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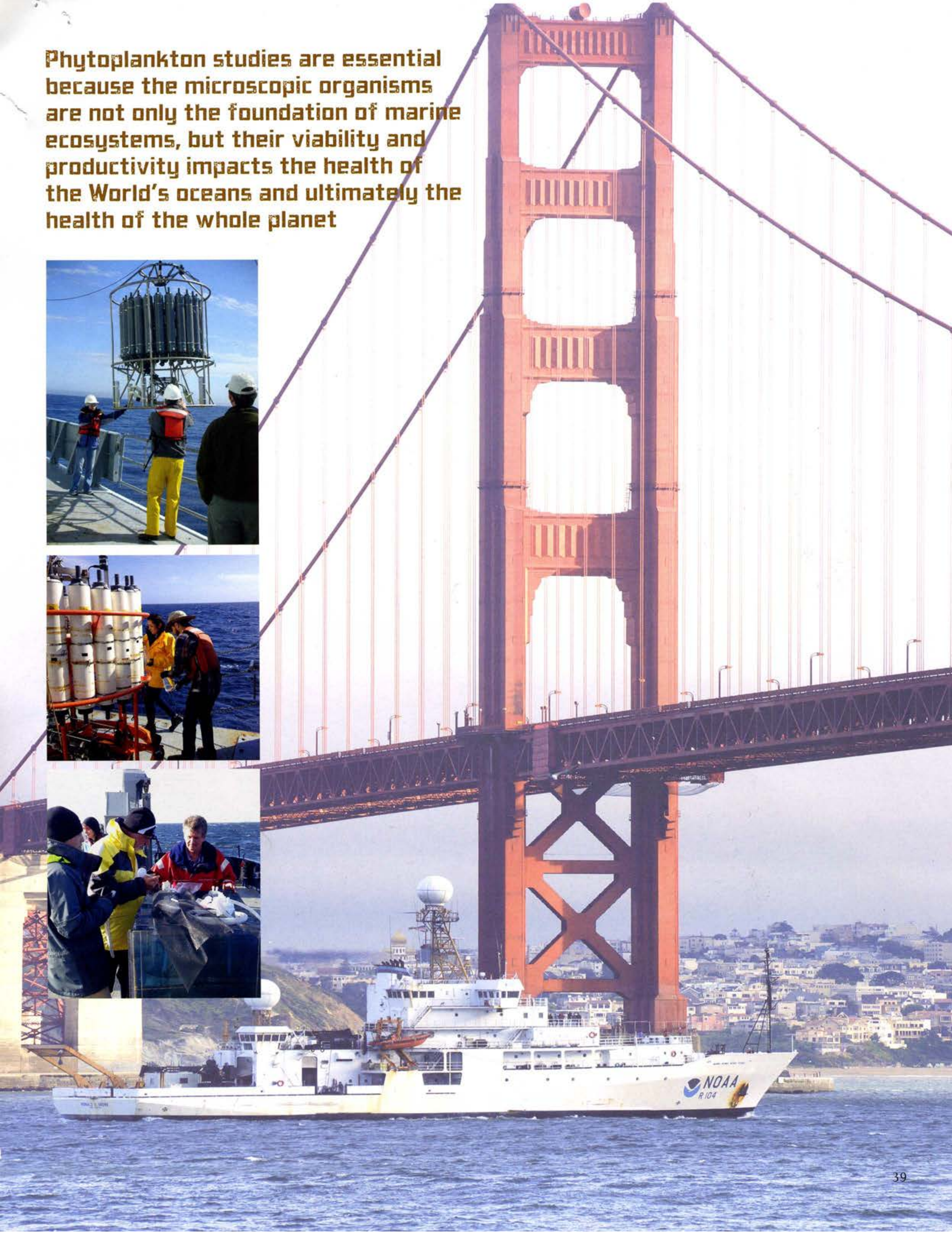
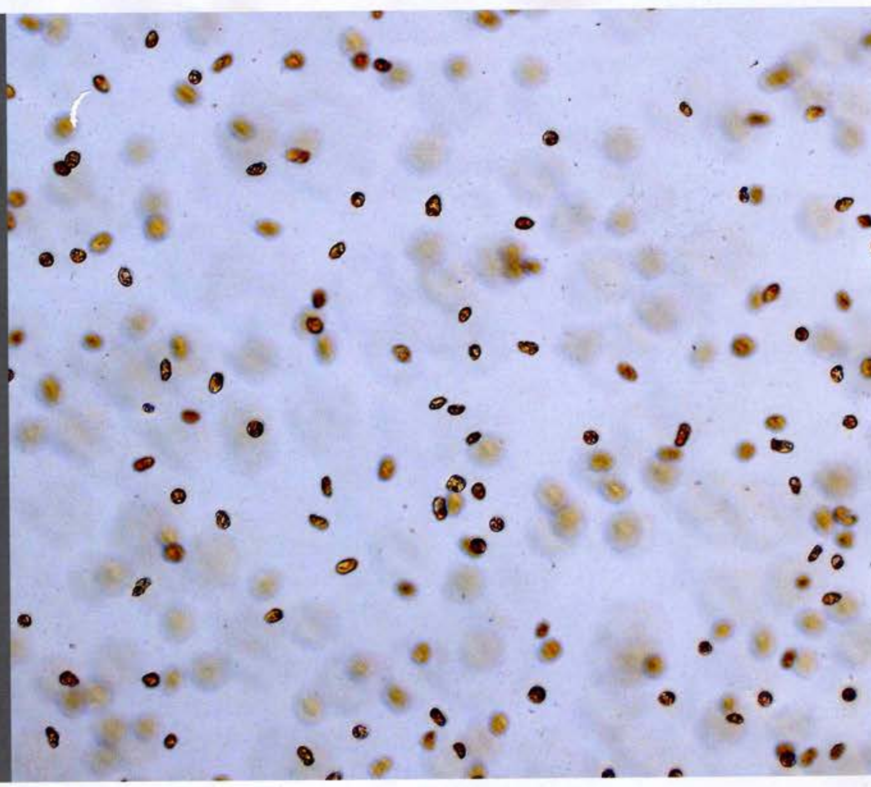


William Cochlan and Phytoplankton: a Quiet Scholar of Unlikely Heroes

by Katharine Merkley

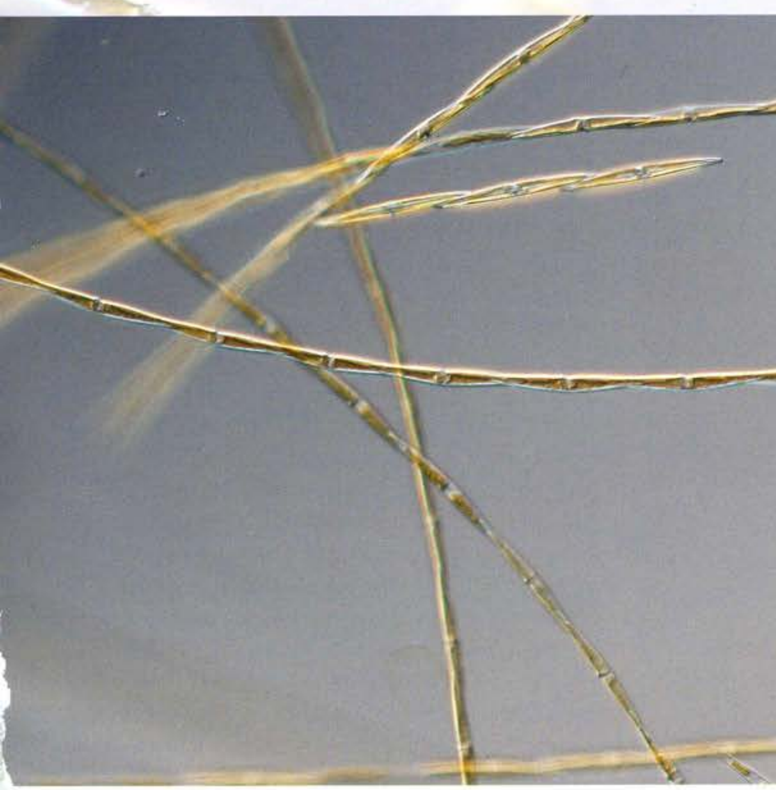
All microscopic images were obtained with a new state-of-the-art motorized inverted DIC phase contrast microscope purchased with a FSML grant awarded by the National Science Foundation to Dr. Cochlan and former Romberg Tiburon Center Director Toby Garfield.

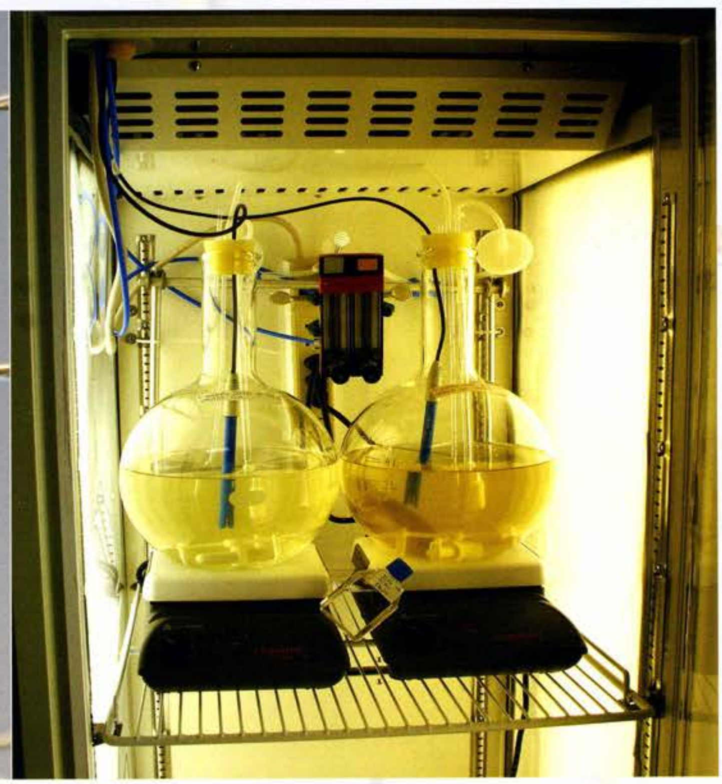


Page 32: Background and Image: The fish-killing raphidophyte *Heterosigma akashiwo*, isolated from the Salish Sea. (C. Ikeda photo, Cochlan Phytoplankton Ecophysiology Lab, RTC).
Page 33: Background and Left Image: The neurotoxin-producing diatom *Pseudo-nitzschia australis* isolated from northern California coastal waters. (C. Wingert photo, Cochlan Phytoplankton Ecophysiology Lab, RTC
Page 33: Right Image: Inside one the environmental chambers used to culture phytoplankton under controlled conditions of temperature, light and acidity.

"We can't preserve an environn

Most living things—plants, fungi, animals, and others—need oxygen to live and thrive. Plants produce oxygen as they capture light energy and build carbohydrates through photosynthesis. Most of our atmospheric oxygen, however, comes from another, less famous source—the phytoplankton. Collectively through their photosynthesis in the world's oceans, single-celled, microscopic phytoplankton pump out 40 to 60 percent of the oxygen that humans and other aerobic organisms breathe. Phytoplankton also recycle the carbon dioxide they use as particulate organic carbon, and by sinking out of the upper ocean, they sequester some of the excess CO_2 to





the deep oceans through the biological pump. By studying these ecological "heroes," San Francisco State marine biologist and oceanographer Dr. William Cochlan is quantifying their sensitivity to climate change, but also determining their crucial role in lessening its impact.

ent if we don't understand it."

Plankton includes both phytoplankton and zooplankton, although the latter are more animal-like and multicellular, both groups assume a wide array of elaborate and dazzling shapes. Some phytoplankton are slim and elongated, others spherical or jagged. In one class – the diatoms, every organism has a gleaming glass-like cell wall made of silica. And if viewed through a microscope, every teaspoon-sized cubic centimeter of seawater glistens and vibrates with thousands of these minute organisms. Marine food chains (or the more complex food webs) begin with phytoplankton and end – after a bigger-eats-bigger bucket brigade – in large ocean predators like tunas and sharks. Beyond the oxygen that phytoplankton produce and the CO_2 they sponge up, these organisms die and sink along with those glass exoskeletons to form diatomaceous earth – layers hundreds of meters thick and rich in silicates. Another phytoplankton group, the coccolithophores, have outer plates made primarily of calcium carbonate. These accumulate over thousands of years and re-emerge from the ocean floor in massive structural works such as the White Cliffs of Dover.

For poorly understood reasons, some kinds of phytoplankton will overpopulate to form massive blooms that form low-oxygen regions (anoxic zones) as they die and are decomposed by bacteria. Other phytoplankton species produce lethal biotoxins that negatively impact the ecosystem and even cause human fatalities. Both types of phytoplankton bloom events are termed harmful algal blooms (HABs).

William Cochlan has made a long career of trying to understand these primary producers and unseen recyclers. "The whole marine ecosystem depends on them," he told this reporter. "So if their health is in jeopardy, it will affect the greater marine ecosystem and the oxygen that we breathe." In his quiet, scholarly way, Cochlan is both a champion and preservationist for these unlikely planetary heroes. By studying phytoplankton and the group's somewhat mysterious status, he can better understand the viability and the health of our oceans and the higher levels of life that are supported by the marine pyramidal base. As Cochlan puts it, "We can't preserve an environment if we don't understand it."

Cochlan's career-long interest in phytoplankton continues with his research at Romberg Tiburon Center for Environmental Studies (RTC) – SF State's off-campus research and teaching facility on SF Bay. His fascination started, however, during his undergraduate years at the University of British Columbia (UBC) in the late 1970s. The single-celled oceanic heroes first intrigued him while he was working under the mentorship of several individuals he recalls as being "bright, caring, and enthusiastic graduate students and faculty." The graduate students, in particular, helped him understand the importance of phytoplankton as they assisted undergraduates like Cochlan with individual research projects and in 'hands-on' lab classes. For his honor's thesis as a senior, Cochlan studied how UV radiation impacts the availability of copper in the sea and the resultant growth of phytoplankton. This research engaged and excited him because it placed him "right on the cusp of new knowledge." He recalls, in particular, learning from one graduate-student mentor that, "If you don't understand the basis – the fundamentals – of what's driving the marine ecosystem, there's no way you can solve problems" such as climate change and ocean acidification today.

Cochlan has devoted much of his career to researching one of phytoplankton's most exciting manifestations: bloom development and the way marine microorganisms use nitrogen. Cochlan describes phytoplankton blooms as being visible as large patches of brown or green discoloration in the water, revealing an abundance of phytoplankton cells. According to Cochlan's research associate, Chris Ikeda, a recent master's degree graduate from SF State, such blooms can grow very large with some "the size of a city." Many of the blooms Cochlan studies are right off the Pacific coast and in the spring and summer of 2015 a toxic diatom species formed a massive bloom from southern California all the way up to his home country of Canada and southern Alaska.

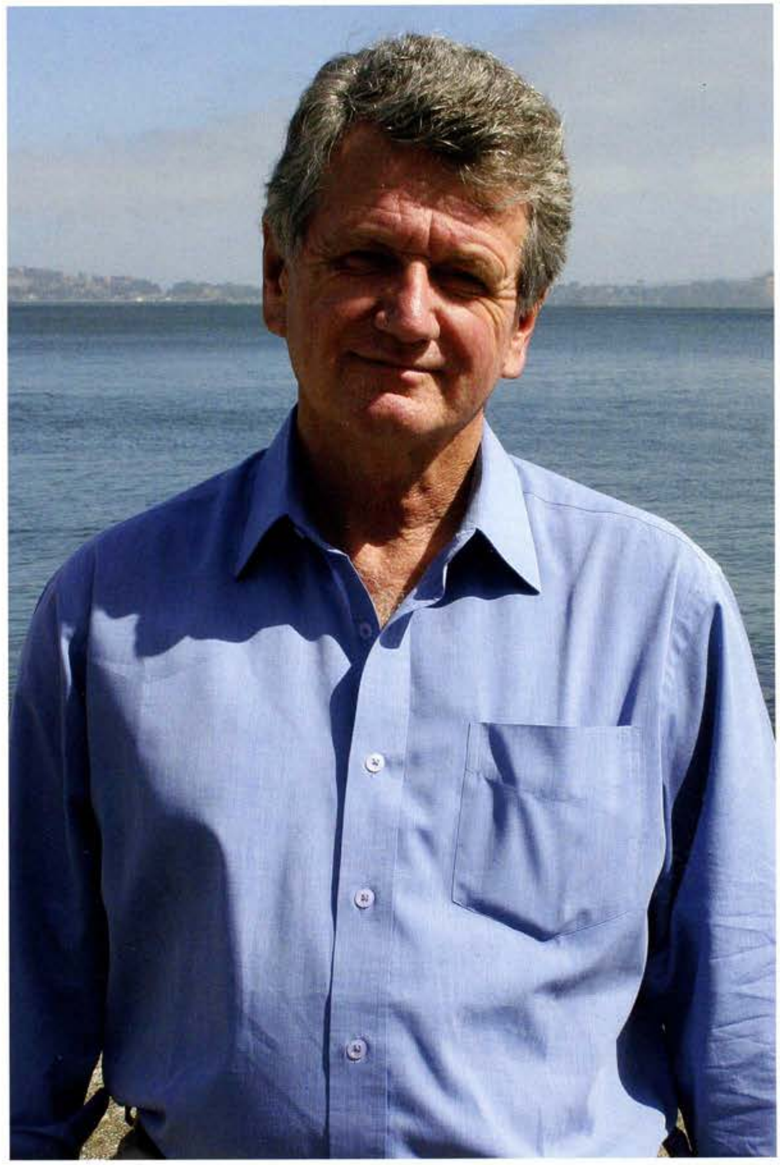
Cochlan explains that phytoplankton cells divide and reproduce exponentially, thus their biomass can increase very quickly...since phytoplankton such as diatoms usually divide at least once each day. At this conservative rate, a single cell could give rise to over 1,000 cells in just 10 days. Dinoflagellates, another common phytoplankton group second only in abundance to diatoms, can look armored with plate-like walls when viewed under a microscope. These phytoplankton swim about and navigate by means of lashing, tail-like flagella. Their continued growth can result in populations of 200 to over 100 million cells per liter and cause Red Tides– a term for blooms that have turned a patch of ocean visibly discolored–usually reddish.

Blooms can crop up quickly when conditions are ideal, and can last from one week to many. They only flourish, however, when environmental conditions are optimal. These include certain pH and temperature ranges; minimal grazing by nearby zooplankton; and the availability of nutrients such as phosphorus, nitrogen, and– for cells like diatoms that make glassy exoskeletons– silicon. The phytoplankton cells usually exhaust nitrogen from the water first, he says, and then the bloom starts to die.

Cochlan started his work on phytoplankton during his senior thesis research project at UBC. The path he followed, however, was much different than the one he planned on taking. While growing up, he was always interested in becoming a naval aviator in the Royal Canadian Navy (RCN). Unfortunately, he says, after the last aircraft carrier in the RCN was decommissioned during his first years of high school, careers as jet pilots in the Navy "ceased to exist." Because of this, after high school graduation, Cochlan declined a commission as an officer cadet at Canada's Naval Academy, then the Royal Roads Military College. While his dream of becoming a naval pilot seemed to be crashing, his career in oceanography arose from the wreckage.

He entered UBC as a general science major, and easily transitioned to an honors marine biology program—a decision, he says, came "natural" to him: Cochlan grew up in a small town about 100 miles north of Vancouver, Canada, on the eastern shores of the Salish Sea, the inland waters of British Columbia. He lived so close to the ocean, in fact, that he "could throw a rock from his front yard and hit the saltchuck" (BC slang for salt water).

Starting then and continuing throughout his formal education and academic career, Cochlan has studied two economically important groups of phytoplankton: certain diatoms that small fish consume in upwelling zones; and toxic golden-brown flagellates called *Heterosigma akashiwo*, which kill fish. Amongst the diatoms, Cochlan and his graduate students work mainly on species in the



Dr. William Cochlan
Romberg Tiburon Center

p. 34: Top;
Dr. Cochlan (R) together with Brian Bill (L: a former RTC-SF State graduate student and currently a research associate at the Northwest Fisheries Science Center, NOAA in Seattle, WA) aboard the R/V *Melville* (AGOR 14) visually examining polycarbonate bottles containing natural marine phytoplankton assemblages.

p.34: Bottom;
RTC-SF State researchers planning the day's experiments aboard the R/V *Melville* off northern California. From left to right: Charles Wingert (former graduate student), Maribel Albarran (former undergraduate researcher), William Cochlan (Chief Scientist), and Heather Richard (former graduate student)

All shipboard images courtesy of the Cochlan Ecophysiology Lab at the Romberg Tiburon Center, SF State University.

Cochlan and his students use a variety of sophisticated tools and instrumentation to study phytoplankton, and measure their responses to the ever-changing chemical and biological oceanic environment.

genus *Pseudo-nitzschia*, which produce a potent neurotoxin known as domoic acid (DA) which is harmless to the phytoplankton. Surprisingly, it also leaves unharmed the filter-feeding clams and small plankton-eating fish (so-called primary consumers; that consume the diatoms directly.) DA accumulates in their organs and muscles, however, and when marine mammals, seabirds or people (secondary consumers) eat the clams or fish, they can grow sick or even die from the neurotoxin.

Cochlan gives this example of accumulation through a food web in a marine ecosystem: Pacific razor clams and small plankton-eating anchovies and sardines ingest DA as they eat the diatoms and the toxin accumulates in their bodies without causing symptoms. If a sea gull, sea lion, or person then eats enough of these contaminated clams or fish, the consumer would experience poisoning. In both birds, and mammals, DA causes symptoms similar to epilepsy, including seizures, unusual behavior, and even death. In humans, this toxicity is called Amnesic Shellfish Poisoning, and it can cause chronic illness as well as short- and long-term memory loss. In three recorded cases of this shellfish poisoning, the people died.

The second phytoplankton species that Cochlan and graduate students have been studying recently–*Heterosigma akashiwo*, has a different impact on the marine ecosystems. When commercial fish species raised in caged systems in the Pacific Northwest and British Columbia encounter this golden-brown alga, it can kill the fish very rapidly. Although scientists know that *Heterosigma akashiwo* produces a toxin, Cochlan and his colleagues at The National Oceanic and Atmospheric Administration (NOAA) have yet to identify it. Mammals seem to be immune to the poison, but it can wipe out the fish in these caged fisheries in a matter of hours. According to Chris Ikeda, who completed his Master's research under Cochlan on *Heterosigma*, harmful algal blooms such as this are "a very complex and expensive problem."

Cochlan and his colleagues would like to understand such complex and potentially costly mysteries, in particular the " environmental factors that cause these specific phytoplankton to do better,

p. 36:
Scripps Institution of Oceanography's resident technician preparing to launch a 20-liter Go-Flo bottle to collect trace-metal clean water samples for analysis aboard the R/V Melville during a research cruise from San Francisco to Seattle led by Dr. Cochlan.

Above:
Recovering an instrumented rosette equipped with an array of electronic instrumentation to fully characterize the water column, and a series of 10-liter Niskin bottles to collect water and phytoplankton from discrete depths in the sea. Photo taken from the afterdeck of the R/V *Melville* off the coast of Oregon.

or outcompete, other phytoplankton, and what makes them produce these bio-toxins." It would be logical to think that microscopic algae make toxins as a form of chemical self-protection, to discourage predators. Since the toxin generally leaves primary consumers—the first predators in the food chain—unharmed, however, this can't be the 'total story' or entirely correct. And to confuse the issue still further, the toxins can negatively affect other competing phytoplankton species in a process called alleopathy. Despite such complicated puzzles—in fact, because of them--Cochlan finds the research "fresh and exciting."

Cochlan and his students use a variety of sophisticated tools and instrumentation to study phytoplankton, and measure their responses to the ever-changing chemical and biological oceanic environment. According to Dr. G. Jason Smith, an Associate Research Scientist at the Moss Landing Marine Laboratory in Monterey and a world authority on diatoms, Cochlan's work is "seminal in defining nitrogen uptake." Cochlan is also a pioneer in researching algal blooms at sea, and has worked from the Equatorial Pacific to the Southern Ocean off Antarctica. In the summer of 2014, Cochlan served as Chief Scientist for a collaborative scientific mission on the 279-foot research vessel the *Melville*, operated by Scripps Institution of Oceanography. On this mission, funded by the National Science Foundation, Cochlan, his students from SF State, and a team of research colleagues from several American and Canadian universities cruised for 26 days off the Pacific coast between Point Sur, CA, and Seattle, WA. They focused their study on how pH affects the nutritional quality of phytoplankton and the toxicity of harmful algal blooms. To accomplish this, he and his SF State co-workers had

Above: Conducting deck-board experiments in the middle of the less-than-calm northeast Pacific Ocean aboard the R/V *Thomas G. Thompson* (AGOR-23). Researchers L to R are: Liza Barney (former graduate student Western Univ.), Maureen Auro (former RTC-SFSU graduate student), Dr. Mark Wells (Univ. Maine), William Cochlan (RTC-SF State) and Charles Trick (Western University).

p. 39 (small photos) top: Launching a CTD-equipped rosette sampler; middle: Charles and Wingert and Maribel Albarran (RTC-SF State) collecting samples from the rosette sampler; bottom: (L to R) Chris Ikeda, Charles Trick and William Cochlan sampling an ocean acidification deck-board experiment aboard the R/V *Melville*.

p. 39 (background): The NOAA ship *Ronald H. Brown* (R-104) departing San Francisco during the mid-point of an ocean acidification research cruise in May 2016. Aboard are three former SF State graduate students, as well as researchers from 17 institutions from the U.S., Canada, Mexico and Europe.

to develop a technique for controlling pH in experiments conducted on board a ship while at sea –something that no other team had done before. They came up with a way to manipulate and regulate the pH to which they were exposing phytoplankton experimentally. Cochlan's team is finishing the final analyses, but so far they have found that in more acidic water (i.e., with a lower pH range), the HABs are much more toxic. This has powerful implications for understanding global climate change since ocean acidification (OA) is one of its dramatic consequences.

Phytoplankton studies are essential because the microscopic organisms are not only the foundation of marine ecosystems, but their viability and productivity impacts the health of the World's oceans and ultimately the health of the whole planet. Cochlan explains that climate change and ocean acidification could intensify the negative impacts of harmful algal blooms, but he and colleagues are just beginning to understand how acidification affects phytoplankton. Cochlan predicts that increased temperature could lead to increased rainfall in Washington State and other parts of the Pacific Northwest and this, in turn, could reduce the salinity (saltiness) of water in the Salish Sea. He and his coworkers recently published studies suggesting that decreases in salinity could promote bigger, more frequent, and more toxic blooms involving phytoplankton species such as *Heterosigma akashiwo*. This would be bad news for fish, fishers, and fisheries. HABs are also very concerning because blooms can harm consumers even at low cellular densities. In other words, even with a low number of poisonous cells per liter of seawater, the HAB can be highly toxic.

Looking toward the future,

Cochlan plans to continue studying how environmental factors such as salinity and ocean acidification impact phytoplankton growth and toxicity and how these environmental stressors may act synergistically to accelerate toxic risk to marine ecosystems and humans.. And he hopes to gather information quickly enough so that marine scientists and conservation managers can both lessen harmful effects and insure that phytoplankton continue to positively imfluence the environment. The alarming increase in harmful algal blooms in some regions is just "another reason we need to be concerned about climatic change and acidifying seas," he concludes. Clearly, phytoplankton species—our unsung providers of global oxygen—can also be intermittent and mysterious poisoners of other sea life. Only through continuing study, adds Cochlan, can we understand their future impacts on "shellfish resources, local economies, human health and wildlife populations in a changing world." Although these are complex and challenging issues, the world-class facilities and instrumentation amassed at Cochlan's laboratory permit him and his student researchers to make dramatic discoveries and provide valuable insight into the health of World's oceans. Through the creation of this transferable knowledge, the potential risk to human health can be assessed, and the toxic impacts on recreational, commercial and indigenous fisheries minimized in the US and around the World. ♦