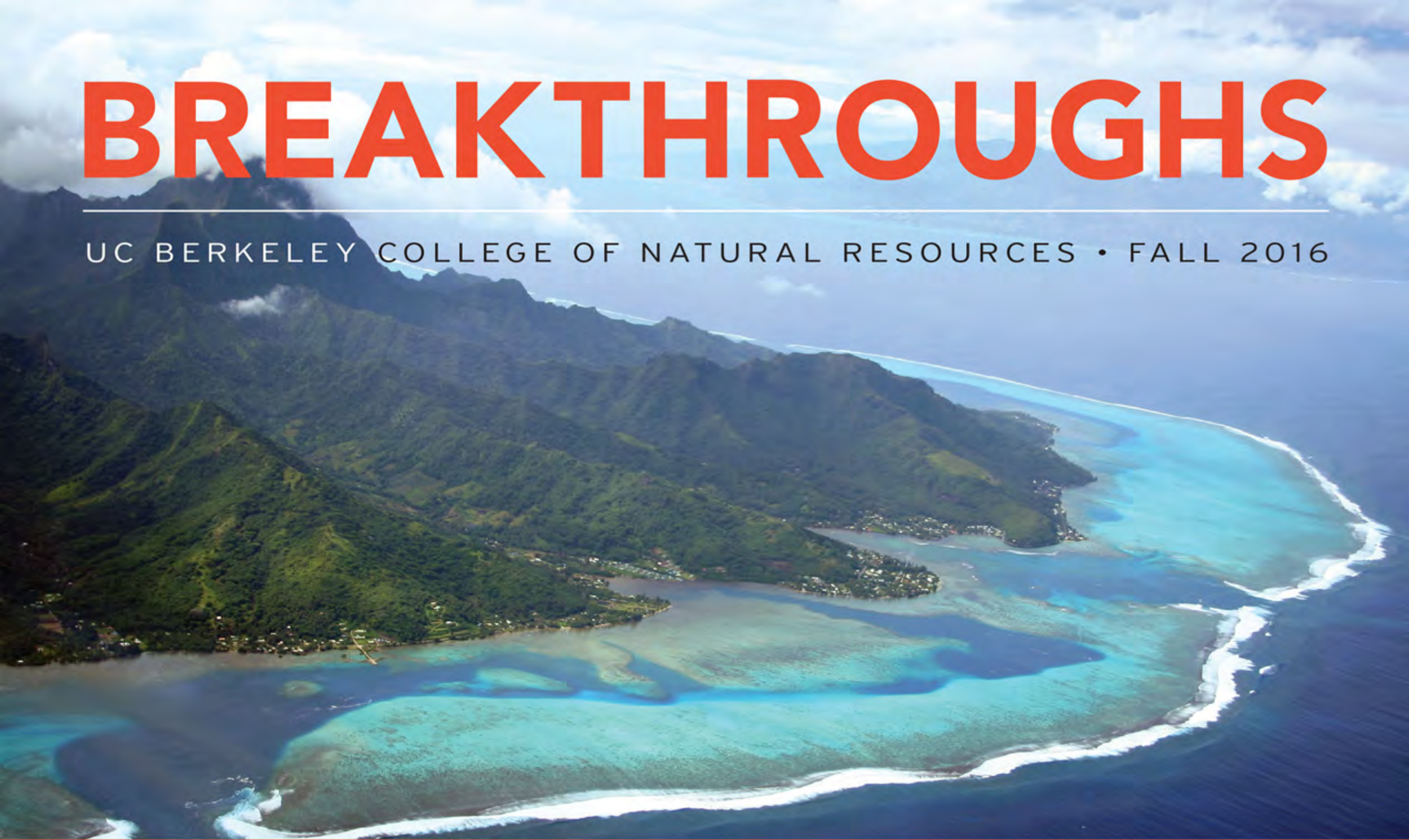
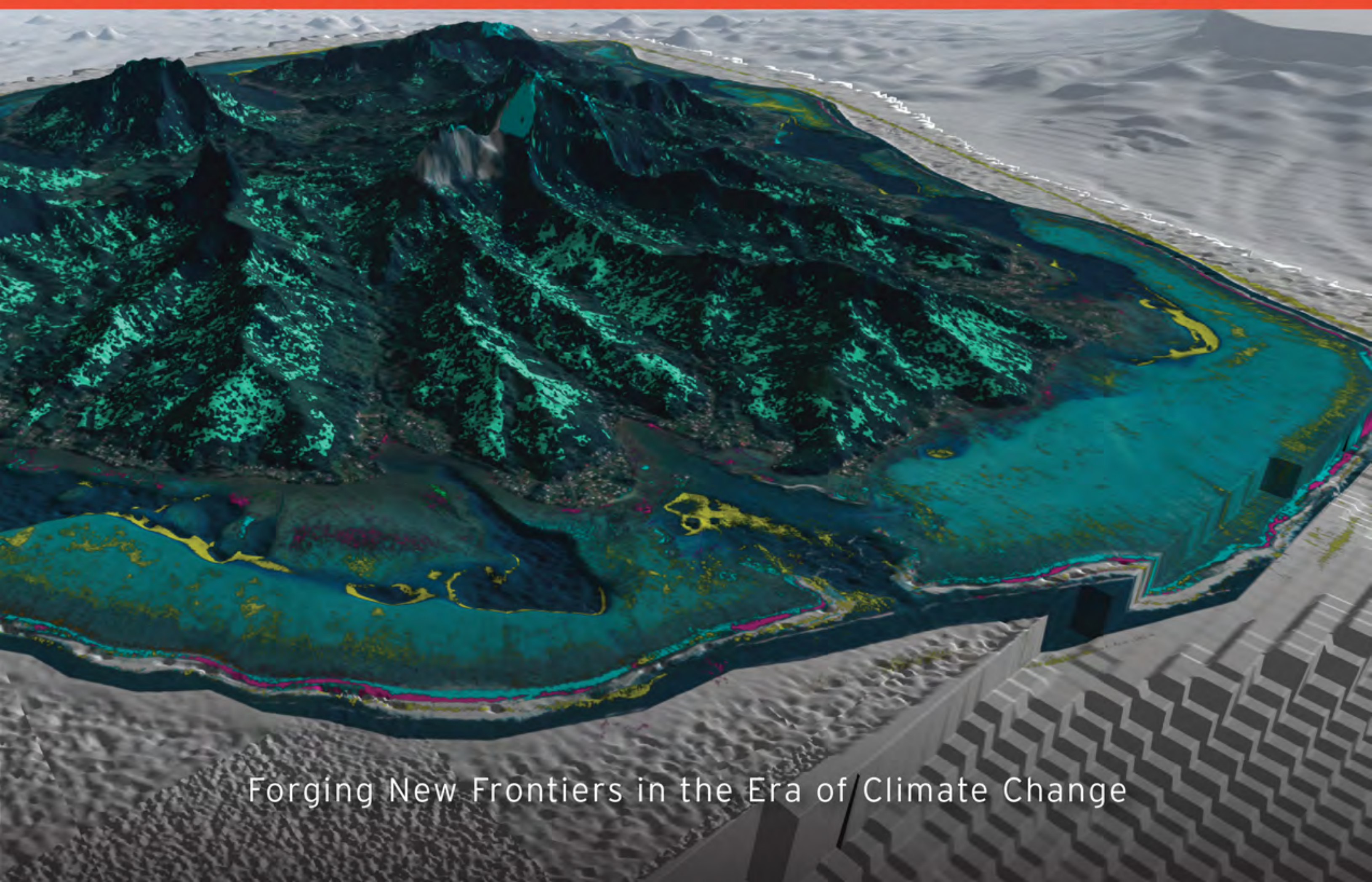
BREAKTHROUGHS

UC BERKELEY COLLEGE OF NATURAL RESOURCES • FALL 2016



FROM AVATARS TO OPEN SCIENCE



Forging New Frontiers in the Era of Climate Change

The agreement resulting from last winter's United Nations Climate Change Conference in Paris marked historic progress in global negotiations on climate change. But with 2015 reported as the hottest year on record, we need swift action to create a sustainable, low-carbon future.

In this issue, we highlight some of the College of Natural Resources' work toward this goal. We reveal how data science can unify a global community of researchers and expand the scope and impact of ecological research in entirely new ways. We also feature two large-scale projects that use advanced technologies to measure and analyze both local and global ecosystems—and to predict how they'll fare under the pressures of global warming and environmental change.

The "climate" at Berkeley has been stressed in 2016 as the campus deals with serious budget issues, negative publicity, and leadership change. Thanks to the encouragement and generosity of our donors, CNR remains a vibrant community with a manageable budget.

We plan to give you regular feedback on the impact that your ongoing support is making. Our On the Ground feature highlights the valuable experience that undergraduates are gaining through the Sponsored Projects for Undergraduate Research program, which is funded 100 percent by our donors. As for students pursuing advanced degrees, the College Support story explains why graduate-student support is one of our highest funding priorities.

At Berkeley, our students assist faculty with cutting-edge research. When they graduate, they become the next generation of scientists and leaders working to preserve our planet. Supporting their success is one of the best investments we can make.

I welcome your comments at gilless@berkeley.edu.

J. Keith Gilless

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J. Keith Gilless

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COVER PHOTOS: The Moorea Island Digital Ecosystem Avatar is a comprehensive model of the ecosystems on the island of Moorea, French Polynesia, which is helping scientists create larger models and predict the impact of global climate change.

PHOTO: Nancy Lee Peluso

Berkeley
UNIVERSITY OF CALIFORNIA
College of Natural Resources

FALL 2016

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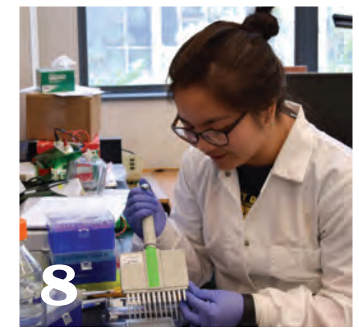
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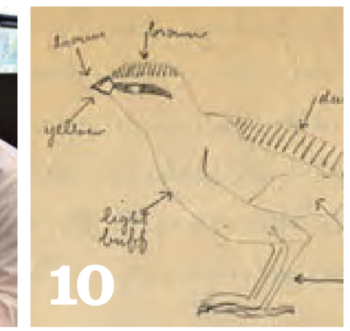

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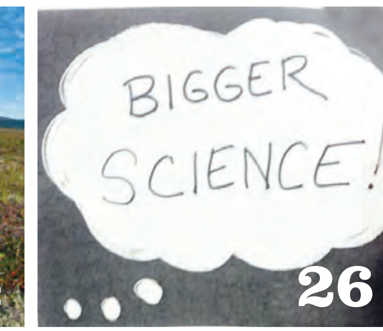

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ONLINE

VIDEO

Berkeley professors participating in the Big Ideas @CNR program explain their innovative suggestions for making real change.

Go to nature.berkeley.edu/big-ideas

Target Found for Triple-Negative Breast Cancer

Graphic representation of cancer cells.

College of Natural Resources researchers have found a long-elusive Achilles' heel within "triple-negative" breast tumors, a common type of breast cancer that is difficult to treat. Such cancers account for about one in five instances of the disease, and they are deadlier than other forms of breast cancer, in part because no drugs have been developed to specifically target their tumors.

"We were looking for targets that drive cancer metabolism in triple-negative breast cancer, and we found one that was very specific to this type of cancer," said **Daniel K. Nomura,** an associate professor of nutritional sciences and toxicology (NST) and of chemistry. Nomura was the senior author for the study, which was published in *Cell Chemical Biology* last spring.

Tumor cells develop an abnormal metabolism, which they rely on to get the energy boost they need to fuel their rapid growth. In its study, Nomura's research team used an innovative approach to search for active enzymes that triple-negative breast cancers use differently for metabolism than other cells and even other tumors.

The team discovered that triple-negative breast cancer cells rely on vigorous activity by an enzyme called glutathione-S-transferase Pi1. The scientists then used a drug-like molecule named LAS17 to successfully target this vulnerability, killing cancer cells in the lab and shrinking tumors in mice.

The team intends to continue studying LAS17, Nomura said, the next step being to study tumor tissue resected from human triple-negative breast cancers and transplanted directly into mice.

The study's authors also included NST's **Sharon Louie, Elizabeth Grossman, Lucky Ding, Tucker Huffman,** and **David Miyamoto;** Roman Camarda and Andrei Goga of UC San Francisco; and Eranthie Weerapana and Lisa Crawford of Boston College.

— ADAPTED FROM AN ARTICLE BY JEFFREY NORRIS

The Secret Language of Microbes

PHOTOS: Courtesy of N. Louise Glass

The fungus *Neurospora crassa* colonizing a burned tree (left) and a microscopic view of the fusion of germlings.

Fungi communicate only via chemical signals, but, like humans, they appear to use different dialects. This discovery came from a Berkeley study of the filamentous fungus *Neurospora crassa*, a red bread mold that has been observed in the laboratory for nearly 100 years. The paper was published last spring in *PLOS Biology*.

Many fungi, including *N. crassa*, grow as filaments or hyphae that often fuse to form an interconnected network. Hyphal networks have been shown to be important to many fungi, including the mycorrhizal fungi that form associations with plant roots, sharing nutrients.

The study's senior author, **N. Louise Glass,** a professor in the Department of Plant and Microbial Biology, said that the finding could help scientists understand how fungi communicate and cooperate for destructive purposes, such as plant diseases and animal mycoses, as well as beneficial purposes, such as symbiotic associations with plants.

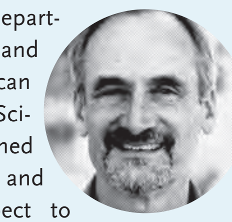
"Our findings reveal a heretofore underappreciated complexity in fungal communication," said Glass. "We have only scratched the surface on the communication and interactions of these enigmatic organisms."

— ADAPTED FROM AN ARTICLE BY ROBERT SANDERS

NEWS

FACULTY ACCOLADES

Professor **Kris Niyogi,** chair of the Department of Plant and Microbial Biology, was elected to the National Academy of Sciences in May. Niyogi studies photosynthetic energy conversion and its regulation in algae and plants.



Professor **Steven Beissinger** of the Department of Environmental Science, Policy, and Management was named to the American Association for the Advancement of Science. He was cited for his distinguished contributions to conservation biology and avian population biology, with respect to endangered species, climate change, avian parental care, and long-term studies of tropical parrots.

Professor **Hei Sook Sul** of the Department of Nutritional Sciences and Toxicology was one of six UC Berkeley faculty members selected as Fulbright Scholars last year. During the yearlong fellowship, she conducted research at the Institute of Genetics and Molecular and Cellular Biology and the University of Strasbourg in France.

Reconnecting Native Peoples with Native Foods

Karuk Tribe food technician Ben Saxon shows young Klamath Basin residents how to press and mount plant specimens.

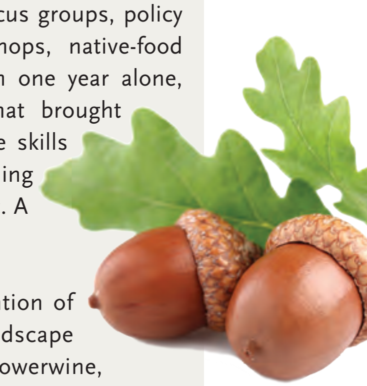
PHOTO: Megan Mucioki/UC Berkeley

In most Native American communities around the country, residents are more than twice as likely as the general population to suffer from type 2 diabetes. The Native people in the Klamath Basin, a river basin that runs from Southern Oregon into the northern part of California, are no exception—they suffer from a range of diet-related illnesses. In some parts of the region, the nearest grocery store is a two-hour drive away, qualifying these areas as "food deserts."

Today, the Klamath Basin is home to nearly 10,000 Native Americans, including members of the Karuk, Yurok, and Klamath Tribes. But the foods and food-related traditions of their ancestors have almost disappeared. These tribes once subsisted sustainably on the fertile land adjacent to the Klamath River. They fished for salmon, hunted for elk and deer, and gathered nuts and berries. Colonization gradually changed all that, with mining, logging, and dams that degraded the natural environment.

Now, the Klamath Basin Tribal Food Security Project is trying to ensure that these native foods are restored for younger generations. **Jennifer Sowerwine** (a cooperative extension specialist in the Department of Environmental Science, Policy, and Management) and her husband, **Tom Carlson** (a professor in the Department of Integrative Biology) are working with other Berkeley faculty and graduate students, as well as leaders in the Klamath Basin tribal communities, to identify the major barriers to producing native foods in the region. Currently in its fourth year of a five-year, $4 million grant from the U.S. Department of Agriculture, the group is seeing real results.

So far, more than 4,000 people have taken part in community garden workshops, surveys, focus groups, policy discussions, food production workshops, native-food camps, and after-school programs. In one year alone, nearly 400 workshops were held that brought together tribal elders with subsistence skills and tribal youths interested in learning how to butcher, can, bake, and ferment. A K–12 program is in the works.



There has been "a really strong retention of knowledge and wisdom around landscape management" among elders, said Sowerwine, especially when it comes to such practices as harvesting food, prescribed forest burns, and basketry.

— ADAPTED FROM AN ARTICLE BY ALIX WALL, ORIGINALLY PUBLISHED ON *CIVIL EATS*

A Tiny House in Berkeley's Back Yard

When about 190 nations attended the 2015 United Nations Climate Change Conference (known as COP21) in Paris last winter, more than half a million activists marched in cities around the world. At the summit itself, three UC Berkeley students presented a project at the Global University Climate Forum, sponsored by the International Alliance of Research Universities. Leading the contingent was **Ian Bolliger,** a PhD student in the Energy and Resources Group (ERG).

The students' project, called Tiny House in My Back Yard (THIMBY), is an off-grid micro-house, which they're designing and building with sponsorship from ERG and campus student-supported groups like the Green Initiative Fund. THIMBY addresses two issues: affordable, sustainable housing and carbon emissions. "Consensus on a global scale can never be sufficiently ambitious," Bolliger said. "We need to take a bottom-up approach, with our own boots on the ground."

Bolliger and an interdisciplinary team of both undergraduate and graduate students from more than 12 Berkeley departments are working on the house's construction at the Richmond Field Station. They plan to have the structure completed by October 2016, to compete in the Sacramento Municipal Utility District's 2016 Tiny House Competition.

The 170-square-foot, 100 percent solar-powered home on wheels will feature such cutting-edge energy- and water-efficiency systems as a living wall to filter household gray water and a composting toilet and solid waste "oven" to allow for composting of human waste. A lithium-ion battery will store energy from eight solar panels, and an air-to-water heat pump will provide hot water and space heating through a hydronic radiant floor system.

In collaboration with the Bay Area Environmentally Aware Consulting Network, the team has developed a tool to quantify the house's embedded carbon emissions, which it estimates to be around 18 metric tons of carbon dioxide equivalent (tCO2e). A typical 1,750-square-foot house has around 80 tCO2e of embedded emissions, plus additional yearly emissions associated with natural gas and grid electricity use. Finally, THIMBY will be small enough to fit in the back yards of most urban lots.

— KIRSTEN MICKELWAIT

The THIMBY student team takes a break from constructing its tiny house in July 2016. From Left: Kenny Gotlieb, Ian Bolliger, AJ Glassman, Sabrina Werts, Laney Siegner, and Oriya Cohen.
PHOTO: AJ Glassman

An artistic representation of the tree of life, with many new groups of bacteria on the left, the uncultivable bacteria at upper right (purple), and the archaea and eukaryotes (green)—including humans—at lower right.

ILLUSTRATION: Zosia Rostomian

Wealth of Unsuspected New Microbes Expands Tree of Life

Imagine that you suddenly discovered 1,000 new ancestors or relatives in your family tree. That's essentially what's happened to the "tree of life," a system of illustrating how earthly life has evolved and diversified.

Over the past 15 years, UC Berkeley researchers have discovered more than 1,000 new types of bacteria and archaea lurking in Earth's nooks and crannies. Now, the tree has been dramatically restructured to account for these newly known microscopic life-forms.

The revised tree, published online in April in the new journal *Nature Microbiology,* reinforces once again that the life we see around us—plants, animals, humans, and other so-called eukaryotes—represents a tiny percentage of the world's biodiversity.

"The tree of life is one of the most important organizing principles in biology," said **Jill Banfield**—a UC Berkeley professor of earth and planetary science and of environmental science, policy, and management, and one of the article's co-authors. Much of this microbial diversity remained hidden until the genome revolution allowed researchers like Banfield to search directly for genomes in the environment, rather than trying to culture microbes in a lab dish. Many of the microbes can't be isolated and cultured, because they're not able to live on their own: They must beg, borrow, or steal stuff from other animals or microbes, as either parasites, symbiotic organisms, or scavengers.

"The new depiction will be of use not only to biologists who study microbial ecology," said Banfield, "but also to biochemists searching for novel genes and researchers studying evolution and earth history."

— ADAPTED FROM A STORY BY ROBERT SANDERS

SUBJECT:
Why I Do Science

PHOTO: Mei Mei

ENTRY BY: John Coates

ENTRY #: 015

I was raised in Ireland by parents who valued education, but a learning disability made school a struggle for me. Supported by my parents and teachers, I eventually learned to read in fifth grade, and I especially enjoyed a series of children's detective stories by Enid Blyton. The father character was a scientist who worked from his basement, and I naively imagined a life of experimenting all day with no reading or writing requirements! My dreams were reinforced by an eccentric but wonderful teacher who believed that science is a subject of demonstration rather than book learning. He often woke us up in morning classes with minor explosions, cool color reactions, or extreme odors. I was hooked.

I entered university in the inaugural class of Ireland's first undergraduate program in biotechnology and focused my studies on process engineering. A brief stint in industry after graduation convinced me that my future lay elsewhere, and I subsequently completed a PhD in microbiology and anaerobic wastewater treatment before moving to the United States to pursue postdoctoral research in bioremediation and fossil fuel recovery. Here I was able to merge my disparate interests in engineering and microbiology into exciting, interdisciplinary research projects.

My current research program seeks to balance society's need to provide ecological protection while maintaining stable economic growth. I'm fortunate to be working during a revolutionary period in science in which we've seen technological advances in next-generation sequencing, computational analysis, and genome editing. Further, being part of a world-class campus is truly inspiring. Discussing my research with Nobel laureates and members of the National Academy of Sciences is always exhilarating. Even so, I still find the year's first undergraduate class to be the most intimidating: Our deeply curious students constantly remind me how little we really know.

Microbiology professor **John Coates** investigates the removal of toxic materials and by-products from the environment. He is the recently appointed academic director of the Energy Bioscience Institute.

CNR Offers Global Executive Education Programs

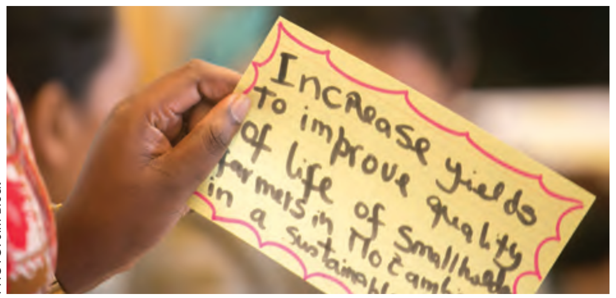


PHOTO: Jim Block

Through expert-led workshops and conferences, the College of Natural Resources' International and Executive Programs (IEP) equips leaders from around the globe with the tools they need to create positive environmental, societal, and economic change. Established in 2014, IEP leverages the unparalleled faculty of the College and their network of leaders in industry and government to provide a stimulating environment for learning and innovation.

IEP is now the home of the renowned Beahrs Environmental Leadership Program, which boasts 615 participant alumni. IEP's open enrollment and custom programs offer career professionals the chance to expand their knowledge and networks in the fields of climate change, environmental policy and economics, energy, agrifood, supply chains, human health and safety, sustainable development, natural resources management, and biodiversity.

According to director **Mio Owens,** IEP is set to expand programming significantly in the coming year. "The professionals who come to IEP are already driven, ambitious, and on a quest to leave a mark in their field," she said. "IEP offers programs that support them in transforming their aspirations into accomplishments that serve the greater good and fulfill CNR's commitment to delivering real solutions to the global community."

JOIN US FOR UPCOMING IEP EVENTS

- Agrifood Supply Chain Programs: *November 2016, Germany, and April 2017, Berkeley*
- Spatial Data Science: *Spring 2017, Berkeley*
- Modern Competitive Strategy Program: *March 2017, Thailand*
- Environmental Leadership Short Course: *May 2017, Singapore*
- Beahrs Environmental Leadership Program: *Summer 2017, Berkeley*
- Economic Tools for Conservation: *Summer 2017, Berkeley*

For more details visit iep.berkeley.edu.

Berkeley's Newest Nobel Spot Is Reserved for Bikes

One of the highlights of a Berkeley campus tour is spotting the parking spaces reserved for Berkeley's 10 Nobel laureates. Now there's a brand-new "NL" parking spot, and it can be used by anyone. Anyone, that is, who commutes to campus by bicycle.

The Nobel laureate bike parking spot, which was installed last spring, sits to the left of a cluster of bike racks outside the entrance to the Free Speech Movement Café. The sign honors Berkeley faculty who contributed to the United Nations' Intergovernmental Panel on Climate Change (IPCC), which shared the Nobel Peace Prize with former vice president Al Gore in 2007. The Nobel was given for joint efforts by Gore and the IPCC "to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change."

Berkeley's contributors to the IPCC research included **Dan Kammen,** a professor of energy and the founding director of the Renewable and Appropriate Energy Laboratory, whose tongue-in-cheek comment at a 2013 panel discussion on climate change at the Goldman School of Public Policy planted the idea for an NL bike spot.

"Dan joked that while Nobelists get NL parking spots, maybe [the Berkeley IPCC contributors] should at least get an NL bike rack," said **John Wilton,** who was the vice chancellor for administration and finance at the time and helped organize and introduced the 2013 panel. "Dan and I thought it would be a good, lighthearted way," he added, "of recognizing both the contribution made by Berkeley to the Nobel Prize and the virtues of cycling as a way to commute."

— ADAPTED FROM A STORY BY GRETCHEN KELL

Idea Incubator

The challenge of conserving our natural resources—while also sustaining healthy and equitable human societies—is one that requires large, innovative initiatives that can make significant impacts. Last spring, the CNR Executive Committee of the Faculty envisioned a new program to help the College of Natural Resources incubate just these types of innovations, and Big Ideas @CNR was born.

Created by faculty who are experts in their fields, the resulting six ideas are about making real change. They offer visions for sustainability, biodiversity, and support for the earth's resilience even as we put our ecosystems under ever-increasing stress. They imagine a concentrated effort to create a sustainable bioeconomy—involving agriculture, agritourism, aquaculture, biotechnology, biofuels, green chemistry, and more—that allows for the use of renewable biological resources while ensuring biodiversity and environmental protection. And they propose combating chronic diseases linked to obesity through a comprehensive consideration of research and clinical studies in the realm of metabolic systems, combined with education and outreach on diet and nutrition.

Check out nature.berkeley.edu/big-ideas for videos detailing each big idea.

CNR'S BIG IDEAS

Resilience Measured: The Key to a Sustainable Future
John Battles, Forest Ecologist

Berkeley Center for Metabolic Health and Disease
Andreas Stahl, Metabolic Nutritional Biologist

Water-Food-People Nexus
Dennis Baldocchi, Bioenvironmental Engineer

An Institute for Parks, People, and Biodiversity
Steven Beissinger, Conservation Biologist

Building the Bioeconomy
David Zilberman, Environmental Economist

Understanding and Conserving California Biodiversity in a Changing Climate
Patrick O'Grady, Biologist and Geneticist

Five Key Lessons

L&S/ESPM C46

Climate Change and the Future of California

Worsening drought, heat waves, and severe wildfires are just a few of the ways in which climate change is already affecting California. Last spring, environmental science, policy, and management professor **Whendee Silver** teamed up with **David Ackerly** (integrative biology), **David Sedlak** (civil and environmental engineering), and **Steve Weissman** (law and policy) to provide students with an interdisciplinary perspective on this increasingly pressing issue. They examined existing and potential impacts to the state's environment, inhabitants, and economy and considered solutions that could reduce the rate and magnitude of climate change, as well as the severity of its impacts.

1 **The challenge is multidisciplinary.** Concentrating on California exemplifies how all the important ideas—from the fundamentals of physical science to public policy and governance—are intertwined.

2 **Global challenges, local response.** Understanding place-specific geology, microclimates, precipitation patterns, groundwater resources, plant populations, community values, and institutional structures is critical to crafting effective climate mitigation and adapting to changing conditions.

3 **It takes a village—or several villages.** Issues such as sea-level rise cannot be solved by a single community. Achieving the right level of regional coordination requires an understanding of the powers and limitations of existing governmental institutions and the opportunities to build stronger bonds between them.

4 **Focus on solutions.** We've all heard the dire predictions, and more bad news doesn't help anyone. Progress is being made on many fronts: Engineers are advancing new technologies in the realms of renewable energy, electric cars, and water recycling, while our leaders are reforming the roles that governments at city, county, state, and federal levels play in tackling different aspects of the problem.

5 **Hope lives in California.** The state is an economic power and home to Silicon Valley, excellent universities, cultural diversity, and many natural wonders. Californians value environmental responsibility, and our politicians are among the world's leaders in acting to meet the challenges of climate change.

ON THE GROUND

A SAMPLING OF

Undergraduate Student Research

Funded directly by our generous alumni, parents, and friends, the Sponsored Projects for Undergraduate Research (SPUR) program provides grant money for CNR faculty and undergraduate students to collaborate on research projects. Students may apply to join a research study run by a professor or may design their own project and be paired with a faculty or postdoc mentor. Since the program was launched over a decade ago, more than 1,200 students have participated.

PHOTO: Courtesy of Alyssa E. Thompson

COMBATING CAMPUS FOOD INSECURITY

As part of the UC Berkeley Food Security Committee's initiative to address food insecurity on campus, in spring 2016 the Department of Nutritional Sciences and Toxicology (NST) offered a new course on preparing healthful meals, taking into consideration student limitations like food availability, budget, and time. **Sabrina Lee,** an undergraduate in the dietetics specialization of the nutritional sciences major, worked with course instructors and the director of the dietetics program, **Mikelle McCoin,** on course implementation and an evaluation of the course's impact on student skills, knowledge, and attitudes. Lee developed a research poster on the course and presented it at the California Academy of Nutrition and Dietetics' annual meeting in Riverside.

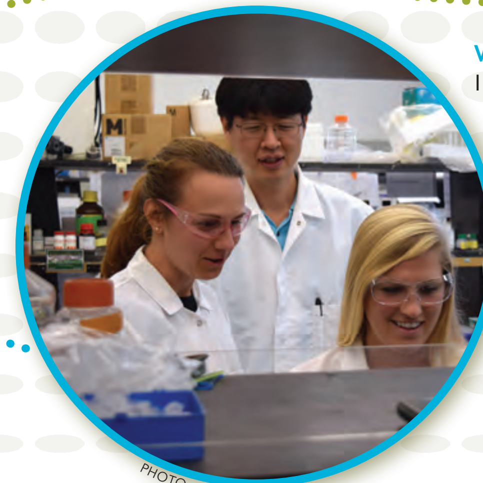


PHOTO: Julie Van Scoy

VITAMIN A AND ENERGY METABOLISM

In summer 2016, **Marta Vuckovic** and **Hong Sik Yoo,** postdoctoral research fellows in NST professor **Joe Napoli**'s lab, advised two undergraduates on research examining vitamin A metabolism and its relationship to energy metabolism in the context of obesity, diabetes, osteoporosis, and neurodegenerative diseases like Parkinson's and Alzheimer's. Students **Adrienne Rodriguez** (microbial biology) and **Emily Devericks** (nutritional sciences - toxicology) learned about histology analysis and gene expression and received hands-on training in mouse-colony management and other techniques used in molecular biology and cell-culture research.

CIRCADIAN CLOCKS AND PLANT MOVEMENT

Genetics and plant biology majors **Alyson Ennis** and **Kristen Poen** worked with **Benjamin Blackman,** an assistant professor in the Department of Plant and Microbial Biology, on a project researching the solar tracking of sunflowers. The developing disks of sunflower plants move to face the sun throughout the day, but when the flowers bloom, they stop moving and face east. To begin to understand why, Blackman and the students grew many types of domesticated and wild sunflowers in the field, keeping track of their daily stem movements and where blooms faced when they matured.

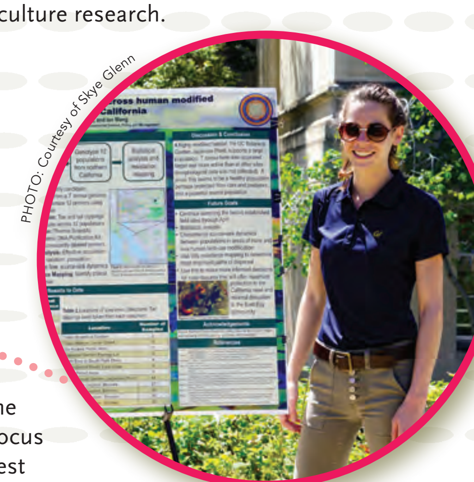


PHOTO: Courtesy of Skye Glenn

LAND-USE MODIFICATION AND THE CALIFORNIA NEWT

Every rainy season, Berkeley's Tilden Regional Park closes roads from November to April to protect migrating California newts (listed by the state as a species of special concern) as they crawl to breeding ponds to mate. In spring 2016, ESPM assistant professor **Ian Wang** mentored molecular environmental biology major **Skye Glenn** on a project she designed to analyze genetic diversity in different newt populations, as well as how different parts of the landscape, including roads, impede the movement of newts between different breeding ponds. The information she collected will allow for better management of limited resources and help focus conservation efforts where they'll be most effective, maintaining the greatest amount of diversity and gene flow while minimizing disruption to residents.

SUSTAINABLY REMEDIATING CONTAMINATED SOIL

Three undergraduates joined environmental science, policy, and management (ESPM) professor **Celine Pallud**'s lab to assist with research on the fern *Pteris vittata*'s ability to remove arsenic from soil by gathering the chemical into its fronds. Through their participation in field and greenhouse experiments, **Kristen Chinn** (conservation and resource studies and geology), **Marcella Depunzio** (environmental sciences), and **Aizah Khurram** (molecular environmental biology) gained experience in field-experiment design and setup, sampling soil and plant tissue, and preparing samples for laboratory analysis. Some of their soil sampling will help community organizations determine how a local vacant lot can be used for urban agriculture.

PHOTO: Julie Van Scoy

ASSESSING RECYCLING AND CONVENIENCE CENTERS

Jared O'Shaughnessy, a conservation and resource studies major, and **Kevin Ong,** an environmental sciences major, worked on a team led by agricultural and resource economics (ARE) professors **Sofia Berto Villas-Boas** and **Peter Berck** to analyze the efficacy and efficiency of California's "Convenience Zones" for recycling centers, which were established as part of Governor Jerry Brown's California Beverage Container Recycling and Litter Reduction Act. The students geo-coded the centers, then combined their data with zip code demographics and the volume capacity of each recycling center to inform the design of user surveys.

CALIFORNIA'S DROUGHT: MEASURING THE USES AND BENEFITS OF WEATHER DATA

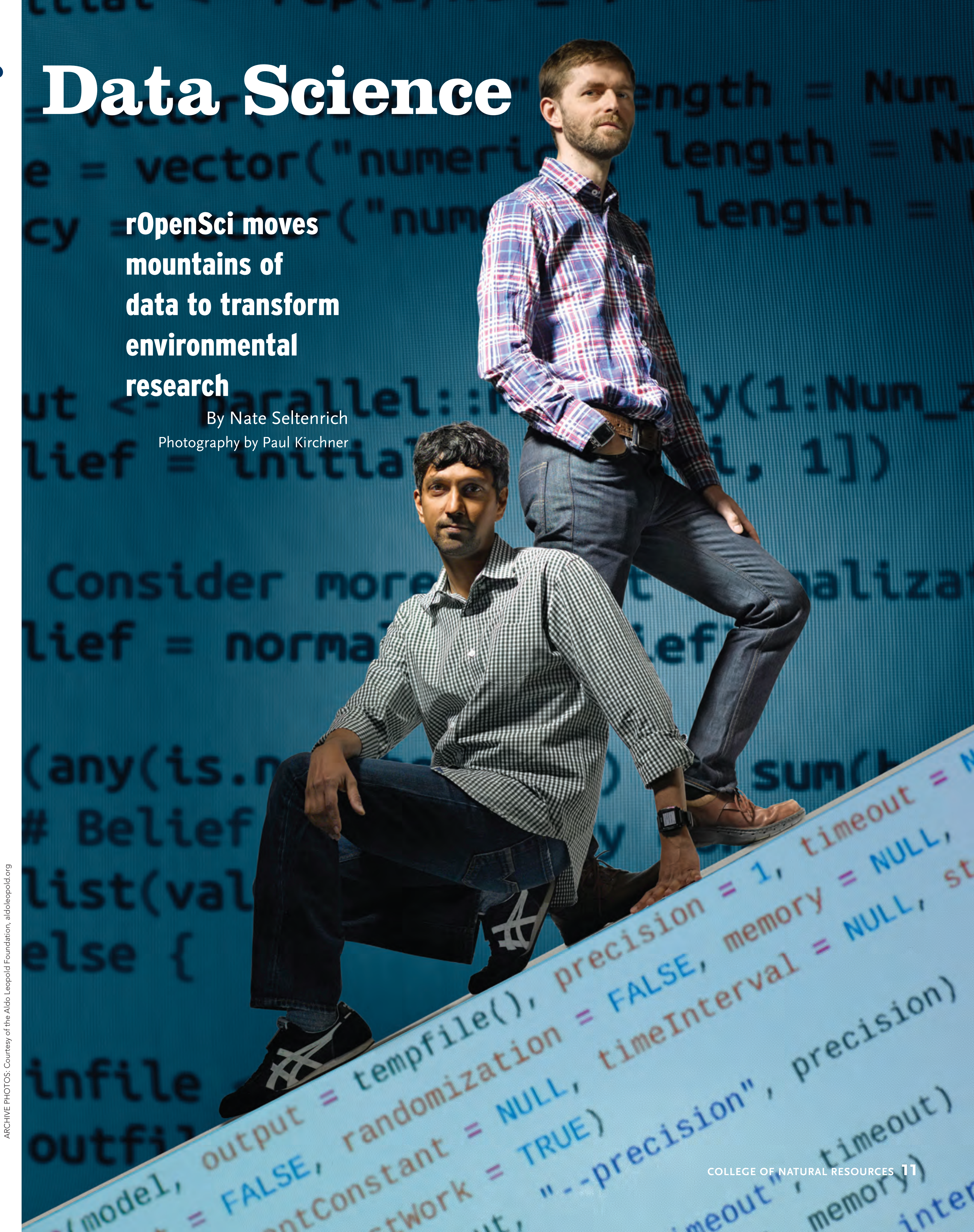
Twenty students joined ARE professor **David Zilberman**'s study of the 150 weather stations across California that have provided information for irrigation decisions in agricultural and urban settings since 1982. The group designed surveys, conducted interviews, and compiled user-feedback forms to analyze weather-station use and the resulting overall impact on water and energy use and greenhouse gas emissions. Gaining real-world practice with survey design and implementation, the students also contributed to a growing body of literature on drought preparation that becomes increasingly important as the effects of climate change intensify.

SUPPORT SPUR

Visit nature.berkeley.edu/give-spur to help us bring another decade of diverse research opportunities to CNR students. For other ways to get involved, contact Andrew Judd: judd@berkeley.edu, (510) 642-6707.

ICONS: thenounproject.com: Hugo Alberto; Aldric Rodríguez Iborra; Blaise Sewell; Alex Vaughn; Arthur Shlain; Tiago Franco; Yorlmar Campos; Rick Pollock

Scaling the Heights of Data Science



rOpenSci moves mountains of data to transform environmental research

By Nate Seltenrich

Photography by Paul Kirchner

America's archetypal ecologist may be someone like Aldo Leopold: binoculars to the eyes, boots on the ground, equally at ease with pad and pencil or rod and reel, a thinking man at home in the field. But this romanticized vision overlooks the myriad challenges and tensions facing the modern ecologist, who must do more than traipse through fields and forests observing flora and fauna. He or she must also climb mountains of data, run complex computer models, and transcend space and time to account for a planet in flux due to climate change.

Perhaps the quintessential ecologist of the 21st century looks more like **Carl Boettiger.** A 31-year-old assistant professor of eco-informatics in the Department of Environmental Science, Policy, and Management, Boettiger believes that the key to the field's future—and, in a sense, to humanity's proper stewardship of the natural world—is technology, and more specifically, technology's ability to unify a global community of researchers and their data.

"We're at a time of unprecedented access to data and increased ability to share and move large amounts of data," Boettiger says. "I think this has the potential to be transformative in the ecological and environmental sciences." This transformation, he explains, is not a matter of altering the core purpose of ecology—to understand how natural systems function and, often, to use this understanding to inform management and policy decisions—but rather of expanding researchers' perspectives to include new variables, new data sources, and new environments.

Connecting the dots

Say you're a researcher forecasting wildfire severity in the Jeffrey pine forests of the Eastern Sierra. One species of native ant is known to clear pine needles from around its nests at the bases of some trees, thus reducing the likelihood that those trees will burn. Wouldn't you want to take that into account, especially if someone else had already collected the data and shared it online?

The ethics of the new ecologist, Boettiger believes, are born not of solitude in the great outdoors or the lab, but rather of cooperation and sharing. They're rooted in software development as much as in hunting and fishing, drawing less from religion and philosophy and more from mathematics and statistics.

Traditional methods in ecology rely on extrapolating from limited data sets collected firsthand. What Boettiger espouses—through his course Data Science in Ecology and the Environment, his own research into ways of improving ecological decision-making, and an open-science software platform called rOpenSci that he helped launch in 2011—is a more inclusive, communal approach. "We want to do the classic science, and then we want to scale it up, learn more from it," he explains. "We just want to take the next step up."

Boettiger came to this way of thinking naturally but unpredictably. As an undergraduate studying physics at Princeton, he didn't even know that ecology was an academic field. By the time he learned, it was too late to switch majors. After graduating, he studied ecology at UC Davis, where he subsequently received funding to do graduate research at the Lawrence Berkeley National Laboratory, aided by the U.S. Department of Energy's "humongous" computers there. "That forced me, almost against my will, to think more computationally," he says.

In 2012, he completed his PhD in population biology at Davis and headed to UC Santa Cruz, where, as a postdoctoral scholar, he explored themes that continue to dominate his research and teaching today: moving advanced ecological concepts and data science out of the realm of ideas and into real-world management and decision-making.

This progression occurred against the backdrop of a larger evolution in science itself. Thanks to new tools for data collection like microsensors—capable of collecting tiny bits of data more accurately and efficiently than older instruments—and remote sensing, wherein

ARCHIVE PHOTOS: Courtesy of the Aldo Leopold Foundation, aldoleopold.org

"I think this has the potential to be transformative in the ecological and environmental sciences."
— Carl Boettiger

"Once people see this, they get more excited about getting involved and participating in open science."
— Karthik Ram

satellite-borne devices record massive amounts of information about the earth's atmosphere and surface from thousands of miles away, the pool of pertinent data potentially available to researchers is growing every day.

Making "scaled-up science" more accessible

Added to this enormous data pool is climate change and its seemingly endless perturbations of the natural world—some understood, some still a mystery, but all representing a massive amount of data.

Consider California's declining steelhead trout population. At a certain age, the fish decide whether to stay in their home river or head to the ocean. Boettiger says there's growing concern that climate change is influencing their decision: that shifting temperatures are confusing the fish. This could have important consequences for how we manage fish populations—and thus requires a careful consideration of how, exactly, temperatures in their territory are changing.

But that doesn't have to mean months or years of data collection; the rOpenSci website offers easy access to the National Oceanic and Atmospheric Administration's exhaustive temperature and climate database. For that matter, rOpenSci is also tapped into AntWeb, the world's largest database of ant info.

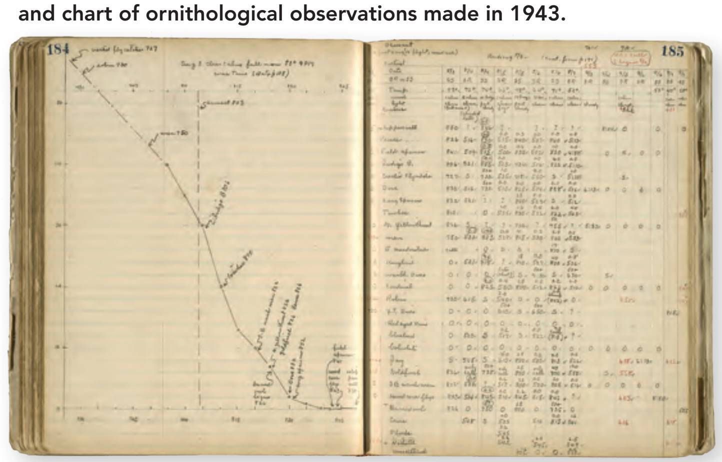
The project's straightforward interface and use of the R programming language, which has been widely adopted by scientists and statisticians around the world, lower the bar for researchers to access and make better use of sources like these, as well as share their own field data. The bigger leap toward embracing open science is conceptual, not technical.

"The goal of rOpenSci has been to lower the barriers, so if you're just curious about something like how global average temperatures over the last 30 years have affected your field site, you can just pull up the data and look at it," Boettiger says. Simply put, the project aims to make "scaled-up science" more practical than ever before.

Expanding to other disciplines

Some researchers still aren't convinced, however, and won't be until they can see a direct benefit, says rOpenSci cofounder **Karthik Ram**, a quantitative ecologist at the Berkeley Initiative for Global Change Biology (BiGCB) and a fellow at the Berkeley Institute for Data Science. So it helps that many of the site's tools aren't geared toward sharing or consuming data at all. In addition to those functions, rOpenSci offers software tools for proofing, organizing, visualizing, correcting, or otherwise processing data in an efficient way, often using statistical methods or accessing other databases. These features prove to be an easy sell—and a sort of icebreaker for rOpenSci's broader purpose.

From ecologist Aldo Leopold's journal: A hand-drawn graph and chart of ornithological observations made in 1943.



"We're helping people clean up their existing data based on current information and automating many of those things that they would normally do by hand over many months," Ram says. "Once people see this, they get more excited about getting involved and participating in open science."

Growth in rOpenSci's early years has been rapid, though "not quite exponential," he concedes. To date, rOpenSci has registered about 100 contributors—power users who participate in the building of this online ecosystem, so to speak, by writing their own software or improving existing tools. But it has many thousands of users who log on simply to access those tools, of which there are now about 75.

Recent private funding has allowed rOpenSci to broaden its reach beyond its core audience—which is scientists studying the natural world—into a wide range of disciplines. It has developed new tools and run workshops at several conferences and

Today, free online fish-catch data help researchers quickly assess the impact of fisheries on marine ecosystems worldwide.

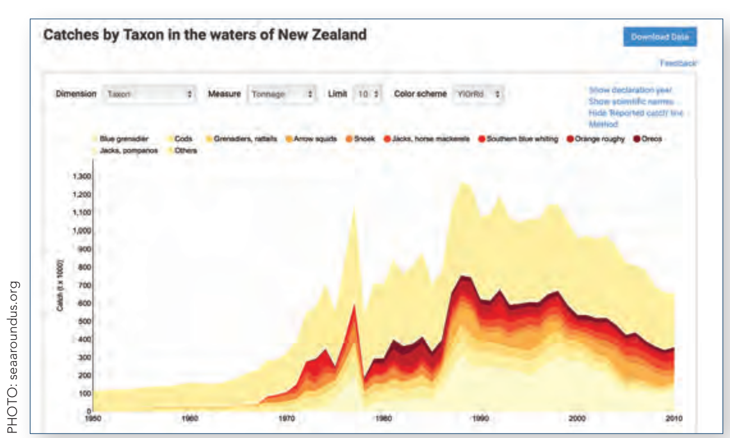


PHOTO: seaaroundus.org

universities as far away as Switzerland. And it has expanded its team from two to six.

Indeed, open science offers immense appeal, and utility, to people working in a host of fields. Look no further than Boettiger's Data Science class for proof: About half of the students are majoring in math, statistics, computer science, and engineering, while the other half come from nontechnical fields like business, anthropology, biology, and ecology. (Like the campus-wide data-science initiative of which it is a part, the class is geared toward freshmen, though in its first year it included a mix of freshmen and sophomores.)

Boettiger embraces this diversity in his environment-centric class, which includes units on climate change, fisheries collapse, megafaunal extinctions, and ecological networks. Students learn to locate, access, and understand messy, real-world data sets, writing software tools that allow them to "walk through the data" and "discover the story themselves," shaping research from a "raw forest" of information. Boettiger calls this "the art of data carpentry," a skill rarely taught to undergraduates despite an abundance of material. "Data science is not just a professional skill that we need to give to graduate students who are closer to research; it's an important part of a liberal education," he says.

From undergrads to managers of wildfire risk or steelhead trout habitat, Boettiger believes that working with big data is not just a new skill but a fundamental one. "We're lucky we already have science informing policy, but we need to inform science that it can use all of the available data to make better decisions," he says. "We can do so much better if we have more data and we know how to use it." BT

Measuring and Modeling

Two Berkeley projects assess the present and predict the future of Earth's ecosystems

By Wallace Ravven

Researchers examine a visualization made by the Moorea Island Digital Ecosystem Avatar at a physical-modeling workshop in Zurich. PHOTO: Neil Davies

Harnessed to a 100-foot-high metal tower surrounded by conifers in Colorado's Rocky Mountains, a research technician checks sensors that measure how fast the trees and the atmosphere are exchanging carbon dioxide. A world away on the French Polynesian island of Moorea, researchers scrutinize the threat that the same greenhouse gas poses to the tiny organisms that make coral.

Two centuries of burning carbon-rich fuels have pushed global greenhouse gas levels higher than they've been in more than half a million years. The warnings are familiar: Global warming and increased ocean acidity will likely bring rising seas, dying corals, struggling wildlife, and disrupted coastal communities.

But how soon will disruptions come, and how problematic will they be? The urgent need for answers requires refined models of global climate change and its impacts. And the models need data—a great deal of data, drawn from ecosystems ranging from alpine treetops to delta wetlands to tropical seas.

"If we're going to live sustainably on the planet—on this island in space—we need a much deeper grasp of how ecosystems function and our likely impact on them," says **Neil Davies**, executive director of Berkeley's Richard B. Gump South Pacific Research Station, on Moorea.

Davies leads one of two ambitious and vastly different research projects in which Berkeley scientists are applying advanced technologies and intense analyses to measure an array of biological and physical processes in unprecedented detail, to refine models of likely local and global change.

BUILDING A DIGITAL AVATAR

The younger project is the Island Digital Ecosystem Avatar, or IDEA. It was launched in 2015 to generate, as Davies puts it, "digital models of island ecosystems—islands in silico." It's a collaborative effort by UC Berkeley; the Moorea-based French Insular Research Center and Environment Observatory; the Swiss Federal Institute of Technology; Oxford University; and UC Santa Barbara, which leads the National Science Foundation's Moorea Coral Reef Long-Term Ecological Research site.

Scientists from these and 18 other institutions are focusing intensely on the Moorea ecosystem, from its reefs to its green-cloaked peaks. Their conception of the ecosystem includes not only the organisms and their physical environment but also social-ecological systems—the local population's resource use and economy.

The pioneering project is intended to develop a model of island ecosystem dynamics in order to inform still-larger models of the impacts of global climate change. Davies expects that the effort to understand the true ecology of a single populated island will provide a template for modeling ecosystem change, both on other islands and, ultimately, on Earth, our island in space.

To convey IDEA's overarching goal, Davies cites fruit flies and nematodes—the model organisms of biomedical research—as an example. "These creatures are not as complex as humans, but they've yielded enormous insights into human biology," he says. "We're developing Moorea as a 'model ecosystem,' and we expect the digital avatar—a computational data science infrastructure—to provide insights that can be applied to other, much larger-scale ecosystems."

Developing the digital ecosystem model involves drawing on dynamic "time series" data ranging from island organisms' genomes to 3-D satellite images of Moorea's entire terrestrial and marine environment. "IDEA is not just a video game," Davies stresses. "We want to put Moorea on a supercomputer, but it must also correspond to how the island works in the

PHOTO: Maheata White

"We're developing Moorea as a 'model ecosystem,' and we expect the digital avatar to provide insights that can be applied to other, much larger-scale ecosystems." — Neil Davies

real world." It makes good sense to concentrate on a limited physical area because it's tractable, he says. Although exuberantly diverse in habitat and species, the island is just 50 square miles—about the size of San Francisco—with a human population of only 17,000. For that reason, it's already one of the best-studied islands in the world.

The IDEA project builds on another ambitious undertaking, called the Moorea Biocode Project, which Davies launched 10 years ago as a first step in building the Moorea model ecosystem. With over $5 million from the Gordon and Betty Moore Foundation, the Berkeley-led collaboration identified and cataloged the genomes of—or at least a snippet of DNA from—every land and sea species visible to the naked eye on Moorea, totaling 6,000 species to date. Biocode involved many College of Natural Resources faculty, graduate students, and postdoctoral researchers, including environmental science, policy, and management (ESPM) professors **George Roderick** and **Matteo Garbelotto**, who coordinated the terrestrial invertebrate and fungal campaigns respectively. "The IDEA project takes a systems approach," Davies says, "and we cannot fully understand systems without a reasonably complete parts list. For an ecosystem, that means all of its constituent species." IDEA investigators are now using Biocode's unprecedented database of marker genes to build a high-throughput "genomic observatory" in which to study how all the organisms interact—for example, through pollination networks and food webs. The effort is, as Davies puts it, "dynamically mapping the island's interactome."

Corals—the canaries in the coal mine

Agriculture and fishing, as well as water and energy consumption, drive a good deal of the ecosystem dynamics on Moorea. In turn, human activities are influenced by those dynamics—for example, logging and increased sediment runoff damage coral reefs and deplete fish populations, and these changes loop back to potentially stress the local economy.

"We all live and act primarily at the local level, and our avatar models must include human communities as critical participants in the system of interactions that constitute a place," Davies says.

Essentially, the IDEA project is an exhaustive assessment of connectivity, mapping the biological and social networks that characterize complex living systems. At the hub of the island's ecological and economic connections are the coral reefs and lagoons that protect Moorea from battering surf and provide nurseries for a spectacular diversity of fish and other marine life vital to the island's economy and the ocean's food web—the rainforests of the sea.

On many tropical islands, sediment and other pollutants pouring in from construction and agriculture degrade the ability of the tiny coral polyps to construct their calcified skeletons. Bleaching induced by warming waters can cause widespread coral die-offs. Another devastating potential: Increased atmospheric carbon dioxide (CO_2) levels are leading to an increase in ocean acidity that might doom many calcifying marine organisms. Lab experiments are already demonstrating that the acidity can dissolve their skeletons, says Davies.

For now, French Polynesia maintains an almost ideal pH and a healthy coral habitat. "That was the case when Captain Cook arrived in Tahiti, and Polynesia is still the sweet spot for coral," he observes. But models show that in 25 or 30 years Polynesia's coral habitat will be only marginally good, and by 2100 its corals are really going to be struggling. "It will be difficult to reverse," he says.

PHOTOS FROM LEFT: iStock; Julie Van Scoy

Changes in land use can boost populations of mosquitoes that carry the dengue and Zika viruses, says George Roderick.

For the most part, researchers don't know if coral species are uniformly vulnerable, or if genetic differences might make some species more resilient. The Biocode project promises to distinguish between closely related corals, allowing lab experiments to determine which genotypes may be the hardiest.

Many species of flora and fauna will find themselves maladapted to new climate-induced conditions, and the changes may occur too fast for genetic variation to catch up. "We might need to have 'assisted migration,'" Davies says. "Like it or not, we're going to be designing ecosystems. We'd better get good at it very quickly."

Looking to invasive species

Changes in land use have ushered in aggressively invasive species, such as the purple-leafed miconia tree, which now dominates parts of Moorea's hillside terrain and alters erosion patterns and water availability. These changes, along with higher temperatures, can boost populations of mosquitoes that carry the dengue and Zika viruses. Rising temperatures allow invasive species such as mosquitoes to expand their ranges and alter interactions among other species, says ESPM's Roderick, an expert in insect invasions and chair of his department. After Biocode, Roderick joined the IDEA project, investigating how breakthroughs in molecular biology and a new generation of genetic technologies could be safely and ethically used for insect control, including the reduction of human exposure to disease without disrupting the surrounding ecosystem.

Researchers found that a 2013 Zika outbreak infected two-thirds of the people in French Polynesia, including Moorea. And it's from this region that Zika traveled to Brazil and the rest of the Americas, most likely via infected people. Such are the consequences of globalization, says Roderick.

Recent hints of a startling cause-and-effect relationship between at least five very different species on Moorea, from mosquitoes to humans, drive home the potential of the IDEA strategy to uncover utterly unsuspected connections. Scientists have noted that coral reefs in French Polynesia bounce back from the impact of cyclones or bleaching events, while those in the Caribbean and some other regions are more vulnerable after these assaults, often decimated by hardy strands of algae that smother the coral polyps.

A key factor in the ecological resilience of Moorea's coral reefs seems to be the fact that coastal development and fishing pressure have not yet undermined the island's herbivorous fish populations. For example, flashy blue and green parrot fish feed voraciously on algae. UC Santa Barbara marine biologists Sally Holbrook and Russell Schmitt, both members of the IDEA consortium, have found that shallow, near-shore lagoons appear to protect parrot fish larvae. This assures a thriving adult population of the algae-eaters, allowing corals to regain their foothold even after severe weather.

Because IDEA scientists investigate so many different levels of interactions, Holbrook and Schmitt learned that the alarming 2013 spike in Zika infections on Moorea may have coincided with a coral die-off in some—but not all—island lagoons. Other investigators noted that the areas of concern were favored fishing sites.

Avatar researchers began making the connections: They suspect that when mosquito-borne viruses sickened family members, the illness prompted people to fish more to pay for mosquito repellents and medical services. This in turn may have reduced the parrot fish populations in these fishing lagoons. As a result, algae growth spiked and corals died.

So buzzing mosquitoes might threaten coral below the surface of the ocean. Who knew? Along the way, people suffer, lagoons are overfished, and algae snuffs out the island's biological and economic engines.

For now, this chain of events remains a working hypothesis, but it shows how integrating interdisciplinary data across an entire system can lead

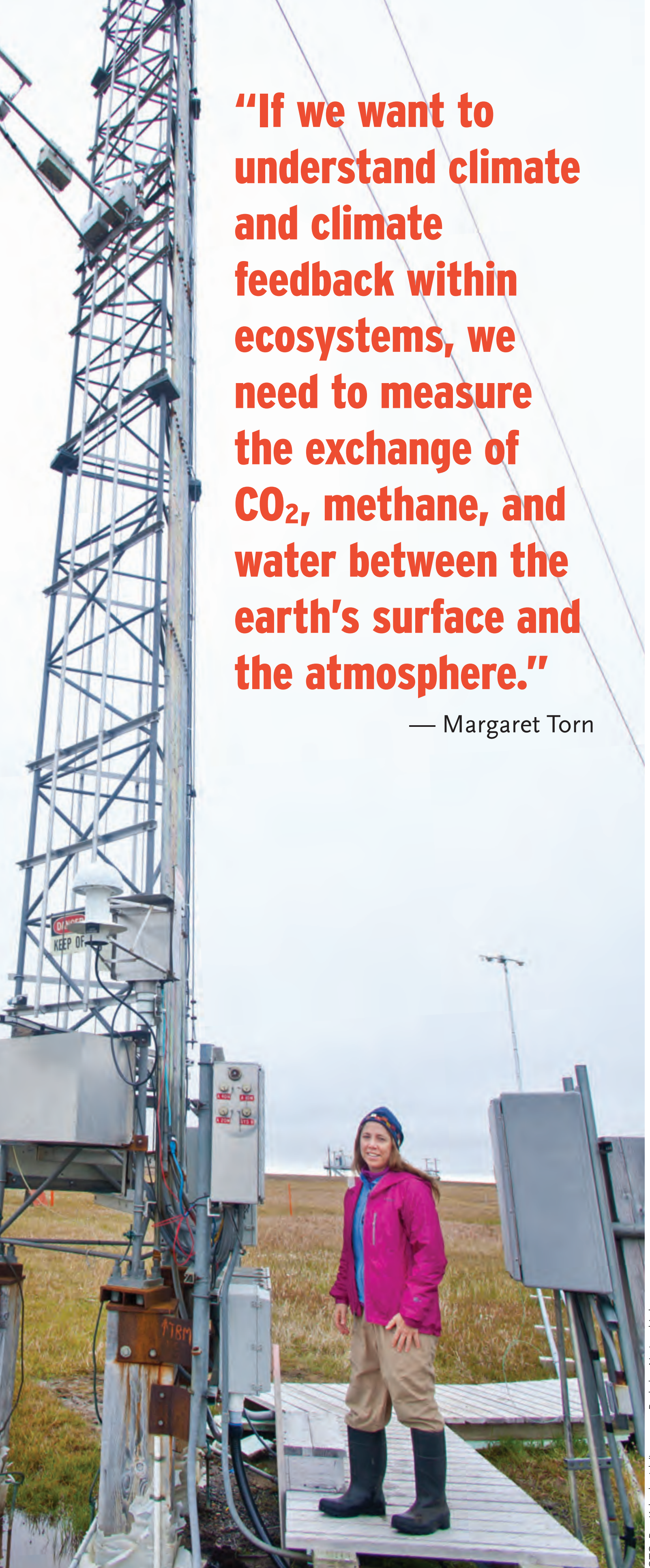


PHOTO: Roy Kaltschmidt/Lawrence Berkeley National Lab

"If we want to understand climate and climate feedback within ecosystems, we need to measure the exchange of CO_2, methane, and water between the earth's surface and the atmosphere."

— Margaret Torn

to new discoveries. The implications extend from health and economics to ecology and ecosystem stability.

"We have everything to gain by recognizing the drivers of ecosystem dynamics both at the local level and across the planet," Roderick says. "Many of the players influence each other in ways we haven't even considered.

"We recognize the overall threats of increased greenhouse gases and globalization, but we need more data at every level to refine our models and predict change and resilience more precisely. That will inform our ability to develop effective responses. This is not a challenge we can ignore."

MEASURING THE CYCLES OF CLIMATE CHANGE

Clearly, to reach their goals, IDEA's scientists need input of all kinds, and they're committed to sharing data and insights with researchers working at different scales. Not surprisingly, climate science is truly a big-data enterprise. It takes intense analysis and increasing collaboration to incorporate the mother lode of data into complex, sophisticated models.

Another research effort, AmeriFlux Management Project, gathers massive amounts of environmental data of the kind that could greatly inform the IDEA model. AmeriFlux aims to refine understanding of how land ecosystems function and how climates and ecosystems interact. The 20-year-old network, managed by the Lawrence Berkeley National Laboratory (Berkeley Lab), integrates data from field stations that monitor carbon dioxide, water, methane, and energy flux in nearly every type of terrestrial habitat—from tundra and savanna to boreal woodlands and tropical forests. It offers data about what controls photosynthesis and plant growth, soil carbon cycling, and the transpiration of water through plants from soil to the atmosphere. Experts in biology, atmospheric science, and biogeochemistry study this interplay at more than 100 mainland research stations from the Arctic to South America.

"Terrestrial ecosystems are the very largest sources and sinks of atmospheric carbon dioxide and water," says **Margaret Torn**, an ecologist, biogeochemist, and leader of AmeriFlux management in Berkeley Lab's Climate and Ecosystem Sciences Division—as well as an adjunct professor in CNR's Energy and Resources Group. "If we want to understand climate and climate feedback within ecosystems, we need to measure the exchange of CO_2, methane, and water between the earth's surface and the atmosphere."

The levels of gases in any ecosystem vary throughout the year. Carbon dioxide concentrations in the air decrease during the growing season—when

PHOTOS FROM LEFT: Joseph Verfaillie; Guofang Miao

Left: Dennis Baldocchi wades through a restored wetland at a research site in the Sacramento-San Joaquin River Delta.
Right: Equipment on the top of an eddy covariance tower in the wetlands of North Carolina's Alligator River.

"We've already waited too long... Our biggest problem is that it's happening very fast, and we have seven billion people who depend on this biosphere."

— Dennis Baldocchi

photosynthesis outpaces respiration—and increase in the dormant period, when decomposition and respiration release CO_2. Levels never exceeded 300 parts per million over the last 800,000 years until the industrial age. We're not likely to see that level again in many lifetimes.

"When I started graduate school in 1977, some of my atmospheric carbon dioxide measurements were 325 parts per million," says **Dennis Baldocchi**, an ESPM professor and one of the founders of the AmeriFlux research network. "When I came to Berkeley in 1999, concentrations in the same season of the year were up to 370 parts per million. Then they reached 400. We've already waited too long. With increasing temperatures, ecosystems will change over time. Our biggest problem is that it's happening very fast, and we have seven billion people who depend on this biosphere."

In order to measure the levels of carbon dioxide, water, and energy in any given ecosystem—what Baldocchi calls the "breathing of the biosphere"—AmeriFlux researchers use a technique known as eddy covariance, which combines precise, continuous measurements with sophisticated statistical computation. Turbulent eddies are found within all moving airflows, with both vertical and horizontal components, Baldocchi explains. Eddy covariance measures the velocity of air drafts as they move up and down and captures the instantaneous concentration of trace gases in the drafts. Direct second-by-second measurements are made without interfering with the airflow. Sensors are mounted on towers of varying heights, about 10 feet for grassland, 300 feet for conifer forests.

An accelerating rate of atmospheric change

Rising temperatures caused by increased atmospheric carbon dioxide will likely stress many plants, which in turn can affect atmospheric processes. And, in at least one key habitat, the changes can unleash a vicious cycle. In Arctic latitudes, when the heat of summer thaws the upper few feet of frozen ground, soil microbes decompose and convert dead plant material into greenhouse gases. Specifically, the summer's microbial metabolism releases huge volumes of carbon dioxide and another potent greenhouse gas: methane.

If global warming raises summer temperatures a few degrees, the increased heat will push the thaw deeper, allowing microbes access to much more organic material. This could greatly boost their growth and might release much more carbon and methane throughout the world's northern latitudes.

"Right now, we can't put precise numbers on this at the scale of the Arctic or the ecosystem," Baldocchi says. "But we're running experiments where we compare the CO_2 emissions in permafrost soil heated to different temperatures."

AmeriFlux aims to strengthen communication within the far-flung community of scientists working at different sites. "A plant physiologist assigns a positive number to the flow of CO_2 from the atmosphere into a photosynthesizing plant," says Baldocchi. "But an atmospheric scientist would record the flow of CO_2 as a negative number because it's leaving the atmosphere. We need to use the same language." Says Torn, "If we get people talking and working together, we can get a look at a bigger, richer picture."

DISRUPTING THE SOCIAL-CHANGE INDUSTRY

PHD 2001 ENERGY AND RESOURCES GROUP

ASTRID SCHOLZ

Astrid Scholz spent her last two years of high school at an international boarding school in British Columbia dedicated to peace and international understanding. It's no wonder she decided she wanted to try to leave the world a better place by doing development work in the Global South. But a gap-year journey from her home in Cologne, Germany, to Africa rid the budding ecological economist of that notion.

By Tom Levy | Photo by Sam Beebe

"I realized Africa really didn't need another white person telling them what to do," says Scholz, a 2001 PhD graduate of the College of Natural Resources' Energy and Resources Group (ERG). Today, Scholz is the "chief everything officer" at Sphaera Solutions, a Portland, Oregon–based for-profit mashup of marketplace, social network, and workflow management that aims to disrupt the social-change industry.

A common shortcoming of nonprofits and NGOs, Scholz says, is that they tell good stories about how they've solved problems, but do a poor job of making their solutions available to others. That's where Sphaera comes in. It invites social-change organizations to bring their problems and solutions together on the company's nascent publicly accessible web platform. The long-term goal: hosting a vibrant online community of more effective problem-solvers. "We need to figure this stuff out much more quickly," Scholz says, "because the world is on fire."

Economics makes the world go round

To fund its ambitious goal, Sphaera's seven-member team offers its cloud-based subscription software to organizations that want to create their own online solution-sharing communities on Sphaera's platform. With first-year revenues of $185,000, paying clients like the state of Louisiana and the Rockefeller Foundation's 100 Resilient Cities initiative, and partners that include the Skoll Foundation, Oxfam America, Mercy Corps, and Ecotrust, Sphaera is on its way. But it's still a lean operation: In addition to leading the company, Scholz earns her "chief everything" title by also doing the books and taking out the trash.

Early on, Scholz decided that economics "makes the world go round." After completing an international baccalaureate at Canada's Lester B. Pearson United World College of the Pacific, she garnered two master's degrees: one in economics and philosophy at Scotland's University of St. Andrews and another in economics at England's University of Bristol.

Around that time, she was electrified by the work of Berkeley economist **Richard Norgaard,** a pioneer of ecological economics—the study of how human economies and natural ecosystems interact. Under Norgaard's wing at Berkeley, from 1996 to 2001, she wrote her dissertation on the value of plant-derived genetic resources within the field of pharmaceutical drug discovery. Scholz and other ERG students were encouraged to follow their curiosity wherever it led, taking any course they found fascinating and learning how to use—or how to create—the tools needed to solve any problem they chose to tackle.

Learning from every discipline

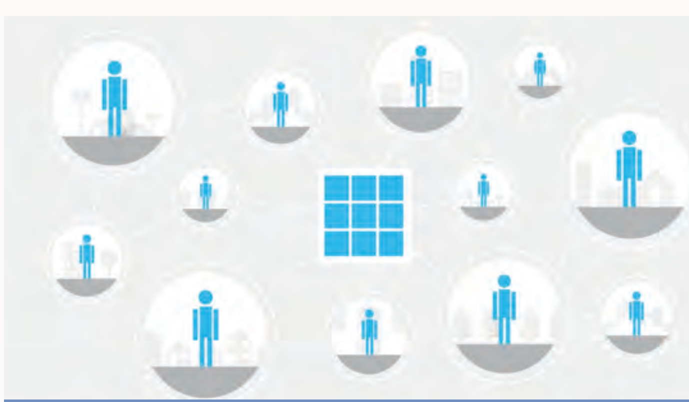
Along the path to her PhD, Scholz picked up interviewing techniques from the late Berkeley anthropologist **John Ogbu.** She bounced ideas off **Ignacio Chapela,** a microbial ecologist and mycologist in the Department of Environmental Science, Policy, and Management (ESPM). And she was inspired by ERG professor emeritus **Gene Rochlin,** a physicist turned political scientist and technology critic. She even took a civil engineering course, where she learned how to build wastewater treatment plants. "Once you've mastered a civil engineering course, you're not going to be intimidated from picking up whatever else you need to learn," she says. "But the main thing I discovered was that I could learn anything."

"We need to figure this stuff out much more quickly, because the world is on fire."

After graduating from Berkeley, Scholz quickly landed a job at Ecotrust, a nonprofit with a $10 million operating budget that fosters conservation projects that help West Coast communities prosper. She spent two years studying how to improve coastal fisheries while keeping in mind the needs of those doing the fishing. "I literally visited every fishing port on the West Coast," she says. "In many cases, the fishing people I met said, 'You're the first PhD who's ever come to find out what we think.'" The think-on-your-feet quantitative skills she'd picked up from ecologist **John Harte**—of both ERG and ESPM—proved invaluable when she testified about Ecotrust's findings to commercial fishing regulators.

Over the next 11 years, Scholz served as Ecotrust's economist; led a group developing, among other things, high-tech mapping tools; and, eventually, honed her skills at managing people and leading a large regional nonprofit—she spent her final two years at Ecotrust as its president. Through the years, Ecotrust had created various for-profit social enterprise subsidiaries and spin-offs. Ecotrust Forest Management, for example, helps landowners and investors sustainably and profitably manage forests through selective logging and thinning; it also provides local jobs and fosters healthier forests by increasing species diversity. As president, Scholz continued this work, eventually spinning off Sphaera Solutions.

The ever-busy CEO credits her daughter with helping her stay grounded. "Parenting reminds us of our obligation to future generations," she says. "I've got my own personal reminder-in-chief to remind me every day what really matters: trees to climb on and time to play, the universal goods."



Sphaera's solution-sharing platform allows users to share, reuse, and adapt ideas that work—what it calls "solutioning."

ILLUSTRATION: sphaera.world

Q&A

Climate Change at the International Level

The impacts of climate change aren't being studied only in the laboratory or the field. Four CNR social scientists talk about the economic and political repercussions of our warming planet. By Kirsten Mickelwait

Maximilian Auffhammer uses actual, not assumed, human behaviors to calculate projections.
PHOTO: Darren Jacklin Photography

Maximilian Auffhammer

Economist
George M. Pardee Jr. Professor of International Sustainable Development
Associate Dean, Interdisciplinary Social Sciences

Your work related to climate change? I do a lot of climate-change and energy-sector research using big data and statistical techniques, quantifying the impacts of global warming on energy consumption. We want to project how humans will react to changes in temperature—for example, at what temperature will they turn on the air conditioner, and how long will they use it? Almost no one in San Francisco currently has air-conditioning, because it's rarely hot enough to require it. But if summers in the city become as hot in the future as Fresno's are now, they'll eventually start installing AC units. We're using climate models—physics-based representations of the earth's climate system and actual, not assumed, human behaviors—to simulate what summer climate and human responses to it will be like by the end of the century. Big data is allowing us to answer questions we couldn't answer before. My job is to tell you what the world looks like if we continue on a business-as-usual path.

Reasons for optimism? Looking at the state's future electricity consumption, my model suggests that increases in consumption will be relatively modest, about 10 percent. But other work forecasts increases in the frequency and intensity of peak events, which are the hottest days of the year. Results suggest that we must invest more in peak plant capacity, turbines that run during really high-load days. Also, in the field of climate economics, there's no other U.S. institution that has the depth and diversity of knowledge that we have here at Berkeley. It really puts us at the forefront of this issue.

David Anthoff creates numerical models of climate policies.
PHOTO: Constanze Huther

Reasons for concern? Our coastal power infrastructure, like nuclear power plants and substations, will be affected by a sea-level rise and more intense 100-year floods. We've mapped out all the nuclear power plants in the world and identified those that could be affected. This simply means that we have to plan for the new normal.

Impact of the Paris Climate Conference (COP21) on your work? In the past, international climate negotiations have been like a family reunion where 200 of your closest relatives have to unanimously agree on one place to eat. Some are vegan or gluten-free; some want meat and potatoes. It never really worked; the resulting prior agreement didn't do much mitigating. Paris was much more like a weight-loss program: Each member committed to losing a certain number of pounds and hence decided how much to contribute to the total weight-loss effort. Paris alone was not enough to get us to the goal of limiting global average temperatures to 3.6 degrees Fahrenheit of warming, but it's a good first step. As for my own work, Paris has presented some opportunities for further research, and I've got my eyes on a few new projects for the long term.

David Anthoff

Economist
Assistant Professor, Energy and Resources Group

Your work related to climate change? My research focuses on cost-benefit analyses for climate change policy. Within that, there are two major strands I work on. I create numerical models that are used to estimate the cost-benefits of climate policies. The other is a more conceptual strand, looking at how to incorporate equity considerations into a cost-benefit analysis of climate issues. The federal government—from the White House to entities like the Environmental Protection Agency—is using my model to do cost-benefit analyses for federal regulations on climate change.

Reasons for optimism? Here at Berkeley, we have a unique opportunity to advance the state of the art in this research area, with a diverse mix of modelers and empirical economists. Our team will be playing an enormous role in shaping this field over the next decade. And because federal policymakers and the U.S. government are using my integrated-assessment model, our group has a very direct link to the policy-making process. It's rare for so many scientists and economists to collaborate the way we do here. Traditionally these fields have been siloed, and by linking our work—the same topic, but different methodological approaches—we're advancing the frontiers in this kind of research.

Reasons for concern? The current administration in Washington wants to make tangible progress against climate change in a very short period of time. How can we scale this research area up quickly enough to satisfy the needs of the policy process? This is not ivory tower research; it's being put into practice immediately. We synthesize the work of thousands of scientists into the cost-benefit process. Yet the funding we receive pales in comparison with that in other areas of climate research.

Impact of COP21 on your work? The impact is probably stronger the other way around: The kind of work I do informs the negotiation position of the parties that try to come to agreements like the Paris accord. For example, the U.S. position in Paris was shaped by the Clean Power Plan rule, and the regulatory analysis of that rule was based on economic analysis that included my model.

Kate O'Neill

Global Environmental Political Scientist
Associate Professor, Environmental Science, Policy, and Management

Your work related to climate change? I study international environmental politics, the global political economy, governance issues, and activism. I work on changing practices of global governance, connections between science and politics, and how proposed solutions can have impacts—both positive and negative—at local levels. Climate change negotiations and governance are linked to almost every environmental issue, from the ozone layer to waste management to biodiversity. While some of these other issues have been amenable to traditional governance mechanisms, including negotiated treaties, climate change has been more complex and conflict-ridden.

Reasons for optimism? There's been a big normative shift in the last few years. Those countries that were "nonbelievers" in the threat of climate change—like India, China, and even the United States—now agree that it's real. Most now understand that all countries need to do something at the global level to mitigate greenhouse gas emissions and help the poorest countries to adapt. The science has become more solid, and scientists are doing a better job of pushing that message of urgency. And political organizations are starting to look at how we can build institutions and rules around the science.

Reasons for concern? If we were at this point of action 30 years ago, we'd be in good shape. But there's been so much foot-dragging, we must now make enormous progress in a very short period of time. Climate change politics are still unstable in a lot of nations—including the United States, with the reversals in our Supreme Court and instability around the 2016 election. The European situation is also shaky; Britain's exit from the European Union (unless it's somehow halted) will have highly negative impacts on EU—and global—climate politics. I also worry that we'll engage in some large-scale technological solutions that could have some negative side effects. Shooting sulfur dioxide into the sky to reduce greenhouse gas emissions, for example, could really affect monsoon activity. And climate engineering could spark conflicts, if not implemented in democratic ways. Silver bullets never work as intended.

Kate O'Neill warns that we should be looking at large-scale restructuring of our global economy.
PHOTO: Julie Van Scoy

Impact of COP21 on your work? The Paris agreement signifies real change in how governments are thinking about their roles in combating climate change. In turn, the "bottom up" approach to negotiating agreements that was adopted at Paris is an exciting new form of global governance. Some of the challenges at the global level are how to inventory national emissions, figuring out ways to transition away from fossil fuels, and how to fund adaptation policies and deal with climate refugees. We're doing quite well with the low-hanging fruit, but we need to be looking at large-scale restructuring of the global economy.

Jonas Meckling

Political Economist
Assistant Professor, Energy and Environmental Policy

Your work related to climate change? My research explores the political drivers of developing clean-energy markets. I'm interested in why governments lead or lag in supporting the development and deployment of clean-energy technologies such as solar power and electric vehicles. I'm also looking to understand the global clean-energy race and how it impacts effective global cooperation on climate change.

Reasons for optimism? Increasingly, the political debate is taking the development and deployment of clean-energy technologies seriously. We're now discussing more explicit policies for stimulating the development and deployment of clean energy, while also looking at mitigation policies such as carbon pricing. At the Paris climate summit, governments created initiatives to advance this progress. The rapidly falling costs of wind and solar photovoltaics have created a major tailwind for this debate. Also, in a surprising twist of history, the economic crisis has proved a boon for climate policy. Governments poured billions in stimulus money into clean-energy sectors—including wind, solar, electric vehicles, and batteries—and this has helped to speed up the trend toward decreased costs.

Jonas Meckling is studying the political drivers of developing clean-energy systems.
PHOTO: Julie Van Scoy

Reasons for concern? I have two main concerns around the politics of clean energy. The first one is that countries are starting to engage in trade wars over these technologies and erecting trade barriers. This has led to conflict in global clean-energy politics. The U.S.-China dispute over solar photovoltaics is an example. Prolonged disputes and tariffs just create uncertainty and increase cost. What we need is more certainty and lower costs. My second concern relates to the lack of political support for carbon-removal technologies. Those are technologies that remove carbon from the atmosphere. The Intergovernmental Panel on Climate Change—the United Nations body that collects knowledge on climate science—assumes that we'll eventually need to start pulling carbon dioxide out of the atmosphere to avoid catastrophic climate change. But politically, we don't really see strong support emerging for such technologies.

Impact of COP21 on your work? Paris is a very positive sign that reinforces what has already been happening at the domestic level. For instance, the United States launched the Clean Power Plan before heading to Paris to agree on a global deal. Going forward, I'm interested in how countries can create political pathways that allow for progressively deeper emission cuts. We're now seeing greater interest in expanding gas power, as opposed to coal, to meet the Paris emission targets. But gas infrastructure stays around for a long time. It would thus be harder to make deeper emission cuts in the medium-term future. So how can countries develop climate policies now, but think about the long-term implications? Also, how can we move beyond the power sector to achieve emission cuts in the transport sector?

CNR'S NEW ALUMNI ASSOCIATION PRESIDENT

BS 1995 PLANT AND MICROBIAL BIOLOGY

CHRISTINA BROWN CAMPBELL

Christina Brown Campbell—a self-described drug-discovery scientist, data ninja, oenophile, designer, feminist, and strategist—is always up for a challenge. When she was little, she thought she might grow up to be a doctor, or perhaps a park ranger. The ranger idea proved impractical due to severe allergies. So as she pursued her bachelor's degree in the College of Natural Resources, majoring in bioresource sciences, medical school seemed ever more likely.

After graduation, however, Campbell "took a complete right turn," as she puts it, when the opportunity came along to join a pharmaceutical start-up, Advanced Medicine Inc., as a founding research member. It was a challenge she couldn't refuse.

By Anne Canright | Photo by Julie Van Scoy

"That was a wild ride," she recalls. "We never knew where our next funding was going to come from, so every piece of data, every scientific breakthrough, was a reason to celebrate and a reason to keep the lights on." In the process, she learned about financial models and venture capitalism, FDA regulations and IPOs, in addition to fulfilling her core responsibilities in preclinical drug development in six target areas: the central nervous system; infectious disease; and gastrointestinal, cardiovascular, metabolic, and respiratory diseases.

Hitting it out of the ballpark

From the start, Campbell had an "outrageous goal": to get 10 medicines into late-stage clinical trials or to market within 10 years. As things turned out, this truly was a "*Mission: Impossible* ambition," even for a hardworking optimist like her. As a respected colleague later pointed out, in the pharmaceutical business you're lucky if you get 3 or 4 medicines from concept to discovery to development to patient in a lifetime, never mind a decade.

Yet now, 19 years later, Campbell expresses deep satisfaction with what the company has accomplished. That start-up, now called Theravance Biopharma, has grown from about 15 employees to more than 350, and it has one medicine on the market and two others in partnership at a spin-off company, Innoviva. "The major push has been to try to improve global health through engines of innovation," she says. "It's truly an honor to be a driving partner of a discovery biology team that's been so successful and so prolific." She laughs and adds, "I may get to that goal of 10 yet!"

In addition to such challenges as an FDA overhaul and the global economic downturn of 2007–08, Campbell was one of very few women in a highly competitive, male-dominated business. "I felt I had to speak up louder, and know what I was talking about to a degree that I couldn't be dismissed," she says. "And I had to struggle to get the sort of visibility that my male colleagues were getting. I was constantly aware that I had to set my standards differently, my bar higher. I needed to hit *everything* out of the ballpark."

Strengthening the alumni link

Campbell's advice for young women embarking on a scientific career? "Never be afraid to take a right or left turn," to creatively engineer the environment so "you feel like you're progressing, getting challenged, doing meaningful work." Also key is "getting the support you need: the guidance, the coaching, the mentorship, the sponsorship"—something Campbell did not have when she started out. Which inspires her now to engage in being a mentor herself, both at Theravance and more formally through the Healthcare Businesswomen's Association.

Campbell is also bringing people together through the CNR Alumni Association, of which she is about to become president after several years on the board. "I'm really excited to take this organization to the next level," she says, "and have it be more valuable for our stakeholders." She points to various events that are helping to unify the college—including the annual homecoming barbecue, career panels, speaker programs, and a biannual networking event.

"I felt I had to speak up louder, and know what I was talking about to a degree that I couldn't be dismissed. I needed to hit *everything* out of the ballpark."

With these activities, Campbell seeks to "blur the lines, providing more opportunities for cross-pollination within areas of expertise," and "create a nexus of communication between the college, the community, and the alumni." In this way, the alumni association can serve as a structural support for the many callings, interests, and interwoven ties that CNR represents, from its teaching program and faculty research to the diverse work of alumni.

"CNR is bigger than the sum of its parts," she says. "The college has these amazing programs going on, the faculty are doing phenomenal things, and there's an infinite number of ways that alumni and faculty researchers can interact with and help one another. We're trying to be the brokering place for that and the CNR vision: 'See the bigger picture. Make a better world.' Let's make that happen."

GET INVOLVED IN THE CNR ALUMNI ASSOCIATION

Visit nature.berkeley.edu/CNRAA to stay up-to-date on networking and professional development opportunities. If you'd like to play a more active role and gain leadership experience by serving on the CNRAA board, contact Andrew Judd, director of alumni relations, at judd@berkeley.edu.

Christina Brown Campbell snaps a selfie in the lab.

Our Promise, Their Future: Meeting the Graduate Studies Challenge

The College of Natural Resources' doctoral students—and our growing number of master's-level students—are already socially conscious and intellectually gifted when they arrive on the Berkeley campus. After devoting years to gaining a deeper understanding of the problems facing our planet, they go on to have worldwide impact at universities, nonprofit organizations, and private companies as well as in the public sector.

THE FINANCIAL HURDLE

However, rising tuition and costs of living mean unprecedented hardships for our students. Currently, incoming CNR graduate students are guaranteed three to five years of funding, which comes from the department, the student's primary faculty adviser, and University teaching assistantships. Last year, these funding packages ranged from $42,000 to $50,000. Subtract from that the in-state tuition and University fees ($17,200 in 2015–16), and the remaining living stipend makes it difficult for students to make ends meet.

Graduate-student support is one of the highest priorities for CNR and the campus as a whole, but the financial needs of our doctoral and master's-level candidates eclipse the available resources. To continue to attract and retain the most talented graduate students—who often have very competitive funding offers from our peer institutions—and to preserve the excellence and diversity of our programs, we must increase the number of privately endowed fellowships and annual support specifically designated for graduate students.

THE MATCH OPPORTUNITY

A 2015 fundraising effort—Berkeley Endowments to Attract and Retain Graduate Students (BEAR GradS)—has succeeded in creating multiple $1 million doctoral fellowship endowments on campus through a creative dollar-for-dollar matching program. CNR has created one such fund through the generosity of alumna Li-Chiang Chu, who in 2015 established the Li-Chiang Chu Graduate Fellowship in Nutritional Sciences and Toxicology. Until December 1, 2016, CNR is eligible for one more BEAR GradS match through this program.

CNR strives to uphold the mission of UC Berkeley's Division of Equity and Inclusion: to promote diversity and to provide "an environment in which all can thrive academically and professionally." Your support can help in this cause. If you're interested in supporting graduate students at CNR, please contact Kathryn Moriarty Baldwin at moriartyk@berkeley.edu.

GRADUATE STUDENT GO-GETTERS

Two CNR graduate students were recognized in *Forbes* magazine's 2016 "30 Under 30" list: **Colin Carlson,** for his research studying how parasites—which are key to many ecosystems—will be impacted by climate change, and **Emily Woods,** for cofounding Sanivation, which is developing the first method for solar treatment of human waste.

This year, agricultural and resource economics students **Allyson Barnett** and **Stephen Harrell** will represent CNR in Washington, D.C., through research positions that directly support White House programs and initiatives.

Recent graduate **Sydney Glassman** was lead author on a 2015 study that discovered that a fungal spore bank under the Sierra Nevada's devastating 2013 Rim Fire has helped to regenerate new forests.

ARE PHOTOS: Edward A. Rubin

From left: Colin Carlson (ESPM), Emily Woods (ERG), Allyson Barnett (ARE), Stephen Harrell (ARE), and Sydney Glassman (ESPM, PMB).

FACTS ABOUT FUNDING

The payout from a $1 million graduate fellowship endowment can fund in-state tuition for two CNR students per year, while the endowment continues to grow over time.

According to an April 2016 report by the *San Jose Mercury News,* rent for a Bay Area apartment averages $2,482 a month—that's $29,784 a year.

Faculty also raise money to fund students through competitive grants with such federal agencies as the National Science Foundation—they have a 20% success rate.

After covering in-state tuition and fees, CNR graduate-student stipend packages ranged from $24,800 to $32,800 in 2015–16.

ICONS: thenounproject.com: Gregor Cresnar; Rediffusion; Luis Prado

Gold Fever | Photo by Nancy Lee Peluso

As part of her research on dynamics of agrarian and forest transformations, professor of political ecology **Nancy Lee Peluso** spent seven months in Indonesia documenting smallholder gold mining, an unregulated industry that has exploded in the past 20 years. Shown here, miners use high-pressure hoses to break down the earth and dredge it up and over sluices on higher ground. After extracting gold flakes from the mud, they use mercury to consolidate the gold by hand. The mining is often environmentally destructive and is hazardous to workers' health. Nevertheless, it offers a shot at prosperity for rural communities exposed to the market risks of industrial agriculture, the primary driver of forest conversion in Indonesian Borneo, where this photo was taken. For many, mining is a better option than the meager returns on smallholder farming or the indignity of plantation work on land they once claimed as their own.

For more images from this series, visit nature.berkeley.edu/breakthroughs.

See the Bigger Picture. Make a Better World.

Support the College of Natural Resources at give.berkeley.edu. Just search for "CNR."

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Formerly a captive of the Lord's Resistance Army, a Ugandan mother surveys the onion field she planted with savings she accrued through a group for survivors of conflict-related sexual violence. Master of Development Practice student Audrey Whiting photographed the scene while an intern for the Berkeley Law Human Rights Center's Sexual Violence Program.