Bay Area Ecosystems Climate Change Consortium

Strategic Science Plan

Scientific Priorities for Detecting, Understanding, and Adapting to Climate Change

Introduction. The past and continued emission of greenhouse gases has altered the energy balance of the earth, and this is forcing our climate to change. These changes will become more significant over the next several decades due to the impact of greenhouse gases already in the atmosphere, and are expected to become more extreme in the second half of the 21st Century due to the limited global success in reducing emissions.

What will happen to the climate of the Bay Area? How fast will changes occur, and what can we do about it? While we have some understanding already of the changes that are expected, more scientific research is required to answer these questions. The Bay Area Ecosystems Climate Change Consortium (BAECCC) has prepared this *Strategic Science Plan* to encourage research and monitoring that clarifies (1) the impacts of climate change on Bay Area ecosystems and the significance of these impacts for human communities, and (2) actions that managers and planners can take to mitigate and/or adapt to these impacts.[1]

In preparing this document BAECCC sought to compile the recommendations of a diverse array of experts who have been considering these questions over the last several years. Given the breadth of climate change impacts and the increasing attention being given to this field, BAECCC expects that this plan will be revised and expanded upon in the future. It is our hope that this document can serve as a model for other regions that are seeking such a compilation, and that the ideas presented here for the Bay Area will nest within efforts on a larger geographic scale (*e.g.*, Landscape Conservation Cooperatives of the US Fish and Wildlife Service, statewide efforts underway in California, and national research efforts sponsored by the US Geological Survey and the National Oceanographic and Atmospheric Administration).

It should also be noted that scientific work on Bay Area ecosystems is of relevance to Mediterranean-climate ecosystems globally, as this biome faces similar threats across the globe and are important centers of biodiversity. This plan and work conducted subsequent to it should contribute to global networks of shared management and research information that are being developed (INCOMME [International Cooperative for the Management of Mediterranean-Climate Ecosystems] http://www.incomme.org/ and UN-IUCN MTEG [Mediterranean-Type Ecosystems Group] http://www.iucn.org/about/union/commissions/cem/cem_work/tg_mteg/).

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[1] Including how ecosystem restoration and management can contribute to reduction in greenhouse gas emissions and the sequestering of greenhouse gases from the atmosphere.

Approach: There are three multi-jurisdictional, interdisciplinary research and planning efforts in our region to which BAECCC turned to begin this compilation: the Terrestrial Biodiversity Climate Change Collaborative, the Baylands Ecosystem Habitat Goals Update for Climate Change, and the Ocean Climate Initiative of the Gulf of the Farallones National Marine Sanctuary. Below we briefly describe these existing efforts for purposes of providing background.

Terrestrial Biodiversity Climate Change Collaborative (www.tbc3.org). 35 climate and ecosystem researchers in the Bay Area are collaborating in TBC3 to develop scientific information to support long-term management and monitoring of the protected lands of the Bay Area. Collaborators include scientists from UC Berkeley, USGS, iNaturalist, UC Davis, The Nature Conservancy, the Pepperwood Preserve, the Bay Area Open Space Council, Climate Central, Point Blue Conservation Science, and the Creekside Center for Earth Observation.

Using sophisticated downscaling techniques, TBC3 is producing projections of precipitation, temperature, water deficit, and other key environmental variables at local scales that will be accessible using Conservation Lands Network Explorer and on the California Climate Commons. TBC3 is investigating the future of fog in the region, generating spatially explicit datasets describing summertime fog frequency and distribution. TBC3 collaborators are developing a monitoring framework for simple, long-term vegetation measurements, and preparing projections of future vegetation cover in the Bay Area under various climate scenarios. The collaborative is also producing a Bay Area BioAtlas that seeks to build a citizen-science inventory of vertebrates, plants, butterflies and dragonflies in the region with the easy-to-use interface of iNaturalist.

Baylands Ecosystem Habitat Goals Update (the Update). The California State Coastal Conservancy is leading the *Update* of the 1999 *Baylands Ecosystem Habitat Goals* to synthesize current scientific knowledge regarding climate change impacts on the Baylands and to develop recommendations for management actions to ameliorate those impacts. Over 100 scientific and managerial experts from across the region are developing the content of the *Update*, with oversight from a steering committee of environmental management and regulatory agencies and an independent science review panel of national experts.

The *Update* is considering how climate change will influence the evolution of Baylands habitats, shoreline migration, the transition zone between Baylands and uplands, wildlife populations, carbon accounting, and the interface between the Baylands and the Bay. This scientific assessment of the predicted impacts will provide an essential foundation for considering associated adaptation strategies.

The Ocean Climate Initiative of the Gulf of the Farallones National Marine Sanctuary (OCI). Initiated in 2008, the goal of OCI is to foster awareness of climate change impacts in the coastal environment, advance solutions, and promote action amongst government agencies, public organizations, private corporations, and individuals to build ecosystem resilience and sustainability. OCI has organized three biennial Ocean Climate Summits (regional meetings that bring together federal, state, and local agencies, non-profit organizations, foundations, and academic institutions), and has convened climate working groups and workshops to bring together interested parties to better understand and respond to impacts from climate change to North-central California coast and ocean ecosystems.

In 2009, one working group of local scientists from 16 agencies, organizations, and institutions produced a report assessing climate change impacts for north-central California coast and ocean ecosystems that has served as a basis for planning for the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries. The OCI is also working with local scientific experts to determine physical and biological indicators of climate change that can be monitored over time to assess the status and trends of climate change impacts along the North-central California coast. OCI is also working to integrate the information it has generated into sanctuary management, and will be producing a *Climate Smart Conservation Plan* to guide management of the sanctuary in a changing climate.

Products from each of these processes, and interviews with scientists participating in them, have been a key source of the scientific priorities compiled in this document. BAECCC also supplemented information available from these ongoing efforts through participation in workshops and conferences (*e.g.*, State of the Estuary, South Bay Salt Ponds Science Symposium, North American Congress of Conservation Biology). BAECCC also convened a special one-day workshop with scientists with expertise in the Bay and Gulf to further refine scientific priorities for these regions.

Criteria. The criteria below are provided to clarify how areas of research are judged to be priorities. This allows nonscientists to understand the rationale for the priorities based on the information to be generated by the research, which is a key component for engaging the management and regulatory community to build a constituency for conducting the work. In addition, review and commentary on these criteria is a valuable mechanism by which the management/regulatory community can influence the identification of research priorities.

Scientific studies are considered priorities if they:

i) Contribute to projecting future conditions and commit to sharing this information in a manner that supports management application;
ii) Reduce or quantify uncertainties in projections of future conditions that clarify options and improve management decision-making, particularly in areas where ecosystem impacts linked to climate change are expected to be significant and where there are important uncertainties that can be reduced through research;
iii) Identify a new or clarify an existing vulnerability of ecosystems to climate change, including ecological cascades of impacts and thresholds for disruptive change;
iv) Clarify mechanisms of impact and response that help identify possible management actions, including recommendations for new "climate-smart" management models emerging from restoration, reconciliation, and intervention ecology;
v) Monitor long-term ecological change and support adaptive management by facilitating learning about the effectiveness of policies/actions;

vi) Clarify how ecosystem processes can be used to help mitigate the adverse impacts of climate change ("green infrastructure" or "nature-based solutions"), including methods to stimulate ecosystems to sequester atmospheric carbon and reduce release of greenhouse gases.

While criteria can assist greatly in making systematic and transparent decisions about research needs, criteria will not eliminate the need to apply judgment when comparing options. This need derives from trying to compare the significance of the future risk being addressed in the research. Our criteria cannot rank the relative priority for research on a high consequence impact from a poorly understood (and possibly unlikely) forcing as compared to an impact of moderate consequence impact resulting from a forcing that is very likely.

Science Priorities - General

In consideration of the criteria above, the following are topics of research priority. These general topics are then followed by ecosystem-specific research topics gathered in part from recent regional assessments and workshops.

I. Define, develop and maintain the best available quantitative projections for climate, hydrology, and habitat to support policy and management decision-making.
    1. Downscale GCM predictions to a regional scale to support informed decision-making, including sensitivity analyses and other steps that clarify uncertainty.
    2. Validate and improve downscaling and modeling methods to reduce uncertainty and increase confidence in future projections of climate, hydrology, and habitat.
    3. Formulate and establish a technical infrastructure for supporting on-going delivery of future projections and related products (a regional "climate service").[2]

II. Use plausible projections of future climate to characterize the decadal scale changes in temperature, hydrology, sea level, or other geophysical factors that can force ecological change;
    1. Project impacts to ecosystems on the decadal scale, including potential thresholds for disruptive change (ecological cascades that can be triggered by decadal scale changes).
    2. Improve projections of future climatic and ecological conditions by assessing the accuracy of previous model projections and by providing measurements of key parameters used by models.
    3. Develop guidance for contingency planning, including how to adapt species-specific management as ecosystems are altered by climatic and other changes.

[2] Parts of this climate service are already appearing, such as the California Climate Commons, which has established an on-line data and information archive with access to ensemble model projections. A "climate service" as envisioned here would have the capacity to design and promulgate formalized data products for use by a broad array of stakeholders.

III. Use plausible projections of future climate to characterize the frequency and magnitude of extremes in temperature, upwelling, watershed hydrology, or other geophysical factors that could produce unusual or unprecedented environmental conditions in the Bay Area for use in risk assessments.
   1. Identify new or clarify existing impacts of climatic change on ecosystems of plausible future extreme conditions (*e.g.*, heat, runoff, storm surge, wave height)
   2. Develop an understanding of the ecological cascades that can be triggered by extreme events, and the implications of abrupt changes ("regime shifts") for planning and management.
   3. Develop guidance for contingency planning, including how to adapt species-specific management as ecosystems are altered by climatic and other changes

IV. Clarify the interaction of climatic change with other factors driving ecosystem change, including land use, pollution, catastrophic levee failures, reservoir and water conveyance operations, and ecosystem restoration.
   1. Clarify the impact of climatic forcing v. other factors on key indicators of habitat and hydrology.
   2. Clarify where climatic change and other factors can act in an additive or synergistic fashion to create more significant ecological changes (*e.g.*, nutrient pollution and water temperature interacting to produce enhanced primary productivity).

V. Identify important ecosystem attributes and representative indicators that should be monitored to track change and anticipate extreme events
   1. Select and measure over time indicators of climate change, its effects, and the status of the region's resilience; [3]
   2. Measure and assess the effectiveness of ongoing management actions taken to address current and future climate change and recommend improvements;

Science Priorities – Ecosystem Specific

To develop this document, BAECCC engaged with a diverse array of scientists and natural resource managers in the Bay Area. After review of existing documents and conversations with numerous individuals, it was decided to structure the research concepts below using three major ecosystems in the Bay Area: upland (terrestrial), baylands, and the open Bay and near shore ocean. While BAECCC seeks to encourage engagement (both interdisciplinary and inter-jurisdictional) across these boundaries, adopting structure seemed appropriate as it

[3] Indicators might include: air and water temperature, precipitation, sea level, Chl[a], upwelling index, unimpaired runoff, salinity, or suspended sediment concentrations. (see, for example, Cloern, J. E., N. Knowles, et al. (2011). "Projected Evolution of California's San Francisco Bay-Delta-River System in a Century of Climate Change." PLOS One 6(9): e24465 or http://farallones.noaa.gov/manage/climate/indicators.html)

reflects how our scientific, land use, and regulatory enterprises are organized in the region.

It should be noted that monitoring is not specifically called out in the following sections, as monitoring is required in all of the ecosystems. This monitoring effort, which has been described by BAECCC in a companion document,[4] includes the development and assessment of regional indicators of climate change, and the monitoring of other ecological endpoints that (1) assess the effectiveness and recommend improvements of ongoing management actions and (2) improve inputs to models used to project future conditions.

Uplands Ecosystems. The Terrestrial Biodiversity Climate Change Collaborative has been conducting a multi-disciplinary research program using projections of future temperatures and precipitation and water deficit patterns to understand impacts from climate change on Bay Area terrestrial ecosystems. The research priorities listed below for uplands ecosystems relies heavily on their insights.

1) Develop understanding of the dynamics of the transition that upland ecosystems will undergo in response to a changing climate.

a) Project the succession of terrestrial vegetation change, and develop an understanding of the impact of drought, disease, and fire on succession and consequent species abundance and distribution.

b) Understand the capacity of native and exotic species to migrate in response to changing conditions, including how changes in winter vs. summer temperatures impact native and exotic species distribution (*i.e.* migration towards or away from coast, and range shifts along gradients of elevation and latitude).

c) Project alterations in trophic relationships and food webs in response to climate-mediated shifts in vegetation.

d) Identify key thresholds where changes in temperature gradients or extremes (*e.g.*, frost frequency) can be expected to result in significant shift in species abundance and distribution.

e) Understand how changes in the coastal fog regime will influence terrestrial ecosystems.

f) Identify methods for standardizing measures of change in biodiversity, productivity, or other ecologically significant characteristics across landscapes.

2) Identify landscape refugia (places likely to experience less change) and climatic nuclei (places on the landscape occupied by native plants that are likely to expand their future distribution).

a) Identify management strategies that anticipate the transition of plant communities (*e.g*., managing for what's coming, rather than what's leaving), considering key mechanisms of transition (drought, disease, fire, other).

b) Conduct tests of existing management tools (herbivory, fuels management, invasive plant removal, fertilization, restoration) to determine their utility in reducing negative impacts

[4] Available at: http://www.baeccc.org/pdf/BAECCC%20Monitoring%20Network%20description.pdf

of climate change to Bay Area ecosystems and communities.

3) Identify the services presently provided to Bay Area citizens from terrestrial ecosystems (*e.g.*, water storage, flood mitigation, disease control, pollination, aesthetic values, shade/cooling from urban trees) that are at risk from climate change, and management actions available to maintain these services as climate changes.

4) Enhance capacity to reflect projected climatic change in the acquisition and conservation priorities for open space. Identify priority wildlife and migration corridors linking open space to enhance resilience of open space networks in the face of climate change.

Baylands. The California State Coastal Conservancy is presently completing, with input from a diverse array of stakeholders, an update to the 1999 *Baylands Ecosystem Habitat Goals* to address the impacts of climate change. While this update is not yet complete (projected completion in early 2014), some likely priority research projects for Baylands ecosystems can already be suggested.

1) Develop projections of the areal extent and spatial distribution of Baylands that will exist in the future.
    a) Prepare projections using different scenarios for sea level rise and sediment supply.
    b) Increase the accuracy of projections by improving (1) sediment supply estimates, (2) marsh accretion models (especially influence of geomorphological processes), (3) peat accumulation in fresh and brackish marshes
2) Determine the present location of transition zones between baylands and uplands, and where there is space for wetlands to transgress (migrate upward in elevation) as sea level rises.
    a) Identify the transgression spaces that have higher native species diversity.
    b) Identify the transgression spaces that are minimally developed or adjoin existing marshes (or marshes expected to be restored).
    c) Develop a set of priority acquisition targets for transition/transgression.
3) Use demonstration projects to improve existing management practices and identify new "climate smart" practices.
    a) Test whether routing of freshwater (streams, storm water, wastewater) into Baylands generate benefits by (1) capturing sediment and encouraging accumulation of organic matter to generate elevation gains, (2) create more diverse habitat options for native plants and animals, (3) reduce nutrient inputs to the Bay without worsening other contaminant problems derived from stormwater/wastewater.
    b) Test whether protocols and facilities can be developed to keep managed ponds sustainable as sea level rises, including (1) new types of water control structures, (2) sediment management procedures that allow managed ponds to stay at appropriate depths, and (3) levee engineering and maintenance plans.
    c) Learn how to design and construct optimal transition zones, including (1) creation of transition zones in diked baylands from existing levees with fringing tidal marsh, (2) building riverine levees that provide functioning transition zone habitat, (3) how to prepare acquired terrestrial areas as future transition zone habitat.
    d) Construct "living shorelines" (*e.g.*, artificial reefs, subtidal vegetated plots) as

experiments to test wave attenuation, erosion control, and other benefits.

4) Quantify economic value of baylands for flood protection to facilitate choice of designs when infrastructure updates are being planned.

San Francisco Bay and the Near Shore Ocean. BAECCC convened a group of estuarine and marine scientists in the region to help identify research priorities for San Francisco Bay and the near shore ocean (including the Gulf of the Farallones) in April 2012.[5] The concepts below represent contributions from this group, along with information developed by the Gulf of the Farallones and Cordell Bank National Marine Sanctuaries.

1) Develop projections for how climate change will influence the bay and near shore ocean ecosystems, including:

a) The timing and magnitude of upwelling, tidal prism, and tidal velocities.

b) Projected alterations in water temperature and its impact on plant and animal metabolism, including changes in the composition, frequency, and magnitude of harmful algal blooms.

c) Projected alterations in water chemistry (particularly acidification due to increasing concentrations of carbonic acid) and its impact on plant and animal life.

c) Changes in runoff timing and magnitude altering the physical, chemical, and biological composition of the waters of the Bay and Gulf (*e.g*., depressed or enhanced salinity, transport of plankton, residence time of pollutants).

d) Projected alterations of food web dynamics due to changes in physical/chemical parameters.

2) Develop understanding of how changes in the bay and near shore ocean ecosystems will influence coastal and upland ecosystems.

a) Develop understanding of changes in coastal processes, including wave height, sea level rise, and erosion.

i) Develop projections for impact of altered coastal processes on the erosion of beaches and other coastal habitats.

ii) Identify impacts of altered processes on intertidal communities.

b) Develop understanding of the impact of changes in the bay and near shore ocean ecosystems on the production and transport of fog.

i) Project changes in the timing and magnitude of fog under future climatic conditions, and the impact of these changes on water availability, air temperature, and terrestrial community composition.

ii) Develop improved methods for projecting future fog regimes.

BAECCC welcomes all comments on this document, which will be evolving over time as new information becomes available and resources are made available for revision. Please provide comments to Andrew Gunther, BAECCC Executive Coordinator (gunther@cemar.org; info@baeccc.org).

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[5] A written summary of this workshop is available at http://www.baeccc.org/links.php#baecccdocuments