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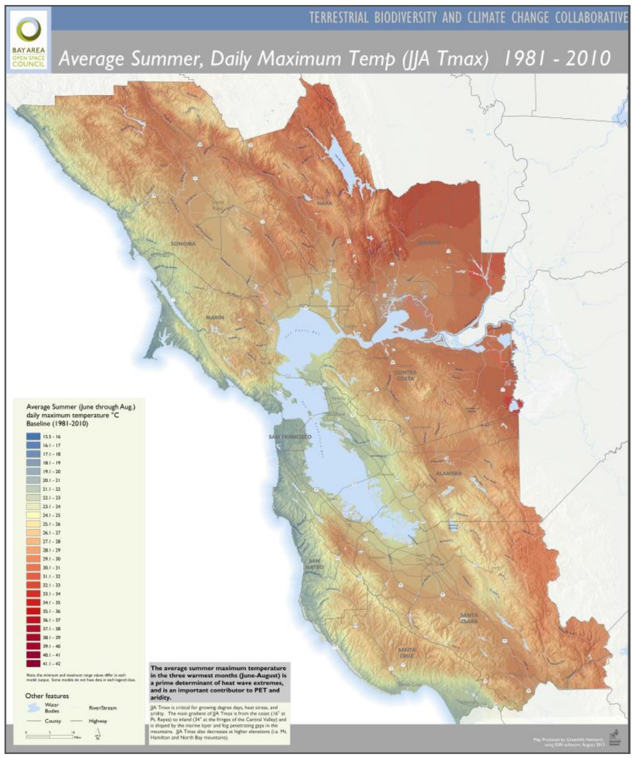
The Terrestrial Biodiversity Climate Change Collaborative (TBC3): an Interdisciplinary Strategy for Advancing Science-based Conservation

December 2013



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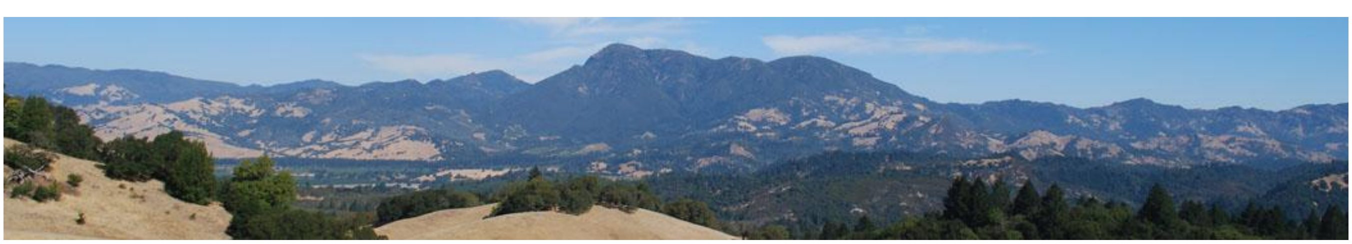

A Dwight Center for Conservation Science **Technical Report**

The Terrestrial Biodiversity Climate Change Collaborative (TBC3):
an Interdisciplinary Strategy for Advancing Science-based Conservation

December 2013 *Lisa Micheli (Pepperwood) and David Ackerly (UC Berkeley), TBC3 Co-Chairs*

I. Introduction

How do you evaluate a landscape's resilience to climate change? The Terrestrial Biodiversity Climate Change Collaborative (TBC3) used this overarching question as a starting point to launch our two-year initiative focused on creating a scientific knowledge-base applicable to management of the San Francisco Bay Area's *Conservation Lands Network*. We recognized that for the Bay Area's complex landscape, well known for its diversity of microclimates, we had to create a high-resolution bio-physical knowledge-base in order to understand how ecosystems may respond to climate change at spatial scales relevant to conservation. As a result, we have piloted an approach that has, to the best of our knowledge, produced the most comprehensive set of integrated fine-scale climate and hydrology map layers (for both historic conditions and future projections) available anywhere on the planet.

TBC3's high-resolution data sets include an analysis of the last 100 years of empirical data as a framework for projecting scenarios for the next 100 years that capture the potential ramifications of a climate perturbed by more or less a doubling of atmospheric CO_2. An innovative component of this project was to evaluate not just climate (i.e. air temperatures and precipitation), but to translate climate variables to their potential impacts on watershed hydrology, which in our water-limited environment is a key control on the distribution of life. By translating downscaled climate projections via a watershed Basin Characterization Model (BCM) into forecasts of local watershed hydrology, we have increased the utility of TBC3 products by integrating the effects of topography, soils, geology and other landscape facet attributes that mediate local climate-ecosystem relationships.

In support of our ultimate interest in biodiversity conservation, our strategy for the last two years has been to lay a foundation grounded in mapping the spatial diversity of the Bay Area's climate-hydrology and linking that map to vegetation distributions in the region. With these results firmly in hand, our goals for long-term research now focus on a better understanding of the potential mechanisms of ecosystem change due to short- and long-term variability in primary climate-hydrology drivers. We now seek opportunities to mine and refine the data products and models that we have generated over the last two years to create stronger linkages to ecosystem services of interest. To support this overarching goal we have defined: A) an outline of immediate conservation applications that could be realized by mining the knowledge-base created as of 2013 (Appendix 1); and B) an outline of potential long term research projects by resource and topic area needed to further advance the state of the science (Appendix 2). The team of TBC3 researchers and analysts engaged in this collective endeavor is listed in Appendix 3.

The following is a summary of next steps, discussed in more detail below.

- Utilize the existing TBC3 knowledge-base and modeling tools to frame comprehensive scenarios regarding potential mechanisms of ecosystem change in the face of climate change.

- Develop a framework for long-term regional integrated monitoring of climate, hydrology, species of conservation concern, and ecosystem services via a network of *sentinel sites* capable of testing hypotheses regarding ecosystem change, to be complemented by remote- and field-based experimental approaches.

- Refine and update modeling frameworks designed to improve forecast projections of the relationships between a changing climate, ecosystem response, and the delivery of our region's ecosystem services based on improved empirical data inputs.

- Bridge the natural and social sciences to better define *resilience* in our management context: link our improved understanding of natural mechanisms of change to goal-setting and socioeconomic strategies for maintenance of ecosystem services.

II. Our Adaptive Approach

Evaluation of ecosystem response and resilience to climate change requires creating and testing hypotheses that address mechanisms of and potential thresholds for change. During the first phase of this project we focused on how climate combined with watershed hydrology drives the current and potential future distribution of native vegetation communities across the region. These vegetation communities generate the habitat structure that shapes opportunities and constraints on where animals can live, and the landscape's potential for ecosystem service delivery. There are now opportunities to tap into real-time data on other ecosystem indicators beyond vegetation distributions alone (including the California Phenology Project, Pepperwood's Bay Area Wildlife Observer Network, and the regional iNaturalist.org BioAtlas generated as part of this project) to better frame hypotheses linking climate, hydrology, and biodiversity.

The progress we have made to date in linking climate-hydrology parameters to ecosystem transitions is portrayed in Dr. David Ackerly's equilibrium vegetation model that utilizes a probabilistic approach to define thresholds for vegetation transitions due to shifts in the distribution of climate. In many cases not all mechanisms of vegetation change are well understood, and thus our long-term research strategy calls for monitoring and field experiments to better evaluate mechanisms of vegetation change due to natural or manipulated variability in climate and hydrology parameters, including extreme events such as droughts and fires. As an example of how we can advance understanding via the TBC3 approach, in this case the vegetation model will be improved via the collection of more comprehensive empirical data designed to better capture physiological and life-cycle responses to climate variability via a field-based framework installed as part of this project.

To support this objective, we have instrumented 50 long-term forest vegetation plots at Pepperwood capable of generating exactly the kind of climate response indicators we will need to understand change in real-time. These vegetation plots are complemented by hydrology and climate instruments including weather stations, soil moisture probes, and a stream gage, plus complementary biological field surveys including bird and amphibian surveys and wildlife camera arrays.

TBC3 is presently using Pepperwood as a site where we can evaluate what an integrated terrestrial *sentinel site* should monitor in order to capture variability in both climate-hydrology drivers and the response of biotic systems. Our vision is that eventually a distributed network of such monitoring stations, covering the gradients of climate-hydrology conditions in the Bay Area, will be implemented to provide critical empirical evidence of the rates of abiotic and biotic change needed to inform adaptive management and the next generation of process-based models.

There are number of areas where refining our current modeling efforts can serve to better define relationships between key ecosystem processes. One of our goals, detailed in Appendix 2, is to integrate a fire algorithm into the vegetation model to enable it to simulate extreme events that will drive vegetation transitions. This enhancement (which we can achieve in part based on the information already generated by monitoring fuel moisture in our long-term vegetation field plots) would allow us to integrate extreme events that currently remain outside the scope of our "equilibrium" vegetation model. Another line of enquiry that can be addressed through scenario testing using the BCM model is how different management strategies for rangelands can influence the water cycle and in turn the amount of soil moisture available to support primary productivity. Appendices 1 and 2 outline a range of arenas where a TBC3 line of natural science enquiry can be advanced through a strategic integration of empirical and modeling approaches.

III. Giving Meaning to *Resilience*

Resilience is generally defined as the capacity of a system to renew itself following a disturbance. Our exploration of *landscape resilience* demonstrates that it is an integrative concept, similar to *sustainability*, which can only be understood in the context of social values and explicit goals. Thus it is not feasible to develop a scientific resilience metric without defining first the resilience of *what* (the system of interest, comprised of specific assets, landscape units, or ecosystem services) to *what* (a disturbance, for example, potential climate stressors) relative to a definition of what would constitute *renewal* (restoration to a historic baseline, level of biodiversity, or a critical threshold of ecosystem service delivery). Thus our products focused on defining resilience – in the context of the Conservation Lands Network relative to the TBC3 knowledge-base regarding potential stressors – demonstrate that *goal setting* is a critical element of defining a framework for targeting *resilience*. TBC3's active engagement with the management community puts us in a unique position to build a bridge between our natural science knowledge-base and the goal of delivering social goods and services via ecosystem management.

An emergent theme, based on our assessment of the Bay Area's complex landscape mosaic of intermingled urban and rural landscape units, is that communities that invest in open space conservation may well ultimately benefit in terms of climate resilience. Open spaces will serve to buffer urban areas from climate change impacts, particularly due to the maintenance of watershed functions including flood retention and water supply, critical to both natural and human communities. The goal of TBC3 is to advance a pragmatic framework for adaptive management focused on better characterizing resilience in the watersheds and landscape units of the Conservation Lands Network. In the process, we are advancing the emerging field of climate adaptation science that necessitates linking a process-based understanding of ecosystems to the socioeconomic framework within which management decisions are made. Appendix 2 includes a section dedicated to outlining a way forward on defining, applying and ultimately measuring resilience at site and landscapes scales.

IV. Immediate Opportunities for Application to Conservation

Having created an extensive foundational data set designed for application to climate adaptation, it is now critical that we work with our community of land, water and biodiversity management practitioners to learn how to best utilize these tools. We seek answers to basic questions such as the following.

- How can we use our knowledge-base of potential climate and ecosystem futures to help update conservation goals to account for climate change?
- How might these climate-hydrology-vegetation projections influence current management directives?
- Are some current management activities maladaptive?
- Are there general adaptation measures that can be promoted to increase the resilience of biodiversity in the region, and if so, how do we spread this knowledge?

To answer these questions with a focus on effective regional climate adaptation, TBC3 will work with managers engaged in climate adaptation planning to ensure a strategic application of our data products. By working directly with resource managers we will develop model adaptation case studies and in the process we will also learn how to better respond to managers' needs in future phases of our work. We are already engaged in a set of pilot case studies in the North Bay and Santa Clara County that will illustrate how to apply this knowledge-base to acquisition planning, stewardship, restoration, watershed management, and agricultural lands protection on the part of local governments and districts. TBC3 will be actively pursuing these kinds of extended partnerships with management agencies focused on a priority decision or adaptive planning needs. We summarize below some of the "low hanging fruit" opportunities to apply the TBC3 knowledge-base to management questions, all outlined in greater detail in Appendix 1.

Strengthening the Conservation Lands Network

Supporting implementation of the Conservation Lands Network (CLN) is critical to TBC3, particularly as that plan gets updated with climate change data and begins to concentrate on prioritizing acquisition and stewardship actions through efforts such as a regional "greenprints" and Critical Linkages implementation. TBC3 has developed expertise in utilizing Marxan, the planning optimization tool that defines the targeted CLN network, in order to incorporate climate data and other parameters into acquisition and stewardship priorities. We have also created tools for evaluating wildlife corridors in terms of their value to building climate resilience. As the Bay Area Open Space Council (BAOSC) will be generating a progress report on the CLN in 2014, Appendix 1 speaks to a range of measures we could pursue to field validate recommended improvements to the CLN based on our evaluation of climate factors on CLN structure and management.

Generating Tools for Watershed Managers

Given the comprehensive hydrological analysis we have conducted for the region, there are opportunities to start evaluating the role of ecosystem services derived from terrestrial freshwater systems (such as stream flow, soil moisture, and aquifer recharge-and in turn, risks of droughts and floods) in meaningful formats for watershed managers. We also now have the potential to integrate consideration of the mediating effects of fog using TBC3's pioneering fog frequency map for our coast. Some of these tasks require simply querying our monthly Basin Characterization Model (BCM), while others would benefit from increasing the temporal resolution of the BCM from monthly to daily time steps, an approach already being piloted for the Russian River basin. Daily model results will be able to more effectively capture extreme events such as flood peaks. With water supply, flood retention and water quality all primary ecosystem services of our protected areas, TBC3's toolbox is clearly applicable to questions of water management as well as biodiversity conservation in the landscape. Appendix 1 outlines the creation of a "watershed managers' toolbox" for specific watershed applications.

Integrating Consideration of Working Lands

Working lands, especially rangelands and working forests, are critical components of the Bay Area's open space landscape. There are a number of extremely practical tools that the current TBC3 knowledge-base can provide to the agricultural and conservation community. We are already piloting an approach to estimate irrigation needs in the Russian River basin for agricultural lands that will result from the increased "environmental demand" generated by the rising temperatures and climatic water deficits associated with climate change. The BCM model also provides the opportunity to test the relative efficacy of varying soil characteristics through management to achieve conservation targets such as increasing the soil moisture holding capacity and forage production for range lands and other "working" conservation lands. These and other applications to agricultural lands resilience are outlined in more detail in Appendix 1.

V. Summary

The TBC3 focus on evaluating the inland impacts of climate change on the lands and watersheds of the Bay Area has largely been "off the radar" of most climate change assessments to date, which have instead focused primarily on the risks of sea level rise to our bay lands and coastal resources, and the impacts of reduced Sierra snowpack on California's water supplies. The issue of sea level rise provides a model of how science-based information can be integrated into long-term planning and ultimately into climate adaptation demonstration projects focused on ecosystem-based solutions to climate risks. TBC3 is committed to advancing our understanding of climate impacts above "the head of tide," which will in turn also create a better framework for understanding dynamics at the land–sea interface. A great example of where these two approaches could be integrated is the Bay Conservation and Development Commission's (BCDC) current focus on strategies to restore the wetland complexes of the San Pablo Bay to provide a climate change buffer for inland resources. Our work will be fully integrated with the activities of the Bay Area Ecosystems Climate Change Consortium (BAECCC) and the California Landscape Conservation Cooperative (CA LCC), linking our understanding of terrestrial and freshwater systems with other active projects related to the Bay and Delta, and the adjacent marine environment.

Our research is showing that communities that have invested in open space resources may be more resilient to climate change impacts in part because of the supporting, provisioning, and regulating services provided by these protected areas. This provides a strong linkage between open space conservation to the overall quality of life for all residents of the Bay Area. Investments in open space and ecosystem services will make the entire CLN system plus its associated urban areas more resilient. But just protecting land is not enough: we need science-based tools to identify best management practices capable of ensuring that ecosystems services and biodiversity are maintained in the future as threats increase in strength and diversity. Our next steps include identifying the management and decision-making arenas where our knowledge-base is most needed in order to prioritize our efforts at outreach and distribution, especially as we promote our approach as a model for application at larger spatial scales (i.e. California, US West).

TBC3's knowledge-base offers a regionally consistent yet locally customizable framework for integrating potential climate futures into regional scenario planning. Summary data products are now available online through the Explorer Tool and the California Climate Commons, but these provide users only a tiny subset of the information. Improving online access to data and interpretive tool kits is a critical need to further develop with our partners. Opportunities for immediate application include more comprehensive collaborations on vulnerability assessment and adaptive planning case studies, such as the one recently funded by the State Coastal Conservancy for the North Bay region including Sonoma County, Southern Mendocino County, Napa Valley, and Marin County. It will be critical for TBC3 to gain sufficient resources to remain engaged with Bay Area regional planners currently focused via the Joint Powers Commission (JPC) on creating a process for a comprehensive scenario planning effort in the region across sectors. TBC3 is committed to promoting the importance of ecosystem services as an asset and a resource in regional climate adaptation and resilience planning.

The remainder of this document is comprised of three Appendices. The first identifies a list of potential short-term conservation applications using the existing knowledge-base. The second outlines recommendations for long-term research by resource area. Both rely on the core group of lead researchers identified in Appendix 3, who have made a commitment to ongoing collaboration via TBC3. Our goal is to remain connected through monthly webinar exchanges, collective collaborations on proposals and papers, and an annual research intensive gathering using Pepperwood as a hub for group activities. We are inspired to continue advancing a unified interdisciplinary vision for applied research anchored by the concrete challenge of shaping and stewarding our region's Conservation Lands Network.

Appendix 1: Opportunities for Immediate Conservation Application

The knowledge-base has been built, but now we seek resources to translate, package, and deliver that information to the conservation, land, and water management communities. All of the proposed efforts below would tap into the existing TBC3 knowledgebase and related products and would proceed in close collaboration with partner agencies and data dissemination outlets.

Multipurpose Queries of Existing Data Layers: Extreme Events and Other Questions
The current data sets are comprised of literally millions of data points representing the future of the Bay Area. Currently the only data sets available on line are condensed time series of 30-year averages for both historic and model output variables. A very simple way to make the data more applicable to on-the-ground conservation is to develop and deliver some additional derivative datasets that would be universally applicable throughout the region to very basic questions on the part of researchers and managers. All of these could be easily disseminated via the California Climate Commons and other outlets. Workshops and outreach activities described below could focus on how to obtain and apply these data derivatives.

- Identify potential change in frequency and severity of *extreme events* such as droughts and potential flooding conditions, by statistical extraction from 18 climate futures
- Extract Basin Characterization Model (BCM) hydrology results for each standardized planning watershed in the Bay Area for watershed managers
- Make Conservation Land Network (CLN) landscape unit vegetation reports that include future projections of vegetation for land managers
- Analyze climate space relative to biological data sets beyond vegetation layers

Conservation Lands Network Implementation
The first phase of TBC3's analysis identified 591 priority locations key to maintaining climate diversity presently included in the CLN and 117 presently not included in the CLN. Priority locations possess rare climate attributes defined at the regional or sub-regional level. Prior to recommending these priority locations for inclusion in the 2014 CLN update, we aim to investigate the biological communities represented there to confirm their conservation value. In addition, the current climate prioritization exercise only considered climate diversity with no bias toward particular types of climate. Our analysis suggests that targeting particular climate space rather than diversity will change prioritizations of both landscape units and planning units. Given the strong directional changes predicted by models (increased warming, aridity) it makes sense to also re-run Marxan models to prioritize regions of cool, wet climate types which are becoming rare relative to warm, arid types. Recommended next steps would support the

Bay Area Open Space Council's (BAOSC) *CLN Prioritization Assessment and Mapping* project currently in the planning phase that aims to identify vital habitats, climate spaces and specific parcels key to realizing CLN objectives. Potential next steps include the following.

- Field-validate conservation value of rare climate locations
- Evaluate CLN Marxan model in the context of future vegetation projections
- Conduct supplementary Marxan analyses: test sensitivity of network to a range of climate prioritizations
- Prioritize Critical Linkages relative to climate
- Identify range limits and outliers of key species that provide foci for spread or trailing edge refugia
- Support CLN progress report slated for 2014

Watershed Managers' Toolbox

This project is a direct application of BCM hydrologic outputs to provide an integrated understanding of how entire watersheds of varying scales, with existing infrastructure, are likely to behave in the face of climate change. These tools would be developed with watershed and water supply managers to find best statistical output formats for planning purposes. The purpose is to develop visualization and analysis tools for watershed and water supply managers that support effective watershed management scenario planning. There are a variety of outlets including the California Climate Commons and CalAdapt that we could work with to host these interpretive products.

TBC3 has produced prototypes of key Toolbox elements including the following.

- Water balance diagrams that provide a monthly visualization of seasonal variation in soils storage, recharge, runoff, AET, and CWD throughout the year
- Diagrams displaying the dynamics of individual years, multi-year droughts, as well as hydro-climate over longer periods (i.e. 30-years)
- Tools to distinguish between vegetation drought (low AET and high CWD) and water supply drought (low recharge and runoff)
- Aggregation into Planning Watersheds to provide ready access to the histories and projections for standardized natural hydrologic units
- Quantiles for 30-year periods for historic and 18 futures for each output , including 2 and 3-year running averages, to identify extreme events

Future development would include the following.

- Extraction of monthly BCM results for each planning watershed in the Bay Area for on-the fly-production of water balance diagrams and time series statistics (for this work, we would extend all analyses to cover the entire watersheds that contribute to Bay Area surface water flows, with a special focus on the Russian River)
- Development of tools for extracting monthly time series for a customized area of interest
- Simple database operations to aggregate data for annual and longer time scales
- Identification of potential change in the frequency and intensity of extreme events such as droughts and potential flooding conditions by statistical extraction from 18 climate futures at the watershed scale
- Development of metrics for human alterations of watershed function – such as extent of impervious surfaces or land use impacts on recharge
- Enhancement of the CLN watershed analysis of aquatic ecological value and human impacts

These tools would be developed with watershed and water supply managers to ensure that the information delivered addresses a suite of potential management alterations that could improve water security. Working with water managers will result in a suite of core products that are useful to all water managers and these can then be disseminated via Climate Commons and other outlets. Coupling our understanding of land conservation with water management is an important direction for strengthening the justification and support for continuing to conserve the CLN.

Applications to Agriculture and Other Working Lands

Our preliminary exploration of TBC3 applicability to working lands demonstrates that there are many agricultural metrics that could be readily generated and would be most helpful to the agricultural community at large, including the following:

- Climatic water deficit and forage production
- Irrigation demand
- Length of growing season, growing degree days
- Chilling hours
- Frost risks
- Pest vulnerabilities

There is also an opportunity to apply the monthly BCM approach to evaluate the potential hydrologic enhancement of working lands as a resilience strategy in concert with Point Blue's Rangeland Watershed Initiative and using Pepperwood as a case study**.** This would provide both a modeling and empirical measurement opportunity to assess the hydrologic impacts of different management practices in rangelands and other agricultural operations. Our approach would be to work with working lands managers to design and implement conservation friendly practices. In the process we could use the BCM to assess what effect the practices will have in the future given climate change and design a suite of field-based indicators to test the BCM model in the field.

Vulnerability Assessments, Adaptation Planning, and Ecosystem Service Valuation Support: Tools and Case Studies

We are presently working on two case studies applying TBC3 data to applied management. Our preferred model is to create a user group that we work closely with at the start of the process and then throughout the analysis to ensure we are meeting managers' needs. We have received partial funding from the State Coastal Conservancy to mine existing datasets for a North Bay vulnerability assessment that will focus on water availability for people and ecosystems. In the North Bay case study, user groups are comprised of natural resource management districts and county and city planners. We are also working on a case study for the Santa Clara Open Space authority focused on prioritizing open space acquisition and management strategies.

- Our North Bay and Santa Clara projects provide a model for extending this approach to the entire Bay Area region and beyond
- We are also exploring a support role in the S3 Ecosystem Valuation initiative and similar projects
- In all cases, we will focus on identifying mitigation/adaptation co-benefits
- The products from these case studies will serve as models that we seek to develop with other groups in the Bay Area in order to build a comprehensive approach to adaptation at the landscape scale

Regional Habitat Connectivity and Greenprint Planning

Connectivity is often cited as a primary strategy for planning for climate change adaptation. Beyond what is currently planned in the context of the CLN via Critical Linkages, our team has demonstrated the value of higher resolution wildlife permeability assessments and planning via our pilot study in the Mayacamas Range. The purpose of expanding these analyses would be to identify linkages at a scale that land trusts and others working on land acquisition operate at. The other objective will be to identify which patches in the Bay Area may not be able to support species in isolation and hence require corridors to the rest of the network for species persistence.

Population persistence metrics - such as mean time to network-wide extinction or probability of extinction within a given timeframe - are necessary for determining the impacts of different network configurations (habitat patches and linkages) on population persistence. These methods can be used to prioritize linkages within the matrix according to their influence on dispersal between patches and the importance of those dispersal pathways to species persistence in the network. We have already developed stochastic, demographic, spatially explicit meta-population models that are parameterized for many species and using simulations to compare how the subtraction of each patch and linkage in a complete network influences mean time to network-wide extinction. Only through this type of persistence modeling will we be able to honestly examine the trade-offs between corridor conservation and augmenting the size of existing protected areas for long-term biodiversity conservation. Importantly, this approach can incorporate economic trade-offs – allowing us to prioritize how conservation dollars are applied within a network of cores and corridors.

Expanding the application of this approach would include the following.

- Extend wildlife permeability analysis to identify fine scale patches and linkages for the entire Bay Area
- Prioritize linkages parcels based on importance for species persistence, across a range of body sizes
- Identify climate adaptation value of patches and linkages at a parcel scale
- Finance questions
- What are the economic tradeoffs of investing in patches (core areas) vs. investing in linkages (corridors)
- Where should mitigation investments, primarily from the transportation sector, be applied to provide ecosystem service and species returns as well as cumulative advantages to the CLN

Bolstering Biodiversity Datasets

The TBC3 Bay Area BioAtlas now provides a framework for utilizing new biodiversity observations to test whether species are starting to shift locations in the Bay Area as a result of climate change and other stressors. Partnerships such as iNaturalist.org, the California Phenology Project, and the Bay Area Wildlife Observer Network have crafted ways that naturalists of all levels of expertise can collect research-quality observations under the supervision of trained biologists. Presently, Pepperwood is working with the Sonoma County Water Agency and Santa Rosa Junior College to develop a coast to inland transect of weather-vegetation monitoring stations capable of tracking ecosystem response to climate variation. iNaturalist.org with partners including Pepperwood, the California Academy of Sciences, the Encyclopedia of Life, and National Geographic are spearheading community “bioblitzes” to rapidly assess species distributions at select protected areas. TBC3's role in advancing these initiatives could include the following.

- Define methods that quantify sampling efforts in order to start documenting species' absences in addition to species' occurrences using Pepperwood as a case study
- Advance implementation of the Sonoma County pilot to implement a coast to inland monitoring transect
- Collaborate with NOAA to extend their Bay Area Sentinel Site project from the Bay to inland watersheds via a terrestrial sentinel site network
- Continue to provide leadership in the Bay Area Ecosystems Climate Change Consortium's (BAECCC) monitoring working group to coordinate a multi-agency effort across the full range of Bay Area ecosystems

Outreach and Training for Land, Water and Biodiversity Managers

We need to work with decision-makers to demonstrate the salience of these data products, to develop our collective understanding of key ecosystem vulnerabilities, and to define how fine-scale climate data can improve conservation investments. To be most effective, we need to better understand where and when this type of information is most valuable so that we can prioritize distribution and outreach. To meet these needs we propose it is key for TBC3 to be engaged in the following kinds of activities.

- Developing and delivering workshops in data use and scenario planning
- Placing TBC3 tools in a comprehensive adaptive management context
- Online dissemination via partners including the Explorer Tool, the California Climate Commons, the USGS Data Portal, Cal Adapt and others.

Visualizations and Messaging

We need to better communicate our findings and use creative methods to illustrate data outputs and findings to build public support for climate change adaptation particularly in terrestrial uplands where the risks and opportunities are not well understood. Our experience delving into communication of our products via the media in a recent KQED Climate One feature on TBC3 demonstrated the value of broadcast media coverage complemented by on-line visualization products developed by the Stanford Spatial History Lab[1]. With dedicated resources focused on visualizations and messaging we will explore the following communication tools.

- Live presentations at regional and national conferences that convey our approach to colleagues, practitioners, and funders
- Messaging partnerships with media experts on how to frame a climate "story" that people can relate to
- Time series animations and other video products via partnerships with big data visualization specialists
- Interactive climate analog models that allow users to locate places that currently have the climate projected for their area of interest in the future
- An interpretive "road show" that could tour science museums and other interpretive centers of the Bay Area
- Complementary products for tool kits that feature scientists describing their products "live" (a recent survey showed that access to in-person descriptions of research products and implications direct from the authors of the research are managers' number one information need)

[1] http://blogs.kqed.org/science/2013/09/09/warming-climate-could-transform-bay-area-parks-and-open-space/

Appendix 2: Long-Term Research Outline by Resource Area

Climate, Hydrology and Fog

1) Daily (versus monthly) Basin Characterization Model for Bay Area to better address freshwater system health and potential for extreme events

This approach of extending the BCM from a monthly to a daily model is currently being piloted in Russian River in partnership with the Sonoma County Water Agency. Extending this approach throughout the Bay Area would entail the following steps.

- Calibration of a daily model for the Bay Area with future projections
- Estimation of flooding and other extreme events at sub-monthly time intervals
- Linking flows and habitat by relating terrestrial hydrology to health of rivers and freshwater ecosystems by defining environmental flows and hydro-ecological thresholds

2) Developing a "dynamic" version of the BCM to capture feedbacks of dynamic land cover on hydrology

The current version of the BCM model is an "equilibrium" version that assumes static land cover that is in equilibrium with available water and actual evapotranspiration that is equal to potential evapotranspiration until soil water content is limiting. A disequilibrium model would incorporate land cover and calibrate for seasonal transpiration coefficients, allowing for modeling feedbacks due to transitions in vegetation cover due to disequilibrium events such as droughts or fires. A dynamic BCM model could be validated with remote sensing data and pre- and post-fire stream flow data. It could also calibrate water deficit to satellite-based NDVI and other nationwide metrics. This approach would directly link a dynamic hydrology model to the dynamic vegetation model described below, and could also address the impacts of urbanization on runoff and soil recharge.

3) Linking fog frequency to water cycle and ecological attributes

Our analyses of the impact of fog on ecosystem functions and services demonstrate it is a critical factor in mitigating the effects of climate change in increasing the aridity of Bay Area lands. For example, during the dry season, redwoods rely on fog for over 50% of their water needs. Next steps in our Pacific Coastal Fog research initiative involve creating stronger linkages through integration of satellite and field-base data collected via a FogNet monitoring network between fog and critical ecosystem services of interest. Key questions to address include the following.

- Are fog occurrence patterns and plant species correlated? If so for what species and how strongly?
- Is there a coefficient that captures the impact of fog on temperatures that can be incorporated into historical climate reconstructions and models of future climates?
- What is the effect of fog on cumulative growing degree days, stream temperatures, and extreme heat events?
- How does fog influence the soil moisture available to ecosystems?
- To what extent does fog influence evapotranspiration?
- How much does fog impact watershed hydrology as reflected in stream gage flows?

4) Regional topo-climate model

The 270 m scale of the current BCM does not capture topo-climatic gradients of maximum and minimum temperatures that operate at scales of 10-30 meters. A research goal is to synthesize general rules that we can apply to any landscape based upon fine-scale topography. The basic methods are empirical measurements using dense networks of inexpensive sensors combined with biophysical/statistical modeling to relate gradients to prevailing meteorology.

TBC3 produced an example of a topo-climate model at Pepperwood based on data collected via a network of Hobo sensors deployed for a year. Results include the following.

- Documented large range in daily T_{min} and T_{max} , with a 10°C average difference across Pepperwood sites. This analysis showed that sites 50 m apart can experience significantly different frost/freeze conditions.
- Clear effects of cloud cover, rainstorms, and tree leaf-out on temperature patterns
- A statistical model of winter minimum temperatures highlights topographic variability in temperature and frost/freeze frequency

Further work would include the following.

- Integrate and supplement the temperature sensor network in long-term vegetation plots at Pepperwood
- Measure canopy cover with hemispherical photography for better estimation of T_{max}
- Further develop and test impacts of key topographic driver variables
- Incorporate prevailing meteorology (clouds, wind, fog, etc.) into a dynamic model
- Generalize models for use in different parts of the Bay Area

- Downscale BCM to 10 meters at Pepperwood (plus downstream basins) for fine-scale modeling in order to calibrate topo-climate results to soil moisture and streamflow
- Downscale Bay Area BCM to 30 m for regional analyses of topoclimate and implications for landscape scale resilience

5) Statewide characterization of environmental flows for all basins (gaged and ungaged) required for ecologic integrity

The BCM provides an opportunity to link watershed hydrology to critical flows throughout an area of interest. Proposed activities to support the objective of defining flows needed to support key ecosystem functions include the following, which could be piloted at the scale of the Bay Area, and ultimately extended throughout the state since our Bay Area BCM work has now been extended throughout California thanks to match funding from the California Landscape Conservancy Cooperative (CA-LCC).

- Use the BCM to develop a hydro-geomorphic classification to regionalize and extrapolate environmental flows to un-gaged basins
- Identify regional environmental flow metrics required to sustain aquatic ecosystems to assist in managing and restoring rivers and aquatic habitats including wetlands
- In selected rivers throughout the state representing all Integrated Regional Management Plans (IRWMPs), investigate the relevant contributions of potential drivers of change, such as climate, land use, and fire
- Summarize changes in environmental flows and identify sensitive landscapes as priority areas for flow and habitat conservation
- Use the models to help water supply managers to better plan for future uncertainty in water availability

Vegetation, Fire and Land Cover Dynamics

TBC3 has developed a unique model to project vegetation distributions under future climate. This model is providing a strong basis to guide dialog around shifting management strategies and to evaluate the efficacy of the Conservation Lands Network (CLN). In the next phase of our work, we will continue to develop this modeling framework and apply it to Bay Area conservation questions. We will need to address three critical problems that have been highlighted by our modeling and field work: 1) dynamic vs. equilibrium responses; 2) limits of climatic tolerance to heat and drought; and 3) coupled responses of fire and vegetation under a changing climate. These goals will be developed through approaches outlined below.

1) Probabilistic vegetation modeling: next steps
To maximize the value of our probabilistic vegetation model, we seek further analysis of fine scale results for projected vegetation change in relation to topographic variation in climatic water deficit and other factors. Three key results of the model merit further exploration to provide local assessments at the scale of individual parks or landscape units.

- The expected shifts of vegetation from south- to adjacent north-facing slopes
- The greater sensitivity of vegetation patches that lie near the edge of the climatic envelope, in a regional context
- The location of climatic 'nuclei' – patches of vegetation that are expected to expand in the future

Steps to address these issues include the following.

- With the development of a 30 m BCM projection, we can rerun the model at a finer scale to take into account detailed topographic patterns
- Additional GIS analyses to project full raster outputs of the model that can be easily incorporated into GIS projects by local conservation and open space planners

2) Long-term field plots
In 2013 we installed 50 permanent vegetation plots at Pepperwood. This entailed tagging, mapping and measuring a total of >4000 trees of 22 species and recording numerous biotic and abiotic features of the plots. In 2014 we will complete installation of a micro-meteorological monitoring network with data sensors in all plots. Long-term permanent plots are critical for early detection of climate change impacts, including tree mortality, shifting species composition, new invasive species, etc. Our network was designed to test specifically for differential impacts across topographic gradients. We will conduct annual monitoring of selected variables and complete resurveys of these plots every five years, following established protocols for long-term forest monitoring. We will also encourage new research projects that use the plot network as a foundation, given the detailed background information available. We will contribute and be involved in coordination and development of regional monitoring that builds on this plot framework, especially in conjunction with the Forest Ecology Research Plot at UC Santa Cruz, sudden oak death monitoring overseen by UC Davis and Sonoma State University, and the National Park Service Inventory and Monitoring Program.

3) Linking physiology, demography and vegetation change
The TBC3 vegetation model uses statistical mapping of vegetation distributions in relation to climate to project future equilibrium responses of vegetation to climate change. In other words, once the plants have had time to disperse, reestablish new populations, etc., where would we expect different vegetation types to occur based on climate suitability? Evidence from various

sources suggests that such equilibrium responses may take hundreds of years to unfold. Thus, on the scale of decades relevant to resource managers, our primary concern will be with the initial dynamic impacts of climate change, and the developing disequilibrium between climate and vegetation. Projecting dynamic responses hinges on improving our mechanistic understanding of physiological and demographic responses to climate. Future research led by the Ackerly lab will focus on direct measurement of freezing tolerance, chilling requirements, and drought tolerance of woody plants that comprise major Bay Area vegetation types. Two key questions (that both hinge on factors that vary as a function of distance from the ocean) include the following.

- How will plants respond to the contrasting effects of release from cold stress combined with increased heat/drought stress in interior locations?
- When will climatic extremes cross tolerance thresholds leading to tree mortality, as has occurred in other parts of the western U.S. and the world?

4) Coupled responses of fire and vegetation to changing climate

Increasing temperatures are expected to lead to an increased risk of wildfire in coastal California. Under 'business-as-usual' emissions scenarios, Bay Area fire regimes may resemble southern California by the end of the century (model results from Max Moritz, UC Berkeley). It remains difficult to link the projected impacts of climate on fire and vegetation, as changing fire regimes will alter vegetation responses, and vice versa. Ackerly and Moritz (with Moore Foundation support via the Berkeley Initiative in Global Change Biology) are developing models to understand these dynamic responses, and future collaborations with climate modelers at Lawrence Berkeley National Lab could lead to new models translating future climate projections into extreme fire weather conditions and scenarios for Bay Area wildfires. Land managers, water managers and county planners all have a very high level of interest in future fire projections.

5) Linking vegetation transitions to invasive species distributions

Invasive plant species are abundant throughout the Bay Area. As vegetation types transition in response to climate change, sites are especially vulnerable to invasion. Widespread dominance of non-native plants could result in loses of important ecosystem services and native species diversity. Conservation managers need to understand where these risks are especially high. The California Invasive Plant Council and the Bay Area Early Detection Network provide maps of the distribution of invasive plant species, and projected modeling of which invasive species may increase in response to climate change. By combining data on invasive species abundance and distribution with vegetation probability change we can estimate risk of invasion. This will refine our measure of site vulnerability as currently estimated by the vegetation transition model. This added metric will help provide priorities for invasive species control and increase the probability for native plant species to colonize areas as systems transition (i.e. post fire).

- Using CAL-IPC maps and modeling, we will identify a set of 10 most noxious and climate change loving invasive plants in the Bay Area
- Map populations of invasive species (IS) by integrating existing data and conducting targeted field work plus surveys with managers
- Intersect IS maps with output from the vegetation probability transition model to estimate areas of high invasion risk
- Integrate data into Explorer and other tools for managers

Biodiversity and Habitat Permeability for Wildlife

Field assessments of wildlife occupancy and mammalian biodiversity using the Wildlife Picture Index (WPI)

Evaluating wildlife biodiversity as an indicator of ecosystem resilience and services in the face of projected climate change on the landscape can generate testable hypotheses using different climate scenarios. Long term monitoring of wildlife populations via Pepperwood's Wildlife Picture Index (measuring trends in biodiversity at the landscape level) is currently setting a baseline for the Mayacamas Mountain. Expanding the use of the WPI would increase our understanding of how climate-hydrology variables measured in real time correlate with changes in diversity and abundance of the upper trophic levels (mammals that are squirrel size or larger). Additionally, small mammal trapping, acoustic monitoring for bats, and insect surveys could round out mammalian presence and diversity.

An Integrated Approach to Long-term Data Collection

A focus of TBC3 has been the science-based design of a monitoring network (series of sentinel sites) to capture fluctuations in climate-hydrology and the biological response. We are currently building an integrated terrestrial monitoring sentinel site at Pepperwood and collaborating with partners to design a regional framework. Variables to be measured include the following.

- Meteorology via a dense network of weather stations, as presently being piloted in the Russian River basin Hydrometeorological Testbed in partnership with NOAA
- FogNet attributes (visibility, liquid water content, fog water collection)
- Soil Moisture
- Plant phenology, composition, reproductive success and vigor
- Mammalian diversity via WPI
- Bird diversity and abundance
- Reptile and amphibian diversity and abundance

- Insect diversity and abundance
- Citizen science data (including eBird and iNaturalist)

Defining and Measuring Resilience

TBC3 has been developing resiliency definitions and frameworks for adaptation planning for terrestrial upland habitat in the context of a research paper on this topic. We propose to continue this work along a number of angles serving to integrate resilience theory with the climate-hydrological outputs, vegetation transition models, and case studies developed with conservation managers. This research will develop a framework for defining and evaluating site, landscape unit, and regional level resilience goals and interventions in conservation decision-making. We aim to address the following.

- Describe the variety of resilience metrics (with input about resilience goals from conservation managers and other stakeholders)
- Map the Bay Area in terms of a range of resiliency indices.
- Identify which resiliency goals are achievable, and which are not, given different climate change scenarios
- Develop a working theory to organize and test knowledge about managing transitioning ecosystems
- Identify gaps in knowledge and data needs about ecosystem states and services, and ecosystem responses to disturbance, stresses and management interventions

Questions we will seek to answer include the following. What are the preferable trajectories for ecosystems when considering biodiversity and ecosystem services? What management options are available and which ones show tight feedback loops between actions and consequences? What management actions are the best leverage points to increase resilience of terrestrial ecosystems and move systems into alternative preferable trajectories? What current management actions may be maladaptative?

We will also work to refine Conservation Lands Network Resilience strategies in the following ways.

- Consider habitat in urban and agricultural lands. The CLN does not currently consider the habitat value of the urban and agricultural matrix. However, some rare and important climate space (i.e. cool, moist) emerges in these areas.
- Explore implications for urban adaptation planning such as ecosystem restoration and tree planting. We need to explore climate space in urban areas to identify important areas for restoration and to take advantage of urban adaptation efforts for native species conservation.

- Evaluate CLN with comprehensive treatment of threats. Add land use change projections from UPlan and USGS LandCarbon projections and invasive species distributions into CLN prioritization exercises.

Appendix 3: TBC3 Participants, 2011-2013

TBC3 Co-chairs
Lisa Micheli (Dwight Center for Conservation Science at Pepperwood)
David Ackerly (UC Berkeley)

Output 1.1 Generating fine-scaled climate-hydrology projections
Stuart Weiss (Creekside Center for Earth Observation), Co-chair
Healy Hamilton (NatureServe), Co-chair

Team members:
Lorraine and Alan Flint (USGS)
Nicole Heller (Duke University)
Kirk Klausmeyer (The Nature Conservancy)
Bridget Thrasher (Climate Central)
Jim Thorne (UCD),
Sam Veloz (Point Blue)

Output 1.2 Generate ecologically-relevant fog data sets
Alicia Torregrosa (USGS), Chair

Pacific Coastal Fog Team Members:
Gary Ellrod (Ellrod Consulting)
Jim Johnstone (U Washington)
Sam Iacobellis and Dan Cayan (UC San Diego/Scripps)
Kelly Redmond (Desert Research Institute)
Travis O'Brien (Lawrence Berkeley National Lab)
Chuck Wash (Naval Postgraduate School, emeritus)
Alex Hall and Alex Jousse (UC Los Angeles)
Eric Waller (UC Berkeley)
Alan Flint, Lorrie Flint, Mary Ann Madej, Crystal Ng (USGS)
Natalie Gates and Daphne Hatch (National Park Service)

Output 2.1 Integrate climate analyses into the Bay Area Conservation Lands Network
Nicole Heller (Duke University), Chair

Team members:
David Ackerly (UCB)
Lorraine Flint (USGS
Ryan Branciforte (BAOSC)
Kirk Klausmeyer (The Nature Conservancy)
Jason Krietler (USGS)
Adina Merenlender (UCB)

Lisa Micheli (Pepperwood)
James Thorne (UCD)
Sam Veloz (PRBO)
Stuart Weiss (Creekside Center for Earth Observation)

Output 2.2 Define relationships of topo-climate gradients to vegetation distributions
David Ackerly (UCB), Chair

Team members:
Lorraine and Alan Flint (USGS)
Michelle Halbur, and Morgan Kennedy, and Lisa Micheli (Pepperwood)
Meaghan Oldfather, Matthew Britton, Mike Hamilton, Shane Feirer (UCB)
Jim Thorne (UCD)
Stuart Weiss (Creekside Center for Earth Observation)

Output 3.1 Compile a Bay Area "bio-atlas" of species presence to provide a contemporary baseline and a basis for projecting extirpation risks from climate.
Scott Loarie (Carnegie Institute, iNaturalist.org), Chair

Team members:
Ryan Branciforte (BAOSC)
Healy Hamilton (Nature Serve)
Morgan Kennedy (Pepperwood)
Kirk Klausheymer (The Nature Conservancy)
Jim Thorne (UCD).
Sam Veloz (Point Blue)
Stuart Weiss (Creekside Center for Earth Observation)

Output 4.1 Facilitate team communications, provide project oversight and deliver project updates and reports to GBMF
Lisa Micheli (Pepperwood), Chair

Team members:
Michelle Halbur, Adrienne Pettit, Tom Greco, Morgan Kennedy (Pepperwood)

Output 4.2 Develop and deliver annual research retreats
Lisa Micheli (Pepperwood), Chair

Team members:
Michelle Halbur, Adrienne Pettit, Tom Greco, Morgan Kennedy (Pepperwood)

Output 4.3 Create on-line interface with BAOSC CLN Explorer tool in the form of a Climate Portfolio Report
Ryan Branciforte (BAOSC), Co-chair

Stuart Weiss (Creekside Center for Earth Observation). Co-chair

Team members:
David Ackerly (UCB)
Lisa Micheli (Pepperwood)
Amanda Recinos (Green Info Network)

Output 4.4 Develop and deliver land manager outreach and a workshop in partnership with BAOSC.
Lisa Micheli (Pepperwood), Chair

Team Members:
Ryan Branciforte and Annie Burke (BAOSC)
Stuart Weiss (Creekside Center for Earth Observation)

Output 4.5 Develop a long-term research strategy
Lisa Micheli (Pepperwood), Chair

Team members:
All output chairs listed above