How a Network of Dedicated Climate-Biodiversity Sentinel Sites can Support 30x30 Implementation

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Outline

A Vision for Real-time Science to Inform Conservation

Imagine a future when the stewardship of California's natural heritage is informed by continuous climate and biodiversity indicators capable of both identifying early warning signs of species at risk of extinction *and* measuring the benefits of our restoration and adaptation investments. As the frequency of extreme climate events increases, this monitoring system would alert nature stewards *in real-time* about potential biodiversity gains and losses. Imagine an information gathering framework designed from the outset to meet the needs of decision-makers and diverse community members through a collaborative process. Imagine a future where even elementary school students could access valid data on the trends for organisms they observe in their very own backyard. This is the promise of a Climate-Biodiversity Sentinel Site Network for California: a shared information service for extinction prevention we can all use to identify species in trouble, ***before*** it's too late to take action.

Members of the California Biodiversity Network's Sentinel Site roundtable are collaborating to realize this vision by creating a real-time observation network capable of responding to priority questions that bridge disciplines and geographies such as:

- What are the impacts of drought, fire and hydrological variability on biodiversity and ecosystem services?
- Where is climate change causing the greatest threat to biodiversity?
- Where are species in decline or recovery?
- Where should acquisition and/or restoration activities be concentrated?
- How are species responding to management/stewardship/restoration activities?
- How does habitat restoration and species recovery this track against targeted conservation goals?

Multi-disciplinary benefits of such a network identified by roundtable members include the following.

- Standardizing measurements at the site scale to allow data comparisons and aggregation
- Improving direct assessments of relationships between climate parameters and biodiversity responses
- Improving data management efficiency and increasing data access via utilization of shared platforms for analysis
- Supporting landscape-scale inferences by combining multiple data sets
- Improving model forecasts of climate effects and other stressors on biodiversity
- Creating a transparent process for evaluating indicators relevant to management and conservation investments

With recent advances in technology and a rekindled commitment to collaboration across jurisdictions, we can now envision and build a network that effectively fills data gaps and integrates the knowledge and findings of diverse practitioners across the state of California into an aggregated whole. Below we spell out the rationale and a way forward towards a multi-jurisdictional Climate-Biodiversity Network serving the State of California's 30x30 Initiative goals and objectives.

The Value of Empirical Data Collection

Recent history shows that California is now subject to increasingly frequent extreme events due to climate change with measurable direct and indirect impacts on the state's biodiversity. This includes two extended periods of

significant drought, wildfire seasons that have increased in severity and length, severe weather patterns and storms, marine heat waves triggering multiple unusual mortality events, and changes to the distribution, phenology, and prevalence of species and habitats. As communities, academic researchers, conservation practitioners, and policymakers work to understand and adapt to these changes, it has become increasingly clear that more comprehensive empirical data, consistent and continuous environmental measurements of key drivers and response variables over time, are needed if we are to accurately assess and respond to current impacts on biodiversity and predict future effects of these widespread disturbances.

There is thus a critical need to collect meaningful empirical data on an ongoing basis at permanent ecosystem monitoring sites (generally field stations or research reserves) across the state to guide conservation efforts. While data inputs for conservation planning generally rely on a "snapshot" of current conditions, and best estimates of projected conditions based on available data, Sentinel Sites provide the opportunity to gain deeper understanding of processes driving change by creating time series data sets capturing rates and direction of change in drivers and response variables. By identifying and monitoring appropriate metrics and indicators collected at these sites, we can vastly improve current and predictive maps and scientific models.

To do this effectively and strategically requires data collection in a manner that is coordinated and intentional to ensure the greatest breadth of application across the richness of California's biodiversity. This section will frame how to build on existing cooperative efforts and California's role in science innovation to develop a Sentinel Site network. The ultimate goal of this network is to unite the results of field stations and reserve sites sponsored by universities, agencies, and non-governmental organizations across the state to help fill the critical data gaps identified in earlier sections of this report.

What is a Sentinel Site?

We use the term ***Sentinel Site*** here to describe a variety of field stations dedicated to long-term physical and biological data collection. In the literature, the ***Sentinel Site*** or ***Sentinel Ecosystem*** approach is described as a means of monitoring ecological resources using a set of fixed locations as platforms for intensive (high-frequency, multivariate) measurements (e.g., Jassby 1998). Ideally, Sentinel Site field stations represent the full range of ecosystems subjected to a shared set of stressors such as climate change, habitat fragmentation, or pollution. For example, NOAA has launched a Sentinel Site network in our nation's estuaries to monitor the impacts of sea

level rise using a consistent approach to facilitate accurate tracking for multiple local applications and comparison across regions. With significant planning, it is also possible to utilize Sentinel Site data to estimate the impact of human disturbance, or alternatively the benefits of stewardship and restoration, on biodiversity and other aspects of ecological condition. Here we explore the benefits of forging a multijurisdictional Sentinel Site network for California across terrestrial, freshwater aquatic/wetland, estuarine and near coastal habitats, and what it will take to get us there.

Fulfilling a Need for Sustained Long-term Monitoring

Why do we need sustained long-term data collection at Sentinel Sites to support biodiversity conservation in California's dynamically changing environment? We can answer this question with a recent example. During the recent severe droughts and wildfires in California (2012-2017, 2019-2021) wildlife management agencies contacted their academic partners to determine whether there were any data sets capable of measuring the impact of these unprecedented climate events on wildlife populations. The answer was essentially no: presently there are no long-term biodiversity data sets capable of reliably answering this question. Differences between data collection methods make fine-scale, short term data sets difficult to aggregate for the purpose of trend detection (Rich and Brashares 2018). Further, the Department of Water Resources concluded that one of the primary lessons learned during this extreme event was the need to improve state-wide monitoring, data availability, and forecasting to support decision-making (DWR 2021).

The value of Sentinel Sites is the opportunity, through a sustained, standardized measurement strategy, to establish "a baseline" against which ecological change may be measured at a variety of scales. In the highly variable ecosystems of California, determining the "signal" of a stressor like climate change against the "noise" of natural variability demands long-term data sets. With the exception perhaps of NSF-sponsored Long Term Ecological Research (LTER) programs, most academic research projects center on a very tightly focused research question to be answered with available historical data and whatever original data can be collected within an approximately 2-to-5-year duration of a typical research degree or grant period.

By contrast, Sentinel Sites are designed to collect basic foundational data by co-locating weather stations, hydrology instruments, biological field surveys, and automated data collection that can ultimately serve to answer multiple kinds of questions, including ones which may have yet to be conceived. An example of this kind of data set is a long-term Wildlife Picture Index monitoring program established at Pepperwood's "Sentinel Site," which is a unique data set capturing the impact of megafires on wildlife (Gray et al in

process). This data collection commenced five years before the advent of megafire events, *before* there was a specific fire-related hypothesis to be tested. So, our challenge today is to do our best to anticipate what the ecologists of the year 2100 will wish we have collected to fully understand our contemporary period of rapid environmental change.

Sentinel Sites provide a foundational data "backbone" of sustained high-frequency measurements over the long-term that can be utilized by academic, agency and community researchers to support and inform hypothesis-focused research efforts aiming to explain mechanisms of observed change.

Sentinel Site data also provide critical empirical inputs to improve species range maps, rare species occurrence records, and the predictive models we rely on to inform our conservation priorities and decision-making. Recent advances in remotely-collected environmental data technology and methods, using automated sensors based on the ground, in the air, or on satellites, now provide a stronger means for extrapolating from local habitat and biodiversity observations to regional, national, and global scales. The establishment of a NEON network of three linked stations in the Sierras now provides the opportunity to tie into a standardized national monitoring network. NASA's new CATALYST initiative around biodiversity in California also affords an opportunity to leverage national and global data collection efforts and technologies. Sentinel Sites are thus a primary means of directly filling data gaps identified in the Conservation Planning and Informatics section preceding this one in a global context and for validating and calibrating the next generation of ecological monitoring tools.

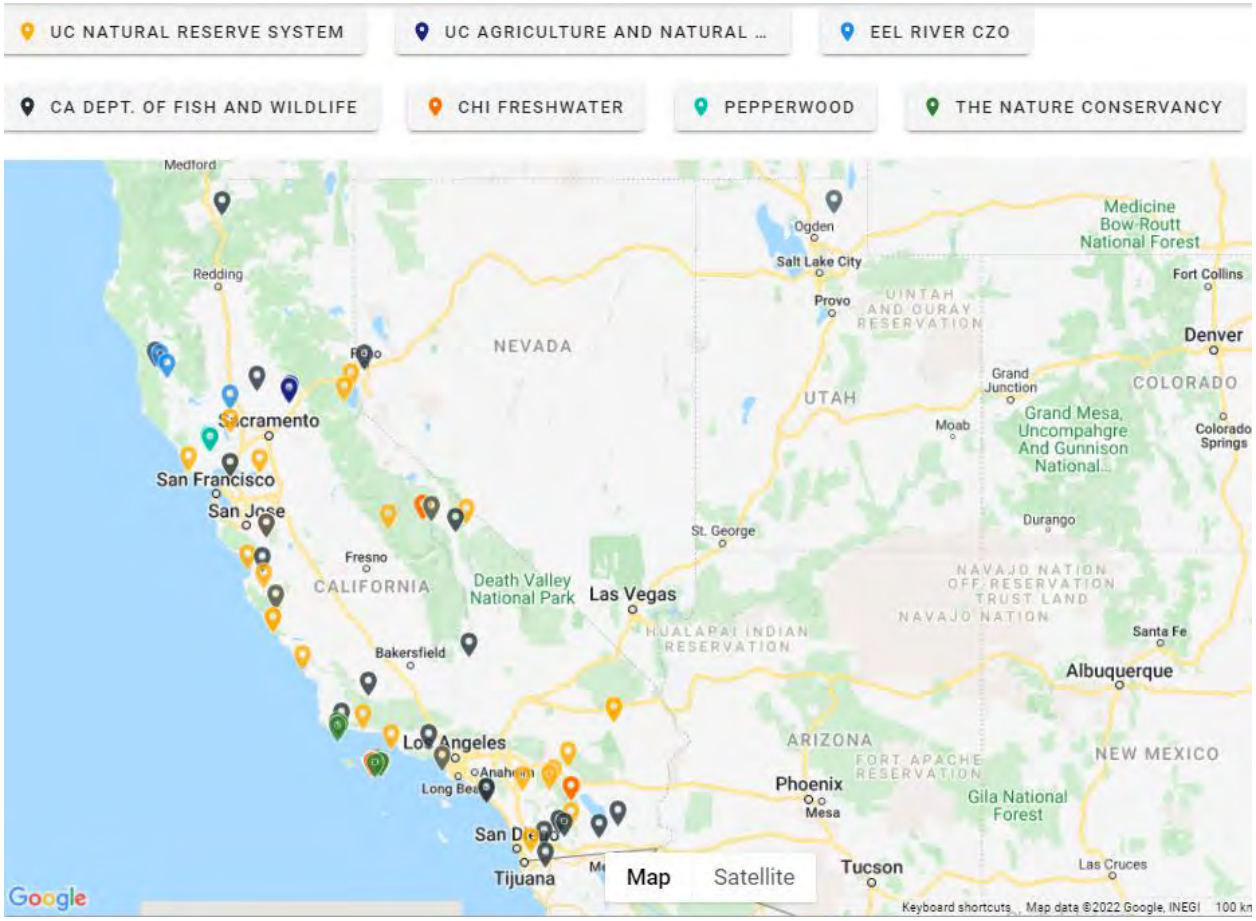
The California Climate-Biodiversity Sentinel Site Network roundtable will work closely with the other CBN roundtables, including Conservation Planning, Informatics, Community Research and Stewardship, to design a coordinated framework for data collection and integration. This empirical knowledgebase will be designed to regularly update state resources including ACE (Areas of Conservation Emphasis) and the CA Nature knowledgebase over time. In this way, Sentinel Sites will continually improve the quality and quantity of data relevant to the adaptive management of California's biodiversity.

Status of Statewide Climate-Biodiversity Monitoring in California

Historically, many field stations and research programs in California have operated largely independently under the guidance of rotating academic faculty or agency leads with episodic shifts in priorities driven by changes in leadership. Primarily occasional coordination has occurred between sites on a project basis. This has allowed for highly valuable scientific discovery and innovations that will be critical for addressing the climate and biodiversity

crises we are facing. However, the lack of proactive coordination has also resulted in a fragmented landscape of data in diverse repositories. Combined, these factors limit the opportunity for comparison across scales and different habitats, or the aggregation of larger data sets for developing more accurate predictive models. This inspired the formation of a Sentinel Site roundtable of practitioners with the advent of the new CBN in 2020.

The 30+ current members of CBN Sentinel Site roundtable have been meeting since 2020 to scope opportunities for closer collaboration, frame a proposal for a convening to design/ build out a more comprehensive statewide network, and to inform this report. To date membership includes representatives from the University of California Natural Reserve System, the California Department of Fish and Wildlife, the Nature Conservancy (Dangermond Reserve), Pepperwood, Jasper Ridge, RESON (central coast- need to add others), the California Institute for Biodiversity, and the National Ecological Observatory Network. This roundtable thus represents a total of over 80 stations total (see map). To date we've held 10+ meetings comprised of founding partners, and in November 2021 held an invitational workshop that added approximately 20 new participants, and provided the opportunity to survey and convene practitioners to inform shared priorities and next steps.



Map Courtesy of https://dendra.science/

Our first CBN Sentinel Site Roundtable joint project, pursued by founding members in early 2021, provides an example of how the group can collectively make strides to close identified data and research gaps. The experts on the Roundtable served as volunteer advisors to CDFW to inform where the agency could add new Sentinel Sites on state-held lands to fill critical data gaps. Using the map of current field stations in the network combined with ACE biodiversity layers and climate space classifications derived from the USGS CA Basin Characterization climate-hydrology model, the CDFW established weather monitoring at an additional 17 stations, and has 18 more in the planning phase, that are specifically located to fill gaps in spatial coverage for the network in the North Coast, Northern Sierras, and Central Valley.

Building the Sentinel Site network will entail recruiting new members including managers and researchers engaged at private, local, state and federal field stations and other long-term monitoring sites to diversify our participants, expand the map of current sites, and refine needs for geographic infill. Current and proposed climate monitoring will be a resource to supplement existing statewide weather networks. Biological monitoring is currently highly variable, so it will be a significant task to inventory current long-term data collection. It will also be critical to standardize a set of core biological data collection methods for participating stations moving forward and to start to realize on the promise of cutting-edge automated biological data collection, including visual, thermal and acoustic sensors and eDNA, a key research interest of this roundtable.

We will also frame this network through the lens of habitat connectivity, tying field station data into the priority habitat corridor maps developed at statewide and regional scales in order to validate habitat corridor and cores' value and function. Ultimately our goal is to capture species distributions, climate drivers, and habitat attributes at multiple scales, with a potential interface with national and global networks (NOAA, NEON, NUT NET, FIA eg Peters et al 2014) while updating the States ACE and CA Nature databases.

Realizing the Value of a Collaborative Approach

Our November 2021 30 x 30 Sentinel Site roundtable workshop stimulated a lively exchange on how to frame an innovative yet sustainable collaboration. An identified key function of this roundtable, that interfaces with the needs of other CBN roundtables, is a focus on how to structure and standardize collection of meaningful ecological data collection at Sentinel Sites. The group also scoped challenges and opportunities in the design of statewide versus regionally significant indicators and ways to increase the diversity of Sentinel Site participants via outreach to BIPOC researchers, community science efforts, and environmental justice communities. These goals foster a

need to overcome cultural as well as funding, technology, and data management barriers and challenges.

The highest ranked potential obstacles to success identified by roundtable participants included the following.

- Will require sustained long-term staffing, funding and governance structure to provide a central backbone supporting a collaborative framework across jurisdictions
- Partner Sentinel Sites will need time and financial resources to curate share data and participate
- Success will require centralized data management analytical capacity and investment to translate data to relevant and meaningful indicators
- Results will need to effectively reach managers and decision-makers who understand the significance and are willing to invest over the long-term

These results speak to the importance of framing a durable governance structure and securing adequate resources to convene key partners, design and operate a functional network from public and private sources.

Another obstacle to overcome identified by Peters et al 2014 will be overcoming cultural barriers inherent to ecological research. These would include the potential reluctance on the part of researchers to share data and publication credits. While academic research places high value and recognition on innovation and creativity, realizing the goals of a Sentinel Site network require a passion and focus on data standardization and cost-effectiveness serving multiple scientific questions. We see these social and cultural barriers as important to recognize and address as the financial and technological ones. We will also seek to increase the cultural diversity of biodiversity practitioners and beneficiaries engaged in Sentinel Site monitoring and its applications.

A Roadmap for Implementation

We envision three phases. While it is tempting to tackle spatial-sensor design challenges right away, **what is really needed to start with is definition of an inclusive multi-jurisdictional institutional framework for this effort under the umbrella of CBN and the State's Biodiversity Initiative.** This institutional foundation needs to include non-scientist decision-makers (e.g., land managers, decision-makers) to inform the outcomes desired to ensure they are aligned with practical applications-and these "end users" of the data need to be part of the team from the start and stay engaged throughout the process.

Meetings to date have identified on the need to secure seed funding to convene a comprehensive collaborative approach to collaboratively build an integrated social, sensor, and data management network. The Roundtable would use this opportunity to focus on defining shared outcomes and how to achieve them. We will create shared metrics of success to guide network design, building off the existing spatial distribution of dedicated field stations, and then address the specifics of how data could be collected in a consistent manner to facilitate comparisons, integration, and meaningful and relevant biodiversity indicators. This effort would tackle the follow elements of a multi-jurisdictional Climate-Biodiversity Sentinel Site Network in partnership with the CA Department of Natural Resources.

Building the social network to support the sensor network (governance) and ensuring from the beginning of the design process there is a mechanism for translating data to relevant indicators for decision/policy makers.

Questions to answer: what does a multijurisdictional monitoring network look like, what are key elements (backbone organization, shared goals, and metrics of success), what kinds of indicators can inform decision makers-about enduring science questions, acquisition priorities, stewardship, regulatory actions?

Standardizing field data collection and management methods (integrating climate-hydrological (physical) and biological monitoring) at site/station scale, optimizing remote sensing tools, leveraging automatic sensors for biological data collection, data management and integration.

Questions to answer: what are the basic climate and biodiversity measurements that should be collected at each station? How can we leverage advances in automated biological data collection (cameras, acoustic, other) and remote sensing (multiple scales)? How do we tie metrics to climate adaptation, stewardship, and connectivity objectives? Can we leverage UC's DENDRA data management system to house and integrate data streams and research access? What supplemental data management would be needed?

Designing a representative station network for the state-linking current & potential new stations, stratified by key collectively defined parameters.

Questions to answer: what are the spatial (habitat, climate type) gaps not covered by the current Sentinel Site collaborative station network? If there are resources for new stations, where are priority sites? How do we ensure scalability of results, using informatics approaches?

***Generating Metrics for Conservation and Opportunities for Engagement*:** cross pollinating with Conservation Prioritization and Informatics/Community Science roundtables, ensuring translation of data products into ACE and meaningful and relevant indicators.

Questions to answer: how can we scale results to support adaptive conservation planning tools (ACE and others)? How can Sentinel Site data effectively serve as a real-time “extinction risk detection/recovery tracking” system? How can data be used to adaptively manage stewardship strategies and measure stewardship outcomes? How can Sentinel Sites attract more diverse research participants and benefit environmental justice communities?

Summary

Developing a Climate-Biodiversity focused Sentinel Site Network in California will unite data from field stations, remote sensing projects, and historical collections to provide a distributed picture of change across the state. It will enable conservation practitioners to leverage existing data streams for ongoing efforts, as well as identify and fill gaps in geographic, taxonomic, and habitat diversity coverage. This will improve our basic understanding of the interrelationships between climate drivers and ecosystem responses, as well as how these responses will affect habitats and species. Importantly, through aggregating common metrics from efforts across the state, the Network can provide a foundation or framework for evaluating the efficacy of management actions and implementing adaptive management across a diversity of public and private ecosystems. This will increase our capacity to effectively prioritize stewardship activities and acquisitions, to ensure investment and capacity is directed where it will have the most significant effect.

References

California Department of Water Resources, *Water Year 2021: An Extreme Year*. California Natural Resources Agency, September 2021. Sacramento, CA.

Jassby, Alan D. "Interannual variability at three inland water sites: implications for sentinel ecosystems." *Ecological Applications* 8.2 (1998): 277-287.

Root TL, Schneider SH (2006) Conservation and climate change: the challenges ahead. Conserv Biol 20(3):706–708. https://doi.org/10.1111/j.1523-1739.2006.00465.x

Peters, Debra PC, et al. "Taking the pulse of a continent: expanding site-based research infrastructure for regional-to continental-scale ecology." Ecosphere 5.3 (2014): 1-23.