Bracing for Impact

Scientists study the effects of increasing ocean acidity on California's marine ecosystems

by Mary Patyten, DFG Research Writer

Nicole Sandoval followed the familiar dirt path past the hundred-year-old Point Cabrillo lighthouse towards the sea. Swinging her bucket full of scrub brushes, she looked like some sort of intertidal maid on her way to clean up after untidy rock crabs or turban snails. Behind the lighthouse, dark sedimentary rock veined with white calcite jutted towards the ocean from the yellow dirt embankment, running in rough peaks and shelves down to pools lined with barnacles and kelp.

Springing from rock to rock, the DFG scientific aid headed for the water's edge, her long, chocolate-brown braid coiled in the hood of her jacket. Far from cleaning duties, Sandoval was collecting samples of young sea creatures—clams, sea urchins, abalone and mussels among them—in part, to better understand profound changes occurring in California's nearshore waters.

Reaching a precipice, she maneuvered her way down a steep path to where two heavy, rusted chains ran into the water, mounds of epoxy cement holding the ends firmly to the rocky shelf. She pulled the few feet of corroded, reddish-brown chain out of the sea, revealing scrub brushes zip-tied to the links and a rusty brake rotor that served as an anchor. Crouching down, she severed the zip-ties with a wire cutter and placed each wet brush into a plastic bag. Taking fresh brushes from the bucket, she zip-tied them to the chain and then, standing up, heaved the chain, brushes, and anchor back into the sea.

With the wet brushes safely stowed in the bucket, Sandoval climbed back up the rocky path. Clinging to the bristles in each plastic bag, microscopic sea urchins and other young, prickly creatures swung beside her, destined for the DFG office in Fort Bragg and, ultimately, Steven Schroeter's sea urchin research project in Santa Barbara.

DFG photo by M. Patyten

DFG scientific aid Nicole Sandoval walks toward her sampling site near Pt. Cabrillo Lighthouse on a foggy morning.

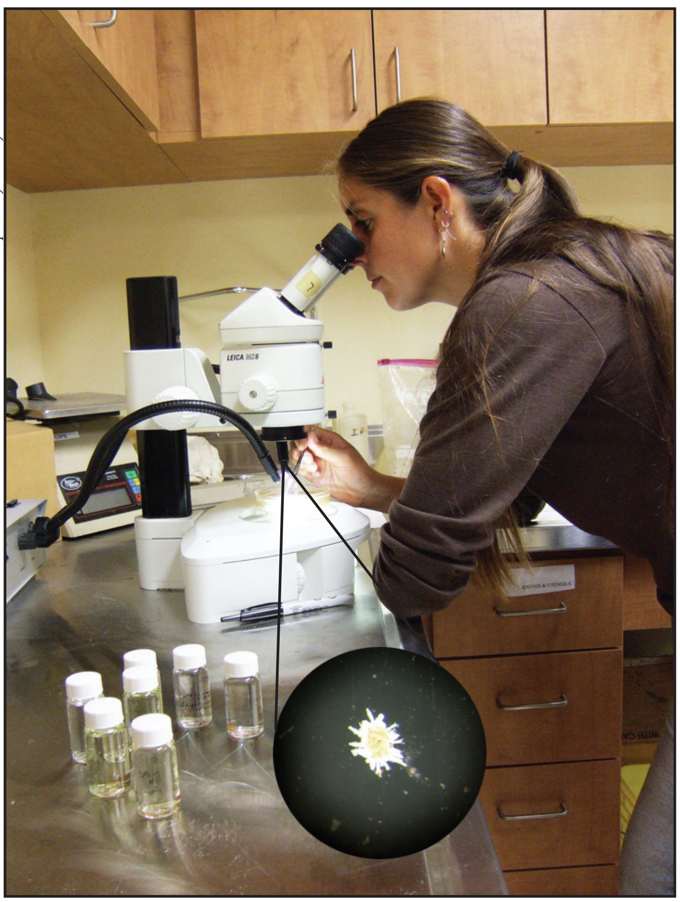
Spiny Research

The red sea urchin supports a multi-million dollar fishery off California and maintains an influential position in the nearshore ecosystem, making it nearly irresistible to fishery researchers. Schroeter, an ecologist with the Marine Science Institute at U.C. Santa Barbara, began studying the small creatures that settled onto scrub brushes in 1990, focusing on sea urchins during their early life stages, along with colleagues from U.C. Santa Barbara, Scripps Institution of Oceanography and DFG.

When first hatched, sea urchins are about the size of a period at the end of a sentence. The tiny hatchlings drift with the currents and feed on equally small plants—called phytoplankton—for about five weeks before they settle to the sea floor. Schroeter's study documented the settlement process, funded by the commercial sea urchin fishing industry itself through a self-imposed landing tax.

Naturally, urchin divers had a vested interest in finding out whether lack of nurturing habitat, or perhaps environmental trends such as El Niños or La Niñas, limited the successful settlement of young urchins. "Along the way, we collected samples of many different critters, not just urchins, preserving them for future reference," Schroeter said.

Although his research set out to document sea urchin settlement patterns, the incidental samples of critters preserved along the way may end up stealing the show. Locked away inside the tiny shells is information that may help scientists understand the effects of ocean acidification, a newly-recognized and growing threat to marine life off the California coast and in oceans around the world.



DFG photo by M. Patyten

DFG scientific aid Nicole Sandoval examines minute sea urchins beneath a microscope.

Gauging the Threat

Underpinning this threat is a simple gas that has been part of the Earth's atmosphere for millions of years—carbon dioxide, which has the chemical formula CO_2 . Plants, animals, and the Earth itself produce and consume CO_2 . The ocean, with its host of plants and animals, has always taken in CO_2 and other gases, and released gases as well, maintaining a sort of slowly fluctuating equilibrium. The ocean's fluctuating CO_2 content causes its pH readings–a measure of water's acidity or alkalinity–to rise and fall slowly, as well.

At the start of the century, data from a broad spectrum of oceanographic research, from tropical coral reefs to North Pacific ice floes, was brought together by researchers to look at the effects of CO_2 on the ocean. Historical data shows that ever increasing amounts of CO_2 have been pumped into the atmosphere and absorbed by the ocean since the beginning of the Industrial Revolution, about two hundred years ago. This ability of the sea to absorb excess CO_2 was at first hailed by scientists as a wonderful way to dispose of harmful hydrocarbons produced by burning fossil fuels—but closer examination has yielded sobering evidence to the contrary. Soaking up that extra CO_2 has caused the ocean's pH to shift in an extraordinary way, as confirmed by readings taken around the globe.

On average, ocean pH readings have fluctuated between 8.0 and 8.3 over the past 20 million years, in a natural rhythm established over millennia. In the same way as small changes on the Richter scale can signal large differences in earthquake intensity, small changes on the pH scale can signal large changes in acidity or alkalinity. For example, a 0.1 change in pH is a large-scale event, but considered pretty normal when spread over hundreds of thousands of years. A 0.1 shift in pH over a few hundred years, however, is unparalleled in Earth history. Yet researchers established that it has occurred and will continue at an unprecedented rate, ushering in an era of unpredictable change.

Acid from the Air

Tracing the cause of the shift in ocean pH has been relatively easy, compared to say decoding the human genome, or determining the age of the universe. When airborne CO_2 meets seawater, the chemistry is straightforward—carbonic acid is created (the stuff that makes soda bubbly), which increases seawater acidity. As more CO_2 is pumped into the air from power plants, factories, car exhaust and other sources around the world, CO_2 levels in the ocean increase. Recent pH readings indicate a 30 percent rise in acidity over the past two hundred years, according to National Oceanographic and Atmospheric Administration researchers.

Rising acidity in the ocean has always been buffered by a deep, slow, natural process that can span thousands of years. However, with recent, rapid increases in atmospheric CO_2, the ocean's carbonic acid level has shot upwards, outstripping the ability of the natural buffering system to keep ocean pH within its historic range.

"We have seen large increases in CO_2 before, in the distant past," said Richard Feely, a chemical oceanographer and senior research scientist with the Pacific Marine Environmental Laboratory. "But when we examine the geologic record very carefully, we see that these events happened over long periods of time. The current change in concentrations of CO_2 is occurring from 10 to 100 times faster than in the past."

As the sea becomes more acidic relatively quickly, creatures that have adapted over thousands of years to living within a certain pH range may find life more difficult. One of the main concerns stems from the chemical process that creates carbonic acid, which steals significant quantities of carbonate ions from the water. Carbonate ions are the key building blocks used by many creatures such as clams, oysters and sea urchins to make their calcium carbonate shells and skeletons.

Off the coast of California, shortages of carbonate ions may cause problems for a wide range of local marine residents and migratory visitors, from tiny plankton to Dungeness crabs to predatory tunas—but the problems start with the animals and plants that use carbonate ions directly.

Unlike land plants, many microscopic ocean plants use carbonate ions from the water to build support structures or shells of calcium carbonate (the chalky White Cliffs of Dover in England are made of the calcium carbonate shells from long-dead, minute plants). Animals such as tiny swimming marine snails, called *pteropods* (terra-pods), and the larvae of larger animals such as abalone, clams, sea urchins, and mussels also extract carbonate ions from seawater to make their shells and skeletons. Thousands of species of these tiny plants and animals provide food for young fish including salmon, tuna and rockfish. When these fish become adults, they eat small forage fish such as anchovies and sardines which also eat the tiny plankton that are the mainstays of the ocean's food web.

photo courtesy V. Fabry

The pteropod, a small swimming snail, is extremely vulnerable to acidic water conditions. Pteropods are crucial food items for many fishes, including salmon.

As it becomes increasingly difficult for certain plants and animals to find enough carbonate ions to fill their needs, they will adapt to the shortage, acclimatize to the changes, migrate in search of more hospitable waters, or go extinct. For some creatures, especially those that don't migrate, adapting or acclimatizing to more acidic waters could mean a reduction in body size or the number of young produced, or a host of other changes. These changes could affect dispersal patterns, change nearshore habitats, or force predators to search for alternate food sources—currently, scientists cannot say with certainty which changes will cascade through marine ecosystems.

"For example, young salmon from northern California depend on pteropods for food," said Feely. "It turns out that these shelled mollusks are very susceptible to the negative effects of more acidic water. If pteropods can't withstand more acidic conditions, we may also see fewer or smaller salmon as their food supply diminishes, moves away, or dies out," he said.

No matter which strand of the food web you examine, problems for calcifying species will become problems for the plants, fish, birds and mammals that depend on those species—including people.

Fishing Industry Concerns

According to a summary of findings presented at the 2010 West Coast Ocean Acidification-Shellfish Workshop, fisheries and aquaculture in the United States that depend on mollusks such as oysters stand to lose possibly billions of dollars by 2060, if more acidic conditions continue to develop and successful ways of coping are not found.

"I really worry that by the time fishermen realize what's happening, it'll be too late," said Bruce Steele, a commercial sea urchin fisherman who has been harvesting urchins for 37 years. "We could be unleashing an extinction event on the ocean. People tell me, 'You can't go around saying that,' but it's true."

Steele, who has also fished for salmon and albacore tuna off the West Coast, now spends summers on his property in Buellton, California with his wife Diane Pleschner-Steele, growing produce for local restaurants and residents. In the fall and winter, he dives for sea urchin, weather permitting.

photo courtesy D. Pleschner-Steele

Urchin diver Bruce Steele maneuvers a load of sea urchins on the deck of his boat. Steele is a strong advocate for research on ocean acidification.

"Around 2005, a whole slew of scientific papers came out about ocean acidification," he said. "The more I read, the more it piqued my interest." Among other things, Steele read accounts of how acidic ocean water may be to blame for the failure of oyster hatchery stock over the past few years in the Pacific Northwest, and realized that acidification might threaten California's shellfish as well.

Recognizing the threat to his livelihood "changed his life," according to his wife, Diane Pleschner-Steele. "He became a sort of closet scientist. We have a whole room full of papers and articles Bruce has collected on ocean acidification.

"He was one of the first to see the need for a coordinated ocean acidification monitoring network that extended beyond state borders, and he played a key role in developing the California Current Acidification Network," she said. The network, known as C-CAN, now brings together the shellfish industry, scientists and government to discuss and investigate ocean acidification and other threats to West Coast shellfish.

In the Pacific Northwest, frigid seawater absorbs and hold onto gases such as CO_2 better than the warmer waters off California, which gives the northern latitudes the dubious distinction of being the first to feel the effects of more acidic seawater. Aquaculture facilities here have seen massive losses of oyster larvae, and production has dropped by up to 80 percent in recent years, according to the 2010 workshop proceedings. In some regions, wild oysters have not reproduced since 2005, and although the exact cause has not been identified in each case, most indicators point to upwelling of acidic waters as a primary suspect.

"Ocean acidification is not a theoretical problem that may happen in the future, it is here, now," said John Finger, co-owner and founder of the Hog Island Oyster Company on Tomales Bay in northern California. Finger and his partner Terry Sawyer have produced oysters at Hog Island for 28 years, and are active participants in C-CAN.

Most of Hog Island's oysters grow from seed stock that usually comes from oyster hatcheries in the Pacific Northwest. "We're definitely in touch with those folks, and know about their problems," said Finger, who now purchases more seed stock from oyster hatcheries located farther south, in Humboldt Bay and Hawaii. "We all understand that acidification is changing ocean conditions. Learning how to deal with it will be a steep learning curve. Things are changing faster than we thought they would."

So far, the Hog Island Oyster Farm has not had to wrangle with the problems experienced by farms and hatcheries in the Northwest.

"Though it's hard to admit, at this point we can't do anything to protect an entire estuary or bay. But maybe we can do something on the hatchery level, like control the water being pumped in," said Finger. "Because ocean pH can be different at different times of the day, maybe we can regulate intake to avoid periods of more acidic water. The more we know about what's going on, the more easily we can adapt to it–which is one reason we participate in C-CAN," he said.

photo courtesy J. Finger

John Finger, co-owner of Hog Island Oyster Farm in Tomales Bay, is concerned for his company's future.

DFG Preparations

As a scientist on the C-CAN steering committee, Debbie Aseltine-Neilson is deeply concerned about changes in the ocean off California, including acidification. A DFG senior marine biologist and ocean acidification researcher, she is in a unique position, tasked with managing the state's sport and commercial fisheries in a sustainable fashion, come what may. "These changes in the ocean will present us, as marine resource managers, with the biggest challenges we have yet faced," she said.

DFG fishery managers and various partners have dealt with regional challenges such as the decline in the sardine populations in the 1940s and, more recently, decreases in some rockfish stocks. Ocean acidification, however, is "tied to global ocean processes that are measured in decades and centuries, and go beyond regional boundaries," Aseltine-Neilson said.

"Cold, dense surface waters in the far northern Pacific Ocean sink and then meander like a giant ocean river first toward the equator, then northward toward the West Coast of the United States," said Aseltine-Neilson. "After 30 to 50 years, these waters well up along our coast. They carry with them the history of their passage, including more acidic waters from different depths as well as surface waters. Researchers have already seen more acidic, upwelled water at some locations off California. We'll likely see this trend increase and cover larger areas off our coast."

To do their jobs effectively in the face of these changes, state fishery managers need information about how ocean acidification may impact living marine resources. "One way to increase our knowledge is to network through groups such as C-CAN," said Aseltine-Neilson. "If C-CAN successfully develops a coordinated monitoring system, the exchange and comparison of data between state agencies and their partners will provide insights into how we can adapt fishery management."

To address the challenges presented by ocean acidification and climate change to state resources, DFG is identifying potential partners and courses of action. California's marine fishery managers have long-standing ties with a variety of universities and research organizations, such as the California Cooperative Oceanic Fisheries Investigations group, or CalCOFI, which includes researchers from DFG, the National Marine Fisheries Service, and Scripps Institution of Oceanography. These partners and others are helping DFG meet its commitment to developing marine ecosystem management practices that will increase the resiliency of ecosystems in the face of future climatic changes, including ocean acidification. DFG's Invasive Species Program also works to safeguard the ocean from the negative effects of non-native species, to support the integrity and function of the ecosystem overall and help that system buffer future impacts associated with climate change, such as ocean acidification.

"We must continue working collaboratively with our stakeholders, the Ocean Protection Council and others to develop a holistic approach for responding to climate change and ocean acidification," said Kevin Hunting, DFG Chief Deputy Director. "DFG can't do this alone. We are actively meeting with NGOs and academic stakeholders to discuss our approach and identify ways we can address this issue together. Among our most important partnership efforts is engaging our stakeholders in regional state teams to help us develop strategies for addressing ocean acidification and other threats to the ocean environment in the forthcoming revision of California's Wildlife Action Plan."

Holding out Hope

The newly-settled urchins and other creatures preserved in glass specimen jars in Schroeter's lab are unique. They may represent one of the few, if not the only, sets of wild, shelled animals collected regularly over the past 20 years from stations along the California coast like Point Cabrillo. Using specialized equipment, the samples can be examined to measure changes in the young creatures' development over time, helping scientists to better understand how ocean acidification works. Documenting these changes over long time periods, through examination of collections such as Schroeter's, helps scientists to uncover long-term trends that help to predict what will happen next.

Along the California coast, especially the North Coast, upwelling pushes more acidic water from the depths sometimes all the way to the surface near shore. "During the summer strong upwelling occurs, often in pulses," said Feely. "But with steady winds, strong upwelling of corrosive waters can occur for longer periods of time," possibly exposing nearshore ocean residents such as sea urchins, oysters and abalone to harmful, or even lethal, doses of more acidic water.

DFG photo by D. Stein

Northern California's iconic red abalone may be susceptible to the effects of ocean acidification.

During a June 2007 research cruise, Feely and his colleagues documented unexpectedly high CO_2 readings for the first time at seasonal upwelling "hotspots" along the West Coast. A repeat cruise in August 2011 confirmed continued, strong upwelling of acidic water in the same areas.

New technologies that can measure and monitor ocean acidification on a daily level are being used by researchers such as Gretchen Hofmann, an ecological physiologist at U.C. Santa Barbara and a leading ocean acidification researcher. Some of the results are surprising. "We always thought acidification was going to get very bad, given estimates of the upward trend in carbon dioxide emissions over the next hundred years," she said. "This past year, with the development of better equipment to measure ocean pH, we have found that nearshore animals may be more used to dealing with wide variations in pH than we thought. We installed new sensors off the West Coast that can record pH by the hour, day, and so on. It turns out that, hey, on any given Tuesday we can get very acidic readings off Santa Barbara." Hofmann, Feely and other ocean acidification researchers are continuing to find instances of this wide-ranging pH in nearshore waters at different locations around the world using newly developed equipment.

The high and low pH readings are often transient—only lasting a matter of hours, or days. So far, California's clams, abalone, sea urchins and plankton seem to be able to cope with these transient pH shifts. Biologists have not seen major downturns in red abalone populations, for example, directly attributable to ocean acidification, as may be the case for oysters in Oregon and Washington.

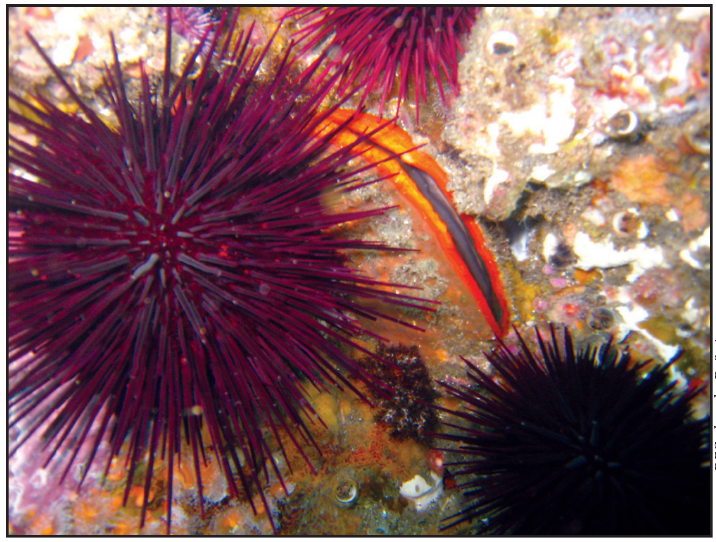
As waters become more acidic, however, the survival of many calcifying ocean residents may depend on the timing and duration of low pH events. For example, if major spawning events occur at the same time as sustained periods of upwelled, more acidic water, some animals may see a reduction in their numbers, or reduced size as vulnerable larvae are affected.

"As ocean acidification increases, organisms may face environmental conditions they have never faced before.

This rate of change is so outside the realm of experience for today's animals, it's bad news," said Hofmann. "We're finding out that nearshore organisms are subject to variable pH all the time, but there's a threshold you cross for each one where they just can't make shells anymore."

Where that threshold lies is a critical question researchers are trying to answer. "We have to look for where each animal is most vulnerable to acidic conditions," said Hofmann.

For some organisms, such as oysters, research suggests the most vulnerable stage may be when they're a few days old, still in larval form. "Oysters spend about 15 days in the plankton before they settle out. This is a very critical stage in their development, because if they don't form shells before settling and attaching to the bottom, they die," said Feely. "We're just now getting data from university studies on the effects of various levels of pH on oysters. The results are very consistent with what we believe is happening already on the coast."



DFG photo by D. Stein

Sea urchins' ability to reproduce is diminished in more acidic water conditions, according to laboratory test results.

Laboratory studies on abalone hold out a bit more hope. Chris Harley, an associate professor at the University of British Columbia and a leading expert on how marine ecosystems respond to change, tested the effects of more acidic water on pinto abalone, known locally as northern abalone in Alaska. Because it's in the same genus as California's prized red abalone, the test results for pinto abalone larvae could apply to red abalone larvae as well, Harley said. The tests showed that as CO_2 levels increased, fewer of the days-old abalone survived, and at the highest levels those that survived often had deformed shells or didn't form shells at all. When normal shells developed, they were about five percent smaller than those developing in less acidic conditions. The "good" news is that, compared to oysters, at least 40 percent of the abalone larvae survived the pH levels predicted for 2100.

Life might be tougher for sea urchins than for abalone. According to Harley, "In sea urchin studies we've found that more acidic conditions affect even the ability of sperm to fertilize eggs." As with abalone and oysters, the larval stage is the most vulnerable to increased acidity. Those same conditions affect adult sea urchins as well, delaying sexual maturity and growth to minimum harvest size.

Yet, some species will probably thrive in more acidic waters. For example, Harley and his colleagues tested ochre sea stars in highly acidic conditions over a 10-week period, and found that they ate more than usual and grew over 60 percent faster. The results were a bit of a surprise, as the same conditions have the opposite effect on the sea star's distant cousins, the brittle stars and sea urchins. Some plants, such as bull kelp and sea grasses, should also thrive in a CO_2-rich environment. Linking all the effects on individual creatures in a way that illustrates how ocean acidification might affect entire regions, ecosystems, and coastal human communities and their fisheries is the ultimate challenge for researchers.

As the larger picture unfolds, the results of research will likely influence fishery management. "Finding out which species are better able to withstand a more acidic environment will help us predict how marine ecosystems may change," said Aseltine-Neilson. "And as managers, we'll need to adjust our management accordingly. For example, we may need to consider smaller bag limits, shorter seasons, or conservative harvest goals for species that decline in more acidic waters. On the other hand, the development of new fisheries might be encouraged for untargeted species that thrive under these changing conditions."

One thing is certain: change is coming. "We will continue to see significant biological effects from increased levels of CO_2 until we come back to an equilibrium point, which will take a very long time," said Feely. "The changes occurring in our lifetime will have implications for many hundreds of thousands of years."

"I had this very sensitive undergraduate student," said Harley, "who came up to me after a lecture on ocean acidification and asked, almost on the verge of tears, whether the oceans were just going to become this wasteland, this empty desert without life." Harley reassured his student, explaining that no, everything wasn't going to die. There will be "winners" and "losers" in the race to survive, but complete annihilation of every living thing in the ocean wasn't going to happen.

Harley emphasizes that although "we can't stop this oncoming train of ocean acidification, we can push our pickup truck off the tracks." By more aggressively enforcing laws already on the books to control land-based activities that increase stress on marine plants and animals, such as erosion and agricultural runoff, the negative effects of rapidly changing ocean chemistry can be delayed or reduced, he said. Adjusting fishing harvest limits must also be included in any discussion of how to reduce stress on marine plants and animals.

Because sustained monitoring of ocean pH and studies investigating the effects of more acidic waters on marine ecosystems has only begun in the past dozen years, researchers cannot yet predict exactly what will happen to each species, how events will cascade through marine ecosystems, or when the effects of ocean acidification will start to seriously impact ocean creatures. "Scientific research is critical, for both ecological and economic reasons. People that rely on the sea for a living need to be prepared," said Hofmann. "All we can do, as scientists, is to keep asking questions. We need to explore how well marine creatures can withstand the changes that are coming."

For more information about ocean acidification, visit the following websites:

- Unity-Integration-Action: DFG's Approach to Confronting Climate Change: ***www.dfg.ca.gov/Climate_and_Energy/Climate_Change/***
- California Current Acidification Network (C-CAN): ***http://c-can.msi.ucsb.edu/***
- Understanding Ocean Acidification: ***http://cisanctuary.org/acidocean/***
- Ocean Acidification: Resources from the National Research Council's Oceans Study Board: ***http://oceanacidification.nas.edu/***

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