<**http://stellwagen.er.usgs.gov/**>) periodically to see what's new.

*A high-resolution flow tripod (Flobee) holding instrumentation to measure flow and sediment resuspension. USGS photograph by **Sandra Brosnahan**. From same report as vessel photograph, <**http://dx.doi.org/10.3133/ofr20151033**>.*

Dive In! Explore Thousands of Coastal and Seafloor Images along U.S. Coasts

By Nadine Golden, Seth Ackerman, and Jessica Robertson

Thousands of photographs and videos of the seafloor and coastline—most areas never seen before—are now easily accessible online. This imagery, available through the U.S. Geological Survey (USGS) Coastal and Marine Geology Video and Photograph Portal (<**http://dx.doi.org/10.5066/F7JH3J7N**>), will help coastal managers to make important decisions, ranging from protecting habitats to understanding hazards and managing land use.

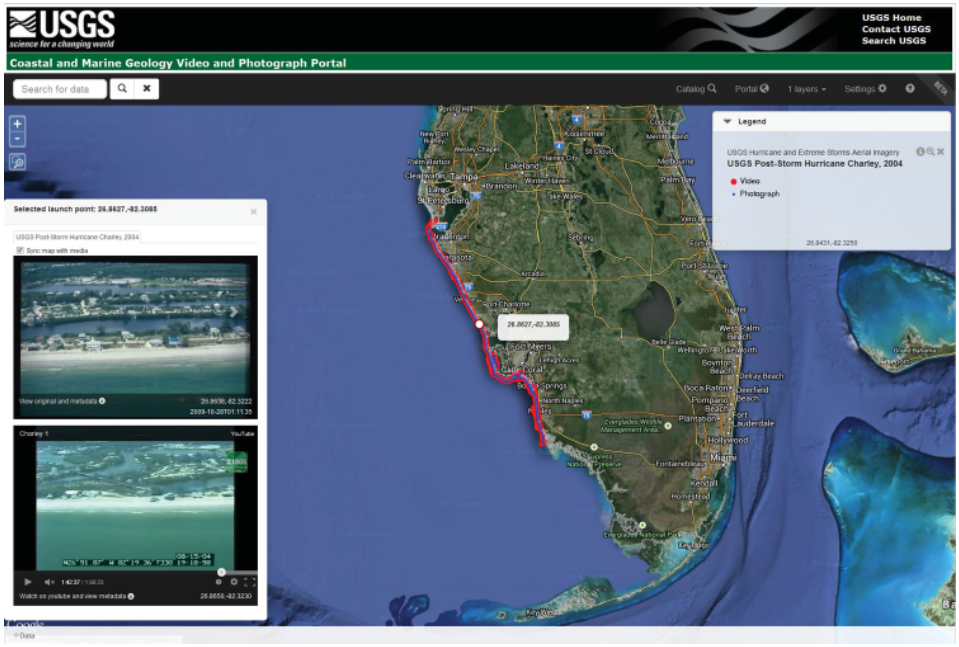
This USGS portal is unique, due to the sheer quantity and quality of data presented. It is the largest database of its kind, providing detailed and fine-scale representations of the coast. The "geospatial context" is also unique, with maps displaying imagery in the exact location where it was recorded.

Before development of the data portal, retrieving this imagery required internal USGS access with specific hardware and software. It was difficult to manage and challenging to share such a large amount of information.

"The USGS has been dedicated to developing a system that allows for convenient communication internally as well as to outside collaborators and the public. We want a wide range of users to be able to access our abundance of coastal and seafloor imagery," said USGS geographer **Nadine Golden**, lead principal investigator for the USGS portal. "The portal makes it easy for users to discover, obtain, and disseminate information."

The new portal contains coverage of the seafloor off California and Massachusetts, and aerial imagery of the coastline along the Gulf of Mexico and mid-Atlantic coasts. Additional video and photographs will be added as they are collected, and archived imagery will also be incorporated over time. Areas of future focus include data sets for Washington State's Puget Sound, Hawai'i, and the Arctic.

Information in this portal assists the creation of coastal maps and representations of seafloor composition and habitats. It provides references for short- and long-term monitoring of changes to the coast, whether from anthropogenic modifications or natural occurrences. Hurricanes and extreme storms are of particular concern, and USGS imagery helps managers, emergency responders, and researchers understand circumstances before, during, and after such events. It supports the assessment of other critical hazards as well, such as coastal flooding and sea-level rise, earthquakes, and tsunamis.



*Screenshot from the USGS Coastal and Marine Geology Video and Photograph Portal (<**http://dx.doi.org/10.5066/F7JH3J7N**>) showing examples of imagery from the west coast of Florida. Zooming into an area of interest reveals lines (red) where continuous video footage was acquired and dots (blue) where still photographs were taken. Clicking on a segment launches the video in a pop-up window. Photographs appear above the video, changing as the video passes each point where a photograph was taken.*

Data accessed through the portal also support coastal and marine spatial planning, including evaluation of sites for renewable ocean energy facilities and the development of communities and infrastructure. USGS science helps designate marine protected areas, define habitats, identify needs for ecosystem restoration, and inform regional sediment-management decisions.

In total, approximately 100,000 photographs have been posted as well as 1,000 hours of trackline video covering almost 2,000 miles of coastline. Imagery was taken by video and still cameras towed by boat or operated from aircraft. Every video and photograph is in the public domain.

This effort supports the National Ocean Policy mandate to provide access to federal data resources (<**https://www.whitehouse.gov/the-press-office/executive-order-stewardship-ocean-our-coasts-and-great-lakes**>).

Take a Look

How does the portal work? Start with the tutorial (<**http://cmgvideo.usgsportals.net/files/usgs/cmg_photovideo/tutorial/**>), and then dive in!

You might also want to explore these related websites:

The California Seafloor Mapping Program Video and Photograph Portal (<**http://dx.doi.org/10.5066/F7J1015K**>) is a successful pilot interactive website offering video and photographs of the

(Dive In continued on page 20)

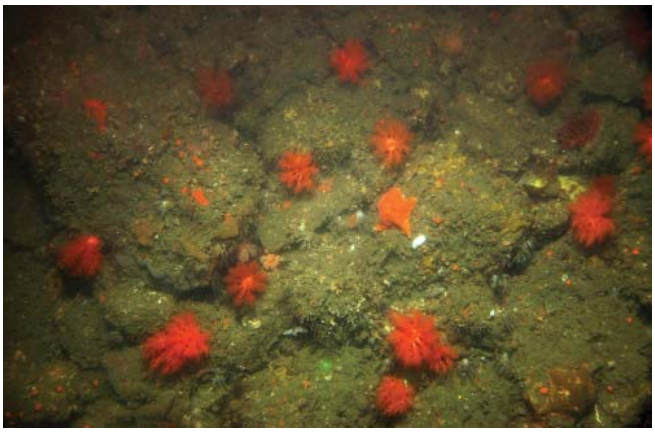
(Dive In continued from page 19)

seafloor off California that was launched in 2013 (<**http://soundwaves.usgs.gov/2013/10/pubs.html**>). Experience with this website assisted construction of the newly released portal, which includes access to the imagery in this earlier website.

"USGS iCoast – Did the Coast Change?" (<**http://coastal.er.usgs.gov/icoast/about.php**>) is a crowdsourcing application that allows citizen scientists to identify changes to the coast by comparing aerial photographs taken before and after storms. The photographs used in iCoast are also accessible through the new Coastal and Marine Geology Video and Photograph Portal.

Media Coverage

Soon after its release on March 18, 2015, the Coastal and Marine Geology Video and Photograph Portal began attracting media attention. For example, see "Scientists explore 2,000 miles of the ocean floor—and you can too" in the *Los Angeles Times*, <**http://www.latimes.com/science/sciencenow/la-sci-sn-explore-ocean-floor-usgs-20150319-story.html**>, and "Dive into 2,000 miles of coastline imagery with U.S. Geological Survey" in the *Santa Cruz Sentinel*, <**http://www.santacruzsentinel.com/science/20150323/dive-into-2000-miles-of-coastline-imagery-with-us-geological-survey**>.



Boulders and biota off San Gregorio, California, in water approximately 30 meters (100 feet) deep. Organisms include bat stars, small sea anemones, strawberry anemone, cup corals, and frilly sea cucumbers. Two green laser dots are 15 centimeters (6 inches) apart; lefthand dot is at bottom center of photograph, righthand dot is on upper right edge of lowermost frilly sea cucumber.

Learn more about USGS coastal and ocean science by visiting the USGS Coastal and Marine Geology Program website, <**http://marine.usgs.gov/**>.

Getting Out of Harm's Way—Evacuation from Tsunamis

By Jeanne Jones, Nathan Wood, and Leslie Gordon

Scientists at the U.S. Geological Survey (USGS) have developed a new mapping tool, the Pedestrian Evacuation Analyst (<**http://geography.wr.usgs.gov/science/vulnerability/tools.html**>), for use by researchers and emergency managers to estimate how long it would take for someone to travel on foot out of a tsunami-hazard zone. The ArcGIS software extension, released in September 2014, allows the user to create maps showing travel times out of hazard zones and to determine the number of people that may or may not have enough time to evacuate. The maps take into account the elevation changes and the different types of land cover that a person would encounter along the way.

Maps of travel time can be used by emergency managers and community planners to identify where to focus evacuation training and tsunami education. The tool can also be used to examine the potential benefits of vertical-evacuation structures, which are buildings or berms designed to provide a local high ground in low-lying areas of the hazard zone.

The Pedestrian Evacuation Analyst software can assist communities with tsunami planning by answering such questions as:

- How long could it take for people to evacuate out of tsunami-hazard zones?
- Will people have enough time to evacuate before the first tsunami waves arrive?
- If people don't have enough time to evacuate, then where could vertical-evacuation refuges provide high ground?
- How do you compare the benefits of multiple sites for potential vertical-evacuation refuges?

(See <**http://geography.wr.usgs.gov/science/vulnerability/tsunami.htm**> for more examples.)

"The tool can be used to provide valuable decision support for tsunami evacuation planning and vertical-evacuation siting, which is just in the beginning stages in the U.S. Pacific Northwest," said **Jeanne Jones**, USGS geographer who led the development of the software tool. The tool has enabled USGS researchers to better understand various aspects of community vulnerability to tsunamis, including community comparisons based on evacuation times (<**http://dx.doi.org/10.1007/s11069-011-9994-2**>), vertical-evacuation decision support (<**http://dx.doi.org/10.1016/j.ijdrr.2014.04.009**>), the impact of post-tsunami recovery decisions (<**http://dx.doi.org/10.1007/s11069-013-0859-8**>), and the evacuation challenges posed by different types of tsunami threats (<**http://dx.doi.org/10.1007/s11069-014-1399-6**>).

The software tool can be downloaded online at <**http://geography.wr.usgs.gov/science/vulnerability/tools.html**>, and the complete user's guide, "The Pedestrian Evacuation Analyst—Geographic Information Systems Software for Modeling Hazard Evacuation Potential," can be downloaded at <**http://dx.doi.org/10.3133/tm11C9**>.

Read more about USGS science that is advancing our understanding of tsunami hazards and helping vulnerable communities plan for them in "Preparing Com-

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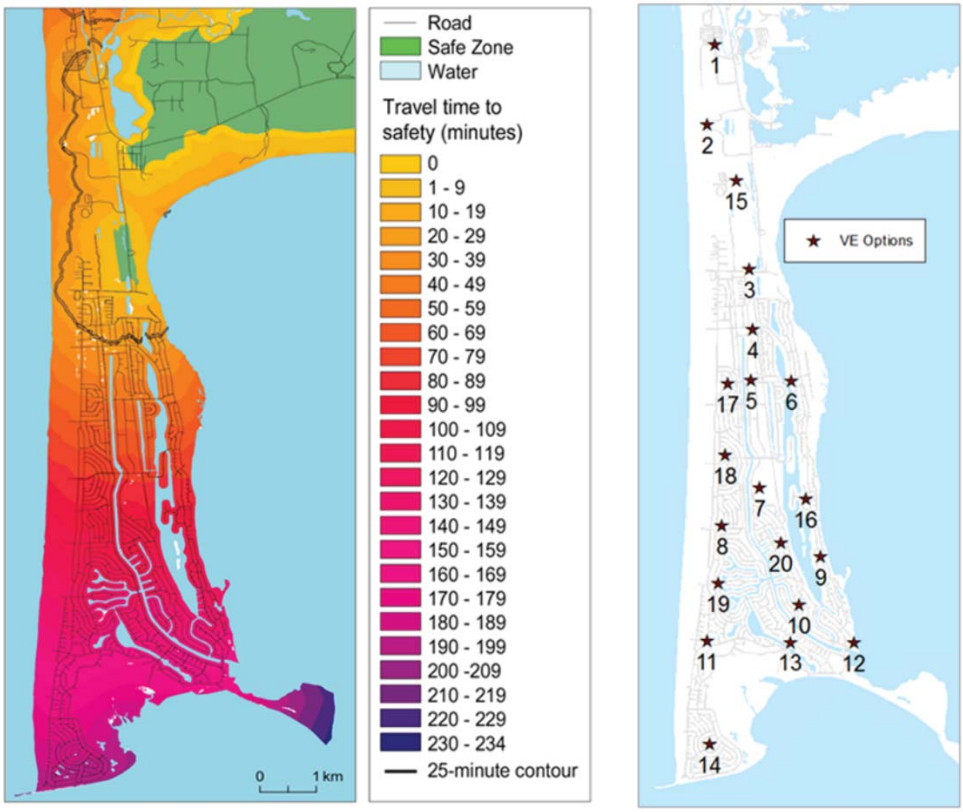
munities for the Next Great Tsunami," USGS Top Story, posted August 26, 2014, at <**http://www.usgs.gov/blogs/features/usgs_top_story/preparing-communities-for-the-next-great-tsunami/**>; and "Earthquake and Tsunami Geologist Brian Atwater Receives Shoemaker Award for Lifetime Achievement in Communications," this issue (<**http://soundwaves.usgs.gov/2015/02/awards.html**>).



*Maps of Ocean Shores, Washington, a city on the state's Pacific coast. Left, estimated pedestrian travel time at a slow walking speed (in minutes) to evacuate predicted tsunami-hazard zones associated with a Cascadia subduction zone earthquake. (The tsunami waves are estimated to arrive approximately 25 minutes after being triggered by the earthquake.) Right, possible locations for vertical evacuation structures proposed at a community meeting. (See <**http://www.waurisa.org/thesummit/The-Summit_Issue37.pdf**>, 7.6 MB.)*

USGS Staff Educate Students and the Public at the 2014 St. Petersburg Science Festival in Florida

By Dennis Krohn

The U.S. Geological Survey (USGS) St. Petersburg Coastal and Marine Science Center in St. Petersburg, Florida, had a strong presence at the 4th Annual St. Petersburg Science Festival held October 17–18, 2014, at Poynter Park, adjacent to the University of South Florida (USF) St. Petersburg campus. In addition to the traditional STEM (Science, Technology, Engineering, and Math) focus, this year's festival emphasized the role of the arts in innovation, broadening the focus to STEM + Arts = STEAM. The 2-day festival included more than 50 exhibitors from around the Tampa area.

The USGS contributions to the festival are a follow-on to Open House exhibits presented previously at the USGS St. Petersburg Coastal and Marine Science Center. For examples of these exhibits, see *Sound Waves* articles from 2004 (<**http://**

(Science Fest continued on page 22)

*On the first day of the 2014 St. Petersburg Science Festival (Friday, October 17), **Jen Flannery** (second from right) passes out literature while **Tess Busch** (USGS t-shirt) explains the USGS Coral Reef exhibit organized by **Ilsa Kuffner**.*

(Science Fest continued from page 21)

soundwaves.usgs.gov/2004/01/outreach.html>), 2005 (<**http://soundwaves.usgs.gov/2005/01/outreach8.html**>), 2006 (<**http://soundwaves.usgs.gov/2006/03/outreach.html**>), 2008 (<**http://soundwaves.usgs.gov/2008/01/outreach.html**>), and 2010 (<**http://soundwaves.usgs.gov/2011/01/outreach.html**>).

USGS research assistant **Kara Doran** organized school tour groups for the festival, and geologist **Caitlin Reynolds** organized the USGS exhibitors from the St. Petersburg Coastal and Marine Science Center. Personnel from additional USGS centers participated as well: researcher **Kaitlin Kovacs** came from the Southeast Ecological Science Center in Gainesville, Florida, and outreach coordinator **Gabrielle Bodin** came from the National Wetlands Research Center in Lafayette, Louisiana. Both enjoyed the event and said that they were extremely glad to participate.

USGS participants in the Science Festival in 2014 were **Gabrielle Bodin**, **Tess Busch**, **Jacy Bussey**, **Soupy Daylander**, **Kara Doran**, **Jen Flannery**, **Christian Haller**, **Kaitlin Kovacs**, **Dennis Krohn**, **Ilsa Kuffner**, **Sophia Liu**, **Joe Long**, **RC Mickey**, **Jen Miselis**, **Nathaniel Plant**, and **Joseph Terrano**.

To view the local newspaper write-up about the festival, see "St. Pete Science Fest, MarineQuest make learning fun" in the *Tampa Tribune*, <**http://tbo.com/news/breaking-news/st-pete-science-fest-marinequest-make-learning-fun-20141018/**>.

For more information about the national Science Festival Alliance, which includes the local St. Petersburg festival, visit <**http://sciencefestivals.org/events/st-petersburg-science-festival**>.

Tribal GIS Training in the Northeast U.S.

By Andrea Toran and Brian Buczkowski

Geographic Information System (GIS) software, used by many U.S. Geological Survey (USGS) researchers, provides a powerful tool to visualize and aid in the interpretation of geographic and other location-based (geospatial) data. GIS software is most often used in the USGS to create geologic and environmental maps that consist of geospatial data layers superimposed on geographic "background" layers (such as topography), and to integrate data layers of different types or from different sources. The tools and capabilities of GIS extend far beyond geologic and environmental mapping, however, and groups outside the formal scientific community can benefit from learning to use and adapt GIS techniques employed by the USGS.

Tribal participants at the GIS training session in Woods Hole, Massachusetts, along with some of the USGS personnel who contributed to the success of the session: ***Brian Andrews*** *(second from left),* ***VeeAnn Cross*** *(fourth from right), and* ***Andrea Toran*** *(far right). USGS photograph by* ***Brian Buczkowski****.*

USGS scientists and outreach coordinators in the Northeast U.S. developed the Tribal GIS Training model following a series of science planning meetings in 2013 between USGS staff and representatives of the Houlton Band of Maliseet Indians, Aroostook Band of Micmacs, Passamaquoddy Tribe of Indian Township, Passamaquoddy Tribe at Pleasant Point, and the Penobscot Indian Nation. At these meetings, tribal representatives discussed their need for assistance in collecting and interpreting field data as well as using GIS to document and protect cultural and natural resources.

The first GIS training session for Northeast tribes was held at the Environmental Protection Agency (EPA) New England Regional Laboratory in North Chelmsford, Massachusetts, March 31–April 1, 2014. A follow-up session was held at the USGS Woods Hole Coastal and Marine Science Center in Woods Hole, Massachusetts, November 12–14, 2014. Invitations to these training sessions were extended to members of the Shinnecock Indian Nation, Mohegan Tribe, Penobscot Indian Nation, Mashpee Wampanoag Tribe, Passamaquoddy Tribe of Indian Township, Passamaquoddy Tribe at Pleasant Point, Narragansett Indian Tribe, Aroostook Band of Micmacs, Houlton Band of Maliseet Indians, and Wampanoag Tribe of Gay Head.

The planning team recruited representatives from Esri (a commercial supplier of ArcGIS software and technical support) to collaborate and participate in the initial training session held in North Chelmsford. Esri loaned laptops to the participants, provided staff to teach the modules, and offered hands-on support throughout the training session. Because

(Tribal GIS Training continued on page 23)

(Tribal GIS Training continued from page 22)

this was the pilot project for a new initiative, the planning team purposely kept the agenda for the first session broad in scope, offering participants introductory-level modules for GIS analysis, geoprocessing, and report generation. **Pete Steeves**, GIS Specialist from the USGS New England Water Science Center in Northborough, Massachusetts, introduced the participants to StreamStats, a web-based GIS that provides users with access to an assortment of analytical tools for water resources planning and management.

The agenda for the second session in Woods Hole was specifically crafted to focus on issues and applications relevant to the tribes' individual needs. Volunteer staff from the Woods Hole Coastal and Marine Science Center provided individual support and specialized assistance to participants for the duration of the training. In addition, customized presentations by USGS volunteers addressed specific requests gathered through needs assessments and discussions with tribal members:

- **Elizabeth Pendleton** discussed the Massachusetts Sea-Floor Mapping Project, with emphasis on habitat monitoring and mapping. In addition to her presentation on sea-floor mapping, Pendleton demonstrated how to use hyperlinks in a GIS: by clicking on a point or line on the map, the user can bring up a related image. Based on the evaluations, the participants particularly liked learning how to enable this feature and apply it to tribal archeological map products; instead of making static maps, they added hyperlinks to images in order to create a dynamic experience for the end user.
- **Brian Andrews** offered a presentation and facilitated a discussion on how to search for free base-map data using the National Map (<**http://nationalmap.gov/**>) and state GIS resources. All participants accessed their particular state's GIS website and downloaded spatial data for their tribal locations. Andrews also discussed the importance of scale and resolution when using third-party datasets for local use.

***Walter Barnhardt**, director of the USGS Woods Hole Coastal and Marine Science Center, addresses tribal participants at the GIS training session in Woods Hole, Massachusetts. USGS photograph by **Andrea Toran**.*

- **Pete Steeves** repeated his presentation on analyzing surface waters using StreamStats. The participants were particularly interested in how StreamStats is used for water and land management and water-quality regulation.
- **John O'Malley** demonstrated how to set up an ArcGIS Map Server. He also provided individual instruction and hands-on support during the GIS exercise and pointed some of the participants to the Esri training website (<**http://www.esri.com/training/**>), where they can access free training modules on GIS and ArcGIS technology.

Final evaluations of the second session indicated a need and desire for further training and ongoing support. Hands-on assistance provided by USGS staff to the program participants was very helpful and much appreciated.

This program benefitted from the development and oversight of the USGS Tribal GIS Training planning team: **Glenn Holcomb**, **Andrea Toran**, **Vee-Ann Cross**, **Pete Steeves**, and **Dan Walters**. GIS experts and support staff from the Woods Hole Coastal and Marine Science Center included **Brian Andrews**, **Brian Buczkowski**, **John O'Malley**, **Elizabeth Pendleton**, **Sue Barton**, and **Kelle List**.

***John O'Malley** (checked shirt), GIS specialist with the USGS Woods Hole Coastal and Marine Science Center, offers hands-on support to tribal participants in the GIS training session in Woods Hole, Massachusetts. USGS photograph by **Andrea Toran**.*

Undamming Washington's Elwha River—Public Lecture on Largest Dam Removal in U.S. History

By Helen Gibbons

The largest dam removal in U.S. history was the subject of a public lecture by U.S. Geological Survey (USGS) research geologist Amy East on February 26, 2015, at the USGS campus in Menlo Park, California. East described changes to the landscape caused by the removal of two large dams—the 32-meter-tall Elwha Dam and the 64-meter-tall Glines Canyon Dam—from the Elwha River in Washington State. This was the largest dam removal ever undertaken, both in terms of the dams' heights and in terms of how much sediment had accumulated behind them.

*USGS research geologist **Amy East** gave a public lecture in February 2015 at the USGS campus in Menlo Park, California, on the effects of removing two large dams from the Elwha River in Washington State. Screenshot from video at <**http://online.wr.usgs.gov/calendar/**> (click on "Video Archives" in bar at top of page).*

Staged deconstruction of the two dams began in September 2011 (see "Elwha Dam Removal Begins—Long-Planned Project Will Restore Ecosystem, Salmon Runs," *Sound Waves*, Nov./Dec. 2011, <**http://soundwaves.usgs.gov/2011/11/**>) and ended in summer 2014. Numerous federal, tribal, state, and academic scientists are collaborating to examine and report the effects of this restoration effort (<**http://www.nps.gov/olym/learn/nature/elwha-ecosystem-restoration.htm**>). East is one of many USGS scientists participating in the collaboration. They began gathering baseline data on the Elwha and the coastal area around its mouth on the Strait of Juan de Fuca more than 5 years before dam deconstruction began (for example, see "Studying the Elwha River, Washington, in Preparation for Dam Removal," *Sound Waves*, Nov./Dec. 2006, <**http://soundwaves.usgs.gov/2006/11/fieldwork3.html**), and they will keep studying the river system to understand its physical and biologic changes.

After introducing her audience to the history of dams and dam removal in the United States, East focused on the Elwha and, specifically, on the effects of releasing massive amounts of sediment downstream during the first 2 years of dam deconstruction. Approximately 90 percent of this sediment made it to the river mouth, even though there were no floods during that 2-year period; in fact, the river's water discharge and peak flows were moderate compared with historical gaging records. "This was probably the biggest surprise of the study so far," she said—that the river could move so much material downstream without floods to push it along.

Additional effects documented by East and her USGS colleagues include a rise of about 1 meter in the elevation of the riverbed, the appearance of new channels, formation of new gravel bars, and a general decrease in bed-sediment grain size—a change that has improved spawning areas for fish. Other USGS scientists have documented significant enlargement of the coastal delta at the river's mouth.

Details about these and many other findings were recently published in the journal *Geomorphology* in a series of papers about the first 2 years of dam removal (see "Scientific Portrait of the Largest Dam Removal in U.S. History," this issue, <**http://**

(Undamming the Elwah continued on page 25)

Location of the Elwha River. Background images courtesy of Google Earth.

(Undamming the Elwah continued from page 24)

soundwaves.usgs.gov/2015/02/research2.html>). This information about how the physical system has changed provides a basis for biologists to understand changes to habitats.

USGS scientists continue to monitor the river system, and, as East told her audience, "We expect to learn from the Elwha for years to come."

To watch an archived video of East's talk, visit the USGS Evening Public Lecture Series website <**http://online.wr.usgs.gov/calendar/**> and click on "Video Archives" in the bar at the top of the page.

Before and after dam removal. Left, ***Amy East*** *(then* ***Amy Draut****) surveying along the Elwha River in March 2007. Right, the same area had finer grained sediment in March 2014; surveyor in the distance is* ***James Starr*** *of the USGS Washington Water Science Center. (Note the tall iron I-beam on the left side of both views.) USGS photographs by* ***Joshua Logan****.*

Earthquake and Tsunami Geologist Brian Atwater Receives Shoemaker Award for Lifetime Achievement in Communications

U.S. Geological Survey (USGS) research geologist **Brian Atwater** was recently awarded the 2014 USGS Shoemaker Award for Lifetime Achievement in Communications, given annually to a USGS scientist who "creates excitement and enthusiasm for science among nonscientists by using effective communication skills." Here is an excerpt from the March 31, 2015, announcement:

"In more than 20 years of investigating great megathrust earthquakes and tsunamis, Brian has helped keep at-risk communities around the world safer. The key has been his ability to communicate and translate field observations of long-ago tsunamis into a picture of what could happen now that is understandable to lay audiences. [For example, see "The Orphan Tsunami of 1700—Japanese Clues to a Parent Earthquake in North America," <**http://pubs.usgs.gov/pp/pp1707/**>.] As a result, the emergency-response community can meaningfully convey these scientific observations to the general public and develop local response and evacuation plans. His efforts to engage international scientists in his fieldwork reflect his strong personal desire to train others

(Lifetime Achievement continued on page 26)

Brian Atwater*, far right, leads a 2008 field trip to a "ghost forest" along the Copalis River, Washington—a stand of trees that died when their roots were submerged in seawater by subsidence of the ground during a tsunami-generating earthquake in 1700.* ***Jenifer Rhoades****, then the National Oceanic and Atmospheric Administration (NOAA) Tsunami Program Coordinator, is at far left in green jacket.* ***Chris Maier****, National Warning Coordination Meteorologist with NOAA's National Weather Service and manager of the TsunamiReady Program (<**http://www.tsunamiready.noaa.gov/**>), stands at center. The trip was associated with a tsunami workshop near Ocean Shores, Washington.*

(Lifetime Achievement continued from page 25)

not only in the best scientific methods and techniques of the field but also in how to educate government and media about the goals and implications of the investigations these scientists conduct in their own countries. [For example, see "USGS Scientist Shows Evidence for 300-Year-Old Tsunami to Participants in International Tsunami Training Institute," *Sound Waves*, October 2007, <**http://soundwaves.usgs.gov/2007/10/outreach3.html**>.] He is recognized in the field as a natural spokesperson in light of his skill at educating audiences through public meetings, radio broadcasts [for example, <**http://www.npr.org/templates/story/story.php?storyId=4629401**>], television documentaries, and magazine and journal articles about the true potential for, and hazards of, megathrust earthquakes and tsunamis."

Brian has received many honors, among them the USGS Excellence in Leadership Award (<**http://soundwaves.usgs.gov/2008/01/awards2.html**>), election to the National Academy of Sciences (<**http://www.washington.edu/news/2007/05/03/atwater-named-to-national-academy-of-sciences/** >), and inclusion in "The 2005 Time 100," *Time* magazine's list of the world's 100 most influential people in 2005 (<**http://tinyurl.com/o8oytz6**>).

The Shoemaker Awards Competition was established in 1997 in memory of **Eugene M. Shoemaker** to recognize extraordinary examples of communicating and translating complex scientific concepts and discoveries into words and pictures that capture the interest and imagination of the American public. **Shoemaker**, a USGS astrogeologist considered the founder of the science of lunar and planetary geology, was an effective and prolific communicator, as well as an innovative scientist and researcher. Today, many USGS employees—like **Brian Atwater**—carry on his enthusiasm, giving voice to all our science programs.-

(Read about another effort by USGS scientists to help vulnerable communities prepare for tsunamis in "Getting Out of Harm's Way—Evacuation from Tsunamis," this issue (<**http://soundwaves.usgs.gov/2015/02/research3.html**>.)❁

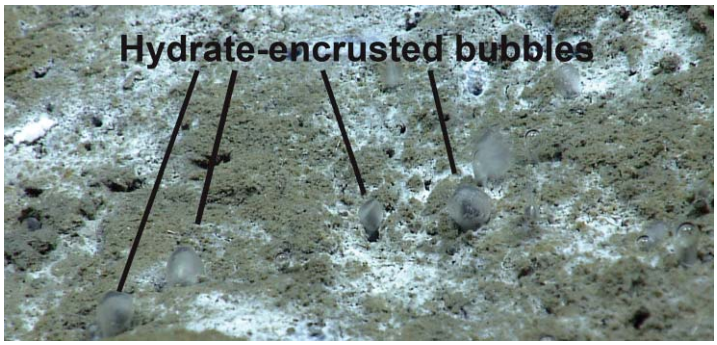
Frozen Heat—New International Report on Methane Hydrates, their Role in Nature, and their Potential as an Energy Resource

By William Waite, Alex Demas, and Carolyn Ruppel

The Gas Hydrates Project at the U.S. Geological Survey (USGS) contributed to a 4-year international effort by multiple partners, including the United Nations Environment Programme (UNEP), to formulate a newly released report entitled "Frozen Heat: A Global Outlook on Methane Gas Hydrates" (<**http://apps.unep.org/publications/index.php?option=com_pmtdata&task=download&file=GasHydrates_Sum_screen.pdf**>, 8.4 MB).

The two-volume report reviews the state-of-the-art in science and technology related to gas hydrates, providing information in a form accessible to policy makers and stakeholders. The USGS Gas Hydrates Project (<**http://woodshole.er.usgs.gov/project-pages/hydrates/**>) contributed scientific results, imagery, editing, and reviews to assist formulation of the report.

Gas hydrate is a frozen form of gas and water that occurs naturally at moderate pressure and low temperature (<**http://woodshole.er.usgs.gov/project-pages/hydrates/primer.html**>). These conditions are characteristic of continuous permafrost and marine sediments at water depths greater than approximately 350 meters (1,150 feet). Methane, the primary component of natural gas, is the most common gas incorporated into global gas hydrate deposits. Gas hydrate sequesters about 1,600 billion metric tons (1,800 billion U.S. tons) of carbon, or as much as 25 percent of the global budget of carbon that can move around the earth-ocean-atmosphere system.



Methane bubbles emerge from the seafloor and form translucent icy hydrate shells on the floor of the Gulf of Mexico in 2014. The white surfaces are bacterial mats, which are common in areas of methane and sulfide emission. Bubbles are estimated to be a few centimeters in diameter. Methane emitted into the ocean is often oxidized to carbon dioxide in the water column, increasing the acidity and decreasing the oxygen content of ocean waters. Methane that reaches the atmosphere can contribute to global warming. Image courtesy of National Oceanic and Atmospheric Administration (NOAA) Ocean Exploration program.

"The USGS plays an active leadership role in gas hydrate research nationally and internationally," said USGS Energy Resources Program Coordinator **Brenda Pierce**. "Having USGS experts join with other scientists to present current scientific knowledge to a broad audience in this report serves an important part of our outreach mission."

The first volume of the report (<**http://apps.unep.org/publications/index.php?option=com_pub&task=download&file=GasHydrates_Vol1_screen.pdf**>, 19.7 MB) focuses on the history of gas

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hydrate research and describes how and where gas hydrates form. USGS research featured prominently in this volume, as USGS scientists have studied the formation and occurrence of gas hydrates all over the world, including Alaska (<**http://go.usa.gov/3rfr4**>), the Gulf of Mexico (<**http://www.usgs.gov/newsroom/article.asp?ID=3588**>), and internationally in countries like Japan (<**http://www.usgs.gov/blogs/features/usgs_top_story/groundbreaking-gas-hydrate-research/**>), Korea (<**http://go.usa.gov/3rfYC** >), and India (<**http://go.usa.gov/3rfYF** >).

Volume 1 of the report also considers how gas hydrates interact with the environment on a small scale (for example, the link between gas hydrates and deep marine biological communities; see <**http://oceanexplorer.noaa.gov/okeanos/explorations/ex1304/logs/july12/july12.html**>), and globally (for example, the interplay between gas hydrates and climate; see <**http://soundwaves.usgs.gov/2012/06/**>).

"We were pleased to work with U.S. and international partners to contribute scientific expertise to this effort," said **Carolyn Ruppel**, chief of the USGS Gas Hydrates Project. "The report dovetails with our project's emphasis on gas hydrates in the natural environment and on the climate and energy-resource implications of methane hydrates."

Volume 2 (<**http://apps.unep.org/publications/index.php?option=com_pub&task=download&file=GasHydrates_Vol2_screen.pdf**>, 7.5 MB) discusses gas hydrates as a potential energy resource (<**http://energy.usgs.gov/OilGas/UnconventionalOilGas/GasHydrates.aspx**>), including consideration of the technology needed to extract gas from methane hydrates. USGS scientists have long been active in this research area and participated in tests of methane production from natural gas hydrates in permafrost areas, such as Alaska's North Slope (<**http://go.usa.gov/3rfr4**>).

The USGS has a globally recognized research program studying natural gas hydrates in deepwater and permafrost settings worldwide (<**http://woodshole.er.usgs.gov/project-pages/hydrates/**>). USGS researchers focus on the potential of gas hydrates as an energy resource (<**http://energy.usgs.gov/OilGas/UnconventionalOilGas/GasHydrates.aspx**>), the impact of climate change on gas hydrates (<**http://woodshole.er.usgs.gov/project-pages/hydrates/climate.html**>), and seafloor stability issues (<**http://woodshole.er.usgs.gov/project-pages/hydrates/seafloorstability.html**>).❁

USGS Gas Hydrates Project scientists participated for more than 4 years in the formulation of a new international report on methane hydrates that was recently released by the United Nations Environment Programme (UNEP). ***William Waite*** *co-edited and* ***Carolyn Ruppel*** *reviewed volume 1, and* ***John Pohlman***, ***Keith Kvenvolden***, ***Laura Stern***, ***Timothy Collett***, *and others contributed imagery, results, and expert advice. The cover of the UNEP report features burning gas hydrate from the USGS laboratory of* ***Laura Stern***, ***Steve Kirby***, *and* ***John Pinkston***.

*The Mount Elbert Stratigraphic Gas Hydrate Test Well was drilled at Milne Point on Alaska's North Slope in 2007 to investigate permafrost-associated gas hydrates as a potential energy resource (<****http://go.usa.gov/3rfr4****>).* ***Tim Collett*** *played a key role in the formulation and execution of this project, which was carried out by the U.S. Department of Energy and various partners. Image courtesy of* ***Rick Colwell***, *Oregon State University.*

Recent Publications

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