Dr. Anne Todgham, an assistant biology professor at SF State, finds fascination in purple sea urchins—plum-colored, hedgehog-like marine invertebrates. Todgham describes the animals as “ecosystem engineers” because their voracious grazing can remodel the kelp beds in a reef ecosystem. Although the urchins are themselves highly prized delicacies in Japan, Todgham’s interest is far from culinary: She has studied the spiny animals and their tiny larvae as bellweathers of global climate change.
A new faculty member beginning in 2009, Todgham has been busy applying for research grants, outfitting her laboratory in Hensill Hall, getting her research program off the ground, and designing new courses. She currently is involving graduate and undergraduate students in her important research on environmentally-induced stress in sea urchins and other marine life. Her goal, she explains, is to understand “the physiological mechanisms animals have in place to tolerate the rapid pace of climate change we are now experiencing.”

Purple urchins live up and down the northern Pacific coast, says Todgham, and she chose to study this particular species because other researchers had already sequenced its complete genome. Animals experience a series of subtle cellular changes in response to environmental stress, she explains. By knowing the entire genetic code, biologists can “monitor changes in the types of proteins in the animal’s cells at any given time.” Such a detailed understanding of an
animal’s stress response to climate change will then allow biologists to make predictions about their survival for the next 90 years if average global temperatures continue to rise dramatically.

“In 90 years,” Todgham says, “we expect the temperature to be 2 degrees warmer, in a conservative scenario, or, maybe 4 degrees warmer in a business-as-usual scenario.” If we do nothing to prevent global warming, in other words, “it’s predicted that our temperature will be about 4 degrees warmer by 2100, than it is today.”

The figures she cites come from a 2007 report by a group called the Intergovernmental Panel on Climate Change, or IPCC. In her postdoctoral research on purple sea urchins, Todgham applied these projected conditions, focusing specifically on the organism’s juvenile larval stage. “A number of people in climate change biology think it’s really important that we not only look at adult animals, but we look at juveniles as well, because maybe the juveniles are more vulnerable, or sensitive to environmental change than adults.” If the larvae are unable to tolerate rising temperatures or increasing acid levels in seawater, then they could have a poor chance of maturing into resilient adults.

Ocean acidification has been one important focus of climate change research. As atmospheric carbon dioxide levels rise and additional CO₂ dissolves in ocean water, Todgham says, it creates an environment that is “more acidic for the animals that live there.” So far, much of the research has centered on marine animals that “calcify,” or build a calcium carbonate shell or exoskeleton, including snails, mussels, oysters, and reef-building corals. “Under high carbon dioxide conditions in the oceans,” Todgham says, “corals, and other calcareous, or calcifying, animals, are not able to make their hard parts as effectively.” The hard parts they do build “are actually disintegrating, as well, in these acidic waters.”
Todgham earned her PhD from the University of British Columbia in 2005, and that same year, began a postdoctoral fellowship at UC Santa Barbara. There, she studied—among other things—the effects of CO₂-driven seawater acidification on larval development of sea urchins. In the laboratory, she recreated a futuristic ocean environment, based on the acidity levels predicted 90 years hence. She bubbled seawater with carbon dioxide gas, to simulate what the oceans might look like in 2100. Then, she and colleagues would “take the larvae that we spawned in the lab, and raised them in these conditions.”

To understand the purple sea urchin larva’s response to climate change at the molecular level, Todgham chose about 1,100 genes important to stress tolerance, biomineralization, development, and metabolism from its total of approximately 23,000 genes. Next, she applied DNA microarray chips to measure changes in gene expression. Todgham describes the microarray chip as an instrument resembling a microscope slide that can detect changes in the levels of messenger RNA (mRNA) from thousands of genes at a time in response to environmental change. Todgham put all 1,100 of the selected genes on a microarray chip to monitor how they responded to changes in seawater pH. Todgham was able to measure changes in the larva’s gene expression in response to the increased CO₂, in particular, monitoring gene expression pathways for metabolism and stress response. Her team found that genes and proteins responsible for building the urchin’s exoskeleton were turned down. She as also able to confirm this through direct observation: Under a microscope, larvae exposed to elevated CO₂ and therefore lower pH levels formed smaller exoskeletons. “We were some of the first to show that a number of genes that were responsible for building the skeleton were turned down,” says Todgham.

Todgham’s passion for biology shows whenever she describes her research. This enthusiasm apparently began at an early age and remained as she followed the long academic pathway that eventually led her to SF State. From the start, she recalls, “I

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was a naturalist." Every summer Todgham’s family vacationed in Maine, where she and her dad would spend four or five hours at a time tidepooling in the intertidal zone. “You swim in the ocean and you don’t really see much, but then you go into these tidepools and they’re teeming with life,” says Todgham.

Her love of biology stayed strong all the way through high school, including the day representatives came from the University of Guelph in Ontario. “I got swept off my feet by the university spokespeople that came over to my high school,” she says. “They talked about the fact that, strangely, being a landlocked university, it had the top marine biology program in Canada.” She eventually enrolled at the University of Guelph, and found that many of the professors were comparative animal physiologists. Experts in that field, Todgham says, “seek to understand how animals living in different environments might have similar solutions to common environmental problems.” They

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Todgham enrolled for graduate work at the University of British Columbia and selected a project on Vancouver’s west coast. Her subject was inducible stress tolerance in intertidal fish. In the intertidal zone such as along Vancouver’s rock coast, she explains, environmental stress may include a temperature increase of as much as 10 degrees in a given day. In addition, oxygen levels in the tide pools can drop to nearly zero at night as the abundant plants and animals consume much of the oxygen produced by plants during the daytime.

During her doctoral work under advisors Trish Schulte and George Iwama, Todgham learned the molecular biology techniques that would later shape her research career. “Instead of looking at hormonal changes like cortisol and glucose” in the stressed fish species, she says, “I had a chance to look at some changes in levels of gene expression, which are the effects of stress on molecular and cellular mechanisms.” Todgham chose to examine so-called heat shock proteins. “They’re called heat shock proteins because they were first discovered in response to heat shock. We now know that they are actually induced in response to a wide range of environmental stressors,” she says. “Working at the molecular level, measuring how gene expression changes in response to environmental changes really set in motion the kind of research that I did in both my post-doc, and now, here at San Francisco State.”

In 2005, with her new PhD from the University of British Columbia, Todgham moved on to postdoctoral work at UC Santa Barbara, where she continued to look at stress tolerance at the molecular level. As mentioned earlier, she looked at how seawater acidification affects sea urchin larvae. She also studied the stress tolerance of Antarctic fishes. “These Antarctic fishes thrive at temperatures right at the freezing point of the sea water,” she explains, “yet they don’t freeze.” Living organisms are “all very similar in the types of genes that we have and in the sequence of these genes.

Todgham spent a lot of time preparing her lectures. Recently, she designed a course in environmental physiology. “It allows me to talk about all of the weird and wonderful creatures we have on this planet and how they’re uniquely designed to deal with harsh environments,” she explains. Much of her scientific writing, she adds, involves applying for research grants. When she is not writing lectures or grant proposals, Todgham reads current literature on climate change biology. She plans to collaborate with Dr. Jonathon Stillman, a marine biology professor at Romberg Tiburon Center, SF State’s marine station on the Bay, and is outfitting her lab with research equipment to conduct environmental physiology research.

“This is an exciting time for students to get involved in biology,” Todgham says, “because we’re in a time where we have a lot to contribute in understanding how our marine ecosystems are going to fare in the face of climate change.” We need more research aimed at identifying which populations are vulnerable to ocean acidification, she adds. “We also need a clear understanding of the costs associated with the synergistic interactions of ocean acidification and ocean warming.” Although environmental issues depress and concern many students, Todgham closes with a word of hope: “There’s a place at the table for us in this challenge that we face as a globe. While it’s a daunting task, it’s an exciting time, as well.”

What amazes me is that different animals have taken advantage of different aspects of their genome to allow them to thrive in different environments, and in stressful environments.” Todgham is still interested in environmentally-induced stress. “It led me into the research I do now,” she says, in climate change biology, including whether animals can “flex” their physiology in response to rapidly changing conditions.

Her position at SF State allows Todgham to pursue both research and teaching. “I really like that San Francisco State University puts a lot of pride into being an institution that provides this nice balance: a strong teaching environment, a scholastic environment for students, and I’m hoping to have a strong research program that will involve both graduate and undergraduate students,” she says.

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