White Paper on the Berkeley Initiative in Global Change Biology (BiGCB)

CONTEXT

"That land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics. That land yields a cultural harvest is a fact long known, but latterly often forgotten." --Aldo Leopold, 1948, Sand County Almanac, p. ix

Human-driven environmental change has already caused huge impacts on biological systems, which are essential to human existence in three broadly-defined ways: for ecosystem services, maintenance of biodiversity, and emotional reasons. Ecosystem services are simply those things we can only get from other species (or interactions between other species). Examples include everything from commonly used high-blood pressure medications to clean water in New York City. Biodiversity is no less than the diversity of life we rely on to keep ecosystem services delivering and also to uphold some of the moral imperatives that make us human. And just as important—arguably more so according to some—are the emotional connections people have to biological systems, a need for nature likely still locked in our genetic code.

Now human-driven impacts on biological systems seem certain to accelerate in dangerous directions as we change climate and habitat in ways most living species have never experienced, primarily too much change, too fast. Multiplying the biological effects of this “new” kind of climate change is that it is occurring on a landscape that already challenges many species’ existence: a world more than half-covered with the by-products of human needs, like cities, agriculture, roads, reservoirs, mines, and garbage dumps.

Having so modified the earth, humans are now responsible to manage the outcomes for biological systems – our evolutionary heritage, the basis for healthy, productive ecosystems, the very foundation of human welfare. Indeed, management efforts are underway and are recognized as important in the general scientific community and in some cases by the general public. However, in contrast to physical modeling of climate systems and socio-economic impacts, forecasting of effects of rapid environmental change on essential components of biological systems like genetic, species and ecosystem diversity is in its infancy. Mapping of areas most likely to experience novel or disappearing climates highlights Mediterranean and tropical biomes – hotspots of unique biodiversity. California, one such biodiversity hotspot, is expected to experience rapid, but spatially variable warming and changes in hydrology. These changes are expected to have profound effects on the distribution, diversity and functioning of ecosystems and species, including the loss of our state bird and state tree – but we have much to learn about how and where these changes will occur (eg. Fig. 1).
We also have some understanding of how climate and associated changes will interact with ecosystem processes and vegetation dynamics, and how all this will play out across increasingly fragmented landscapes to affect biodiversity. However, our knowledge of these dynamic processes remains inadequate for forecasting vulnerability and, thus, management responses. “Bioclimatic” models of species distributions are widely used and typically predict dire outcomes; yet these methods are riddled with uncertainty and assumptions. Having emphasized the critical limitations of such approaches, the eminent ecologist John Wiens concludes “Not using models to peer into the future, however, is simply not an option”\(^1\). We simply must improve our capacity to predict (i) state-changes in ecosystems, and (ii) vulnerability of species given changing interactions and potential limitations on movement and/or evolutionary adaptation. With sufficient understanding of the dynamics of biological systems, we should at least be able to minimize perverse outcomes.

In sum, in today’s world we cannot afford not to manage biological systems effectively, but there are two missing pieces in the puzzle of how to do this.

- In large part we don’t know which species, landscapes, and seascapes will most need our help as the climatic rug gets pulled from under them, and where we do have a general sense, we don’t know enough details to recommend effective fixes.
- Society still lacks the new kinds of policy mechanisms that will be needed to implement biological-systems management that science identifies as necessary.

We propose creating the Berkeley Initiative in Global Change Biology (BiGCB) to fill in these missing pieces.

**Goals of the BiGCB**

- To improve forecasting of future vulnerabilities in the face of rapidly changing climate and land use - the principle drivers of rapid global change.
- To develop maps of predicted vulnerability and resilience that incorporate key biophysical processes, and which represent uncertainty in a way accessible to decision makers;
- To help develop policies that will lead to effective management of biological systems as they become increasingly impacted by accelerating global change, based on firm scientific grounding;
- To promote education in Global Change Biology at all levels inside and outside the University

What makes BiGCB distinct from other such efforts is to emphasize that we must learn from historical responses to environmental change, from millennial to decadal scales, to inform our predictions of the future. In particular, we will combine:

- The record of species, genomic and ecological responses to past environmental change archived in the collections of the Berkeley Natural History Museums as well as in tree-cores, lake sediments, and organic compounds in a wide range of materials;
- Decadal-scale studies of ecological processes at the Field Stations; and

\(^1\) Wiens, J. et al. 2009. PNAS 106:19737
• Comparative and experimental studies of contemporary ecological and evolutionary processes.

The integration across space & time will demand development of novel theoretical frameworks to identify processes and levels of biological organization amenable to prediction, advanced spatio-temporal modeling of dynamics and high-level informatics spanning ecological, genomic, biophysical and biodiversity information.

**WHY BERKELEY?** UC Berkeley has:
• Demonstrated capacity to tackle problems of global relevance, and broad enthusiasm for this specific initiative
• An outstanding and diverse student body, befitting its status as the premier public university
• Breadth and depth of faculty expertise in appropriate disciplines, and key infrastructure:
  o BNHM collections & UCNRS field stations
  o Modern analytical facilities focused on isotopes, genomics, remote sensing & computational biology
  o Ecosystem dynamics and biophysical processes
  o Ecological and evolutionary dynamics
  o Organismal physiology and behavior
  o Biodiversity informatics and spatial modeling
  o Environmental planning and policy
  o Climate modeling

BiGCB will focus on biological systems, a crucial concern, but one not yet addressed in campus initiatives relating to climate change. A substantial number of other initiatives that address physical, policy and socio-economic challenges associate with climate change, providing a large network with which the biology-focused BiGCB will interact, including:

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<thead>
<tr>
<th>Berkeley Institute for the Environment</th>
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<tr>
<td>Climate &amp; Carbon Sciences, LBNL</td>
<td>Cal Energy &amp; Climate (CEPI)</td>
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<td>Center for Environmental Biotech.</td>
<td>California Climate Change Center</td>
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<td>Berkeley Energy &amp; Resources Collaborative (BERC)</td>
<td>Earth Sciences, LBNL</td>
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**STRATEGY**

**Long-term:**
We envisage that BiGCB will encompass fundamental research directed at overcoming current limitations to predicting vulnerability of species and ecosystems, translational activities and education spanning from postdoctoral scholars and students to policy-makers to the general public. Research is likely to be centered around 3-5 research themes, connected via a model-
driven theoretical framework of biological response. Details are to be resolved during Spring 2010 (see below), but examples of possible themes include:

- Using knowledge of past responses to environmental change to rethink strategy and policy for environmental management;
- Understanding limits to adaptive and migratory responses of species to rapid change;
- Understanding when and how species interactions modulate responses;
- Monitoring sensitive systems and organisms and conducting experiments that mimic the future changes that are predicted to come;
- Predicting state-change in ecosystems by understanding context-dependence of strong ecological interactions;
- Developing a theoretical and computational framework that identifies levels of biological organization at which there are emergent properties and which offer potential for robust predictions.

Translational activities should be guided by the needs of exemplar stakeholders, spanning local to regional agencies, NGOs or community groups. A key challenge is to identify effective ways to communicate predictions of biological dynamics and vulnerabilities, including inevitable uncertainties. To achieve these goals will require flexible research teams crossing disciplines in biological and physical sciences and engagement with policy-specialists and end-users. A necessary step is to maximally digitize the resources of the museums and field stations and make them available to our own research community and scholars throughout the world—a biological diversity resource “cloud.” Further, we will build on existing strength in biodiversity informatics to improve web-based visualization tools for researchers and the public alike.

**Education strategy.** We will build upon a philosophy of cascading mentorship to provide a model for science-based education. Students at all levels will be encouraged to mentor those at different levels, thereby developing mentorship skills that are essential to academic success. Likewise, they will participate in the development of public exhibits, thereby simultaneously receiving training in communication skills, while building a public face to the research. This approach incorporates the full chain of educator-student relationships, including college/university faculty, postdoctoral and graduate students, K-12 students and their teachers, and lay public, in an integrated instructional community.

**Short-term (1-2 yr) strategy:**

The initial development of BiGCB follows from a workshop on Dec 9th 2009 attended by > 50 faculty and preceded by a series of working group meetings. To develop the initiative further will require (i) continuing engagement of faculty with diverse interests, leading to more clearly defined research themes by mid 2010, (ii) discussion of education and training needs among faculty and with potential partners, and (iii) initiation of a small number of enabling projects. The intent is to be in a position to launch the initiative and seek external funding in Fall 2010.

1. **Maintaining faculty engagement:**

- GCB Fora: We envisage a regular (eg. biweekly) informal gathering of faculty to continue sharing of information about current research interests and strategies for enhancing
collaboration in research and teaching. These would also be an opportunity to invite potential external partners and foundations with interests in specific themes.

- Working groups to define synergistic research opportunities: Our aim is to define practical elements of a research strategy that combines interdisciplinary research at a set of core sites or systems with necessary advances in technology and theory (Figure 2). Each of these should address one or more of the major research themes identified above. The BiGCB steering committee will resolve how best to do this in the early Spring semester.

2. Building the mission in education/outreach

- Review and implement graduate/undergraduate courses in GCB, including "capstone" course on Global Change Biology.
- Work with local partner institutions that have different target audiences, allowing UCB students access to the resources at those institutions, and providing a window to research at UCB.
- Collaboration with international partners: In particular in tropical areas. Explore options for certificate program in global change biology

3. Enabling projects & infrastructure – each should be innovative and enable trans-disciplinary analyses.

- Data-theoretical framework for connecting spatial & temporal data, with the goal of linking data to (i) ecological models that describe interactions among organisms; and (ii) ecosystem models that describe interactions with abiotic variables. This will combine field station eco-informatics with museum databases (including genomics) and environmental layers (past, present, future) to reveal opportunities for integrative research. In the first instance, we will use Berkeley field stations as models for developing this integrated bioinformatics.
- Enabling tools for understanding past and contemporary responses, e.g. mining genomic and stable isotopic signatures of past (decadal or millenial) responses from specimens using new high-throughput technologies, connecting where appropriate to the paleorecord and spatial models of species or habitat change.

4. Development of long-term strategy.- Having defined the overall research goals and strategy by summer 2010, our group will also identify the optimal administrative structure and needs for resources and faculty expertise (eg to inform future FTE requests). This will include preparation of proposals for grants and fundraising, the latter in close liaison with development personnel in both VCRO and the colleges.
Addendum to BiGCB proposal:

**Digitizing and sharing biodiversity knowledge**

Biodiversity informatics, spanning genomic, specimen (including field notes, images, sounds etc.), phylogenetic and ecological knowledge is central to BiGCB and to the entire enterprise of organismal biology. Digitization and georeferencing of collections transforms research capability and access to information and knowledge by scientists and the public alike. Huge advances have been made over the past 5 years in developing the necessary information standards and sustainable IT architectures for this enterprise, often lead by the Berkeley museums and field stations (with support from NSF, GBMF, Mellon and the campus). The museums have recently agreed to move to a single IT platform to achieve greater efficiency and sustainability, and similar efforts are underway to integrate high-resolution environmental data from field stations.

The BNHM hold some 15M specimens, often with associated images, field notes etc., with between 95% (MVZ) and 10% (Essig) digitized and georeferenced. This is the time to achieve the goal of being the first major set of completely digitized and web-accessible museum collections in the world. Moreover, we can lead the way in combining ecological and environmental knowledge from long-term studies at field stations with these collections. The campus has invested substantially in a major project to unite the information resources and underlying IT architecture across museums, and we are ready to proceed towards our ultimate goal.