Berkeley Initiative in Global Change Biology (BIGCB)

University of California, Berkeley
June 2010

The very survival of humankind depends on the Earth's biological resources — from the provision of food, water, and natural pharmaceuticals, to the regulation of climate and pollination of crops. Yet as human populations grow, so do the demands — and resulting impacts — placed on these resources. Air and water quality are increasingly compromised. Oceans are overfished. Habitats disappear. Available land is replaced with cropland and cattle pasture. Rising CO_2 levels change climate. Never before has human activity caused such rapid change for Earth's rich and varied resources, to the detriment of our own wellbeing for generations to come.

UC Berkeley, internationally renowned for it distinguished faculty and groundbreaking research, can make a critical difference. Global change — a defining scientific issue of the 21st century — is inherently multidimensional and nonlinear and requires sophisticated, innovative solutions to avoid catastrophic outcomes. As the world's leading public university, UC Berkeley is already forging approaches to global change in such areas as public policy, economics, and energy research. Less addressed, however, are the biological responses to global change — how our evolutionary legacy will be affected and what strategies will retain our planet's maximum diversity. The Berkeley Initiative in Global Change Biology (BIGCB) has access to this critical data and — with new conceptual and analytical tools — is ready to fill in this gap.

Global change from a biological perspective

BIGCB is a multi-year initiative involving more than 60 faculty, as well as staff and students spanning the intellectual capital of UC Berkeley. Combining the University's outstanding expertise in ecology, evolutionary biology, paleontology, climatology, microbiology, computational biology, and other disciplines; the extraordinary collections of the Berkeley Natural History Museums (BNHM); and decades of research at field stations, the initiative's primary aim is to understand how biological systems have responded to past global change in order to predict their responses in the future. Our ability to tap into a wealth of historical information, from millennial to decadal scales, makes this initiative the largest and broadest of its kind. The ultimate goal is to provide the knowledge and information systems that anticipate and address responses to change so that the world's terrestrial and marine environments remain as resilient as possible and we, as humans, can continue to receive their benefits.

BIGCB's initial phases involve developing novel combinations of enabling tools, then applying them to exemplar ecosystems. The tools are: 1) conceptual and modeling approaches that identify key variables and thresholds and provide the integrative framework for harnessing data; 2) biodiversity informatics that enable multidimensional analyses and effective sharing of knowledge; and 3) new technologies (e.g. genomic, isotopic, and spatial modeling) that allow high-resolution analyses and understanding of past response to rapid change. Initially, we will demonstrate and refine these tools on the Sierra Nevada, central California coast, and oceanic islands of eastern Polynesia, distinct systems for which we have extensive information and faculty expertise. Our strategy is general and can be applied globally.

Developing a new theoretical framework

We see change everywhere — such as the introduction of invasive species, the fragmentation of habitats, and the extinction of species — but we often do not know which changes are most consequential. It is essential to identify when natural services (e.g. water filtration or plant pollination) or whole ecosystems (e.g. coral reefs) are on the verge of disappearing.

Ecological theories predict that such losses occur suddenly when they hit tipping points, shifting dramatically from a healthy to an unhealthy state. Once a threshold is crossed, it is difficult, if not impossible, to return to health. BIGCB's goal is to clearly characterize the warning signs that precede such state-shifts by:

- Integrating analyses of fossil, historic, and modern biological dynamics to define "normal" benchmarks in such metrics as species composition, diversity, and abundance.

- Identifying which species or dimensions of diversity hold the most information for predicting outcomes of rapid change.

- Determining ranges of reasonable expectations for conserving genetic diversity, populations, species, landscapes, and ecosystem services in specified areas by developing models that explore the relationship between human activity and species survival.

- Highlighting the shortcomings of current predictive models, which are usually based on the here and now rather than the natural dynamism of systems, and improving their ability to address critical conservation and land-use issues.

Resources and innovation in biodiversity informatics

The Berkeley Natural History Museums (BNHM) contain an irreplaceable record of flora, fauna, and eco-evolutionary dynamics from across the globe, with particular emphasis on California. Highlights include:

- Essig Museum of Entomology – 6 million pinned insects, with a focus on California, the eastern Pacific Rim, and the islands of the Pacific Basin.
- Museum of Vertebrate Zoology – 680,000+ specimens of amphibians, reptiles, birds, and mammals, 88,000 tissue samples, and 180,000 pages of field notes, illustrations, and photographs. The largest early 20th-century record of diversity in California.

- Museum of Paleontology – 3 million specimens highlighting microfossils, invertebrates, paleobotany, and vertebrates. The largest collection of any university museum in the world.
- University and Jepson Herbaria – 2.2 million specimens of pressed plants, with an emphasis on California and the Pacific Rim.
- The Berkeley Field Stations – Eight in all (six of which are part of the University of California's system of 36 reserves), spanning much of California's extraordinary ecological diversity.

These resources contain vast amounts of untapped information that are central to determining how organisms have responded to past global change. Recent advances in bioinformatics, many developed at Berkeley, have enabled us to capture such critical information as changes in species distribution and characteristics over time and a complete genetic inventory of a tropical island. Yet much is unavailable, still restricted to tiny, often handwritten, specimen labels in the collections. Until this data is entered in digital format, it cannot be accessed or analyzed. Only 10 percent of the entomology collections have been digitized (compared to 95 percent of the vertebrate zoology collections), and much important data from the field stations remains invisible to researchers.

A major thrust of BIGCB is to digitize the collections and create a single portal for enabling complete integrative analyses. By linking specimen data from the museums and ecological knowledge from the field stations, we can develop a clearer picture of how species are expanding, declining, or shifting ranges, from local to regional scales, and identify the underlying processes. BIGCB offers an unprecedented opportunity to build the first major set of completely digitized and web-accessible museum collections and field stations in the world, thus transforming the research capacity of our own faculty and scientists worldwide.

Applying new technologies to understand past responses

A key component of BIGCB is to apply new analytical technologies to historical specimens in order to broaden our knowledge of eco-evolutionary responses to past episodes of rapid environmental change.

Genomics and evolutionary response

Analyzing genomes provides incredible information about such broad-ranging issues as historical patterns of selection, demographic changes, and insights into physiology, behavior, metabolism, and development. Opportunities to apply new approaches to global change biology have proliferated with the advent of whole genome sequencing projects, "next-generation" DNA sequencing technologies, and high-throughput platforms for genotyping. By comparing historical (e.g. skins or pressed plants) and recent specimens, BIGCB will measure species' genetic, phenotype, and distribution changes over time with unparalleled resolution. Combined with advanced statistical genomics, another UC Berkeley strength, we can identify genes and pathways under selection because of rapid environmental change. Coupling genomic dynamics with measured changes in traits — e.g. shifts in morphology and timing of life history events — will deepen our knowledge of key processes and identify robust predictors of population collapse.

Isotopes and ecological change

The recent development of stable isotope tools has revolutionized our ability to address previously unanswered questions and interpret what led to chemical (isotope) changes in species. For example, analyzing the carbon (C), nitrogen (N), and oxygen (O) composition of insect, plant, animal, and soil samples have recently provided new insights on how human-induced climate change is affecting biodiversity in tropical forests, grasslands, woodlands, and shrub lands around the globe. When coupled with geographic information, scientists can create novel maps or "Isoscapes" that show how regions are responding to never-before-experienced environmental change. UC Berkeley faculty and students — some of the world's most creative leaders and innovators in the emerging fields of stable isotope ecology, biogeochemistry, and forensic science — are conducting a great deal of this research.

Spatial analyses of environmental change

Sophisticated tools, combining historical vegetation maps, remote sensing, and spatial modeling, are being developed to measure and visualize change in climate and ecosystems across space and time. This provides the essential context for using our knowledge of past responses to improve future predictions. An important component of BIGCB is to integrate our expertise in environmental analysis and spatial modeling via Geographic Information Systems (GIS) and apply it to specific systems of interest.

Exemplar systems

As part of BIGCB, we have identified several target organisms — including insects (e.g. honeybees as key pollinators), small mammals, and plants — that would serve as initial "proof-of-concept" systems for demonstrating how these new technologies can be applied to understand eco-evolutionary response to past change in California. As one example, more than 100 years ago, the Museum of Vertebrate Zoology's founder led a massive effort to document California's mammals, birds, amphibians, and reptiles across hundreds of locations, resulting in a remarkable snapshot of early 20th-century biodiversity. Today's Grinnell Resurvey Project is reexamining diversity at these locations, especially in the Sierra Nevada and central coast, to identify changes in distributions. Results demonstrate variable response, with formerly low-elevation species expanding upwards, high elevation species contracting, and yet other species remaining unchanged. BIGCB will expand this benchmark study by applying the above tools to understanding how and why species respond differently and to putting the observed 20th-century changes into a broader ecological, genomic, and longer-term (paleo) perspective. This study, one of several we intend to develop, demonstrates how rich historical collections combined with modern resurveys and new technologies can elucidate the dynamics of biodiversity in the face of rapid change.

Applying the tools to three unique ecosystems

We have chosen three ecosystems to demonstrate how these new theoretical models and tools can be applied to understanding the impacts of global change. These ecosystems were selected for a variety of reasons, including dramatic gradients in temperature or landscape, strong representation in the collections, or their extreme vulnerability to change. Each area has its own research agenda, but with common threads.

Sierra Nevada

- Special focus on meadow systems, which span different elevations and are biologically rich, because of their sensitivity to hydrological and temperature change and the dynamics with adjacent forest communities, i.e. the invasion of lodgepole pines and climate-driven changes in small mammals.

- Studies include: 1) quantifying environmental change across meadows at different elevations using historical versus modern vegetation plot data, aerial photography, and remote sensing; 2) documenting change in community composition and species interactions; 3) producing spatially explicit models of response to climate change that can help shape management options.

Central California Coast

- Reflects diverse land/seascapes and climates, from kelp forests to redwood forests, cool coastal to hot interior climates, that have shown dramatic shifts in the past, including sea level fluctuations emptying and refilling the San Francisco Bay more than 40 times in 250,000 years. While plant and animal communities have responded to past dynamics, BIGCB explores whether the rate of current climate change exceeds their resilience, resulting in reduced productivity, plant mortality, extraordinary fire regimes, or invasion by exotic plants, animals, and diseases.

- Marked by a heavy human footprint — with the arrival of Native Americans at least 13,000 years ago, Mexican and American colonization starting in the 18th century, and more than 5 million residents today — all of which transformed the landscape through harvesting, grazing, logging, mining, urbanization, etc. An improved understanding of global change will help us sustain the ecosystems and services (e.g. forests, farms, and vineyards) that support our cultural and economic wealth, in California and beyond.

- Research agenda focuses on three areas: 1) studying both the terrestrial and marine fossil record (paleontology/paleoecology), alongside geographic analyses of genetic differentiation in relation to landscape and climate history (phylogeography) at four major episodes dating from 3 to 10 million years ago; 2) understanding how environmental gradients, fine-scale topography, and land use shape species' distributions and patterns of biodiversity across the landscape of our region. Includes establishing a program that engages citizen scientists in mapping species through a Google Maps-style interface using observations and photographs; and 3) integrative analyses of changes in organisms' performance, physiology, and interactions cross gradients, and the sensitivity of ecosystem processes to these changes.

Oceanic Islands

- Among the most vulnerable ecosystems in the world, and ideal natural laboratories for understanding global change. Focus on eastern Polynesia, particularly Hawaii and French Polynesia, with the goal of gaining important insights in the following areas:
- Temporal perspectives (from millions of years ago to future time scales) on such issues as how the islands formed, the impacts of human colonization, what organisms have invaded, the influences of repeated hurricanes on devastation and recovery, and the effects of climate change on biodiversity (i.e. cloud forests, which are rich with life and provide essential services such as water purification and rainwater retention).
- Fragmented landscapes, a defining feature of small islands with steeper ecological gradients, allowing juxtaposition of different habitats and selective pressures.
- The impacts of global change on island peoples, particularly increased aridity and decreased land area and drinking water as sea level rises.

Education, Outreach, and Policy

Addressing threats to biodiversity requires an engaged, informed citizenry that understands the science of global change and participates in conservation. Our goal is to enhance education and outreach in global change biology by strengthening formal and informal science education programs, with a particular focus on fostering life-changing experiences for our undergraduates — including field courses and internships — and strengthening the broader public's connection with scientists and global change research opportunities.

To support this goal, we plan to: 1) consolidate and enhance course offerings in global change biology, providing field-study opportunities, real-world experiences, and mentoring through a guided internship program; 2) expand the capacity of partnering institutions involved in informal science education to address global change biology; 3) develop a web portal to promote participatory and co-generated research between professional and trained citizen scientists; and 4) engage the media in understanding the social and environmental consequences of global change biology.

BIGCB also plans to develop and implement a strategy in partnership with authorities, agencies, and existing programs to ensure the effective integration and mainstreaming of the initiative's results into land-use policy, planning, and decision-making. The goal will be to promote conservation and the sustainable use of biological resources within economic sectors and development models, policies, and programs.

Summary

As the world's top public university, UC Berkeley excels in tackling problems of global relevance. To manage biological systems effectively in response to global change, it is essential that we challenge and rigorously test the current science on which predictions are based. The University's strength lies in its exceptional faculty — numbering more than 60 from across the intellectual spectrum — students, collections, and research. BIGCB will harness this unique set of strengths to forge a new and dynamic approach to addressing global change.