CALIFORNIA'S FIFTH
CLIMATE CHANGE
ASSESSMENT

Monitoring Biodiversity in the Context of Climate Change

A State Agency Report for:

California's Fifth Climate Change Assessment

Prepared by:
California Department of Fish and Wildlife

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DEPARTMENT OF
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About California's Fifth Climate Change Assessment

California's Climate Change Assessments are the state's scientific foundation for understanding future climate-related vulnerability across California's regions and systems. Senate Bill 1320 (Stern, 2020) requires the State to report the impacts and risks of climate change across California at least every five years, beginning with California's Fifth Climate Change Assessment (Fifth Assessment). Building on decades of climate research and previous Assessments, the Fifth Assessment presents new findings about California's climate future, with a dedicated focus on Tribal partnerships, public engagement, and communities most vulnerable to climate impacts.

The Fifth Assessment's research and tools are designed to fill knowledge gaps about California's climate future, inspire strategic climate actions, and shape planning, investments, and policies at the state, regional, and local scales. Guided by research priorities identified by state, Tribal, and local leaders, community representatives, and subject matter experts, its findings are designed to help illuminate potential climate futures, the challenges they may present, and the opportunities to build resilience through adaptation pathways.

For the full suite of Fifth Assessment research products, please visit: www.ClimateAssessment.ca.gov.

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About This Report

California's unparalleled biodiversity faces mounting threats from a variety of stressors, including the accelerating impacts of climate change. Effective monitoring is essential for understanding biodiversity trends and the influence of climate change, informing adaptive management, and achieving ambitious conservation goals, such as California's 30x30 initiative. This report provides an overview of recent and/or innovative monitoring tools and approaches for assessing climate impacts on biodiversity in support of adaptive management, especially approaches that have increased in pace and scale since California's Fourth Climate Change Assessment was released in 2018. This report will also highlight a sampling of biodiversity monitoring projects in California, many of which are employing these approaches. Rather than summarize all biodiversity monitoring efforts taking place in the state, we highlight exemplary monitoring projects across terrestrial, aquatic, and marine ecosystems at large spatial scales. Lastly, this report discusses current knowledge gaps and operational challenges in this field, and opportunities to address these deficiencies in the future. It is our goal to provide a high-level summary of the state of biodiversity monitoring projects and challenges in the state rather than an exhaustive list of monitoring efforts or methodologies. This summary emphasizes the importance of monitoring and assessment-type activities as they directly inform natural resource management, the development of climate adaptation goals and strategies, and our ability to measure the effectiveness of conservation and resilience actions in California.

This report is not intended to offer a comprehensive synthesis of climate change impacts to biodiversity in the state. For readers seeking more detailed information on the state's terrestrial biodiversity and climate change, please see additional references provided throughout this document and in the scientific literature (e.g., Harrison et al., 2024; Rapacciuolo et al., 2014).

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Introduction

California is home to some of the most diverse and vibrant ecosystems in the world. From coastal wetlands to mountains, forests, deserts, and marine environments, the state's incredible biological diversity includes a higher total number of species than any other state, and the highest number of endemic species, which are species that occur nowhere else (CDFW, 2021; Stein, 2002). Biological diversity, also known as biodiversity, can be defined at different levels and spatial scales. For the state as a whole, or a regional landscape, it is the "diversity of species, habitats, and vegetation types. For a habitat or vegetation type, it is the diversity of life forms within it. For a species, it is the genetic variation within a population or among populations" (CDFW, 2021). This natural diversity is integral not only to ecological health but also to California's economy, culture, and the well-being of its people. Nature provides Californians with clean air and water; shade and cooling in urban areas; recreational opportunities like fishing, hunting, and hiking; climate change mitigation; flood protection; food security; and so much more. From an economic standpoint, the value of crops that depend on pollinator species is approximately $11.7 billion (Chaplin-Kramer et al., 2011), and nature-based tourism in the state accounts for billions of dollars each year. Additionally, tribal connection, ownership, stewardship, and uses of ancestral and traditional areas—including living, fishing, hunting, gathering, and ceremony—are central to tribal identity and sovereignty. For more information about California's biodiversity, see the Atlas of the Biodiversity of California.

Figure 1: There is a higher total number of species in California than in any other state. To have a holistic picture of biodiversity in the state and how it is being impacted by climate change, it is important to strive to have biodiversity monitoring data across a variety of taxonomic groups.



Clockwise starting from upper left: Sierra Nevada yellow-legged frog (Rana sierrae) in Fresno County, wood ducks (Aix sponsa) in Sacramento County, mule deer (Odocoileus hemionus) in Sacramento County, ochre sea stars (Pisaster ochraceus) in Humboldt County, Chinook salmon (Oncorhynchus tshawytscha) in Sacramento County, and purplish copper butterfly (Lycaena helloides) in Yolo County. Photo source: Sierra Nevada yellow-legged frog – Whitney Philbrook (California Department of Fish and Wildlife), remaining photos – Travis VanZant (California Department of Fish and Wildlife).

Given this unparalleled biodiversity, conserving and managing California's natural resources are critical. To that end, the State Wildlife Action Plan (CDFW, 2025), a conservation blueprint for the state, prescribes actions to conserve wildlife and vital habitat before they become more rare and more costly to protect. The state has also embraced bold conservation commitments, including the California 30x30 initiative, which aims to protect 30 percent of California's lands and coastal waters by 2030. These efforts align with broader regional and global goals, such as the California Biodiversity Initiative and the Kunming-Montreal Global Biodiversity Framework, which seek to halt and reverse biodiversity loss.

Central to achieving these ambitious goals is the effective monitoring of California's biodiversity. Monitoring provides the scientific foundation needed to understand how species and ecosystems are faring in the face of numerous challenges. It enables us to understand the current condition of biodiversity, track trends over time, evaluate the effectiveness of conservation actions, and adapt strategies as conditions change.

Stressors to Biodiversity

California's rich biodiversity faces a range of significant and interrelated stressors that threaten the health and resilience of species across the state. Among the primary challenges are habitat loss and fragmentation due to land-use change, invasive species that prey on or outcompete native flora and fauna, overexploitation, pollution from urban and agricultural sources, and the increasing impacts of climate change. These stressors do not act in isolation; they often amplify one another, compounding risks to ecosystems and making conservation efforts more complex.

Climate change is exposing biodiversity to unprecedented risks by altering temperature and precipitation regimes and other climatic factors that can determine suitable habitat for a species, and increasing the frequency and magnitude of extreme, sometimes landscape-altering events, such as wildfires, floods, droughts, and sea-level rise (WWF, 2020). The expanding body of research into climate change vulnerability and responses of various species has grown in recent years. While this report does not include an in-depth review of climate risk-related studies, there are examples in scientific literature of the impacts of climate change on biodiversity, both observed and projected (Frawley et al., 2025; Gardali et al., 2012; Thorne et al., 2016), and these impacts are described in more detail in previous California Climate Change Assessment reports and the California Environmental Protection Agency's Office of Environmental Health Hazard Assessment's Indicators of Climate Change in California, Fourth Edition (OEHHA, 2022).

Collectively, climate change vulnerability and risk assessments and observations highlight the unprecedented pace and scale of impacts to biodiversity, presenting a challenge for both monitoring of and responding to ecosystem changes. These studies also demonstrate that sustained and adaptive monitoring is critical for addressing the uncertainties evident in risk assessments and for informing conservation strategies under rapidly changing conditions.

Climate Adaptation Strategies

To address these challenges and reduce climate-related risks to biodiversity, California employs a range of conservation and adaptation strategies focused on maintaining and enhancing ecosystem resilience. Key strategies include increasing connectivity between habitats to allow species movement and genetic exchange,

restoring critical habitats, and actively managing invasive species to protect native biodiversity. Land and water conservation aimed at protecting essential habitats and ecological processes is also a vital strategy. Identifying and conserving refugia is a priority, as these serve as critical safe havens for vulnerable species. In some cases, active species restoration techniques are a necessary strategy, including breeding programs, reintroductions, translocations, and managed relocation (McLaughlin et al., 2022). Each of these strategies can be informed by the data gleaned from monitoring biodiversity. Observations of species abundance, movement, and health increase our understanding of climate change-related vulnerabilities and inform decisions about how best to respond.

Effective adaptation strategies and actions incorporate climate data into the planning phase, often climate projections, to ensure adaptation actions and goals are forward-looking and go beyond business-as-usual conservation practices, where necessary, to increase the likelihood of meaningful impact. Decision-support frameworks can guide adaptation planning by helping natural resource managers determine when to resist change, accept new conditions, or strategically transition ecosystems. Examples include the Resist-Accept-Direct (RAD) Framework (Schuurman et al., 2020) and the Resistance-Resilience-Transition (RRT) approach (Peterson St-Laurent et al., 2021), and other adaptation menus and checklists (Hansen et al., 2021; Swanston et al., 2020), which provide structured methods to evaluate conservation actions in a changing climate. Ultimately, a combination of climate change adaptation tools can be used in tandem to adequately account for uncertainty, consider a broad range of potential strategies and actions, and make transparent and robust choices with flexibility (Miller et al., 2025).

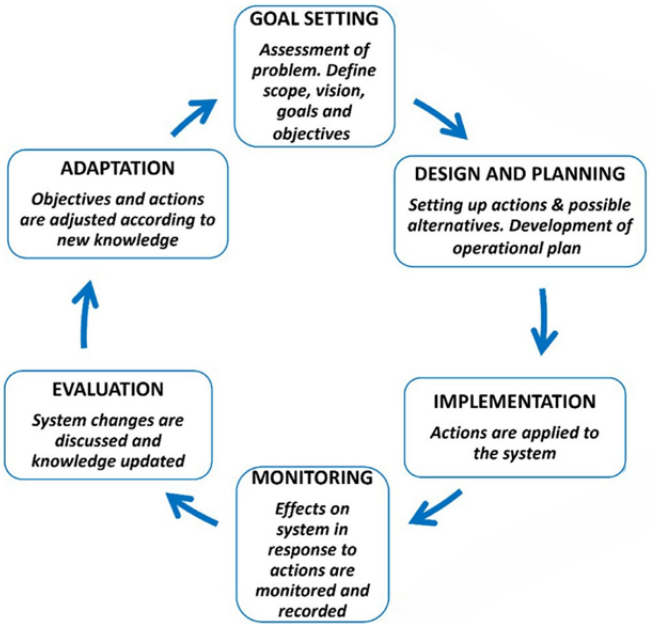
For extensive information on California's adaptation goals and strategies for conserving biodiversity, and examples of state agency actions to achieve these goals, refer to the California Climate Adaptation Strategy, the Pathways to 30x30 Strategy (CNRA, 2022), the Natural and Working Lands Climate Smart Strategy (CNRA, 2022), and the California State Wildlife Action Plan (CDFW, 2025).

The Importance of Science and Monitoring

Our ability to understand biodiversity trends, climate change, and the impacts of climate change on California's biodiversity is rooted in science and observation. Whether via formal research study, observation by the casual naturalist or recreation enthusiast, or generational knowledge passed down over time, these data are critical to our ability to understand what is happening on the landscape and consequently how to respond and support the persistence of fish, wildlife, and plants for their intrinsic value and for their use and enjoyment by the public.

Science-based or evidence-based planning and decision making are crucial, not only for understanding ecosystem or species status and for informing adaptation goals and strategies, but for the ability to determine whether conservation actions are successful and to decipher how to adjust management practices to be more effective. Long-term monitoring is especially important given that ecosystem and climatic changes are often not instantaneous but can occur over both short and longer timeframes. Monitoring is a critical part of the adaptive management cycle, which is increasingly important in the face of climate change (see Figure 2). Science-informed, ecosystem-based management is so crucial that it has been codified in the state of California, alongside the concept of adaptive management (California Fish & Game Code § 703.3).

Figure 2: Adaptive management framework illustrating the importance of monitoring within the process.



Adapted from Månsson et al. (2023).

Biodiversity monitoring encompasses a wide variety of activities, undertaken by a diverse set of organizations and individuals, to track California's natural resources. By definition, monitoring is "the scientific practice of taking systematic, repeated measurements of environmental conditions, using the same methods over time to make long-term comparisons" (CDFW, 2025). Monitoring efforts may target anything from genes, to taxa, to ecosystems, from common to sensitive or invasive species, and from terrestrial to aquatic and marine environments. Biodiversity monitoring often occurs in natural areas, but data collection in working lands, urban areas, and the wildland-urban interface is increasingly important. Species are not confined to living

in natural areas, and as the human population grows and human-wildlife interactions become more prevalent, data collection in these locations can help us better understand species' adaptations to these changes and mitigate potential conflicts.

Monitoring can be conducted for a variety of purposes, including compliance monitoring, evaluating restoration or adaptation success, evaluating species status, and identifying or detecting threats. Regardless of the primary intent, monitoring must be intentional—data collection should inform management decisions, policy, or scientific understanding. Currently, datasets from biodiversity monitoring are used to develop and inform state conservation and climate adaptation activities, including but not limited to: supporting connectivity and corridor planning, determining the potential listing or de-listing of threatened and endangered species, identifying appropriate limits for harvest or consumption through recreational or commercial activities, evaluating and ensuring food sustainability, preventing the spread of pathogens and diseases, informing land management, evaluating ecosystem health and potential ties to human health, informing recreational opportunities and supporting associated industries, and supporting urban planning and development. It is difficult to inform or adapt these important activities for climate change without understanding how climate impacts biodiversity over time, which is information gained through long-term monitoring as described throughout this report.

Monitoring can also help confirm or reject ecological forecasting that is conducted to project how ecosystems may evolve under climate change—information that is often used to set long-term conservation goals. Monitoring data can also improve model forecasting itself by providing observational data. Given the broad applicability of biodiversity monitoring, it is imperative that these datasets be current and consistent. Monitoring for biodiversity change is distinct from monitoring for climate change, and biodiversity monitoring alone does not constitute climate impact assessment. Truly understanding the effects of climate change means analyzing climate as a potential driver of biodiversity change or trends across decades; but without biodiversity monitoring data, these analyses are not possible.

The data generated by monitoring activities can serve diverse partners, such as government agencies, the general public, tribal communities, and conservation organizations. All of these entities benefit from access to accurate and timely information. Coordination among these groups is essential for maximizing the utility of monitoring efforts.

Figure 3: California is home to a variety of ecosystems. Monitoring across a variety of ecosystem types can improve understanding of how climate change is unfolding across the state.



Clockwise starting from upper left: redwood trees in the Avenue of the Giants in Humboldt County, Echo Lake in El Dorado County, a coastal view from Pacific Grove in Monterey County, and Joshua Tree National Park in San Bernardino County. Photo source: Joshua Tree National Park – Matt Elyash (California Department of Fish and Wildlife), remaining photos – Travis VanZant (California Department of Fish and Wildlife).

Tools and Approaches for Assessing Climate Impacts to Biodiversity and Tracking Ecosystem Change

This section highlights a selection of tools and approaches for monitoring biodiversity in California and the impacts of climate change, with a focus on methods that are widely applicable and scalable and could be used in various types of ecosystems. The information generated by these efforts supports decision-makers by helping to identify where climate impacts to biodiversity are emerging and to evaluate the effectiveness of current conservation strategies, which can guide policies to enable effective and proactive adaptation or resilience actions. The tools and approaches presented here may not be entirely novel, but we focus on them because they have become more prevalent in use since the release of California's Fourth Climate Change Assessment (the Fourth Assessment) in 2018. This increased application may be due to multiple factors, including lower costs as technologies have improved, greater awareness and subsequent adoption of particular tools, and innovative applications of existing technologies. The tools and approaches described in this section are not without limitations, so we recommend researching them in more detail before adoption and implementation. Moving forward, the potential of these tools and approaches could be harnessed by operationalizing them across agencies and organizations, which would significantly streamline the efficiency of data collection and processing and therefore increase the likelihood of the data to be used more broadly. These tools can be used in tandem with each other and in combination with existing, traditional monitoring methods that continue to be effective, such as camera traps and acoustic sensors. As progress in data science continues to accelerate, especially with the increasing improvements to artificial intelligence (AI), the possibilities are rapidly expanding for how data across different approaches are integrated.

Remote Sensing

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation from a distance, typically from satellite or aircraft. It is a powerful, non-invasive tool for mapping land and cloud cover, vegetation, and species distributions over large areas (Kerry et al., 2022). The ability of remote sensing to provide large-scale coverage and enable temporal analysis makes it particularly effective for detecting changes in ecosystems and phenology driven by climate change (Wang & Gamon, 2019). The automated, remote nature of this approach also allows for observations of areas that are difficult to access and enables rapid expansion of monitoring efforts.

Specific technologies include:

- **LiDAR**, or light detection and ranging, uses pulsed lasers to generate three-dimensional information about the Earth's surface. In aquatic environments, LiDAR with water-penetrating capabilities can measure bathymetry underlying water bodies (Kinzel et al., 2013). In terrestrial systems, this technique can directly measure the height and density of ground-level vegetation, allowing for the study of plant life and habitat structure across vast areas (Wasser, 2024). The Wildfire, Ecosystem Resilience, and Risk Assessment (WERK) Initiative is a partnership between the State of California and the National Aeronautics and Space Administration's Ames Research Center to develop landscape monitoring systems specific to California using remotely-sensed data. In 2025, the WERK Initiative released the first statewide datasets on forest and vegetation conditions, derived from LiDAR. These datasets provide a comprehensive picture of forest and vegetation conditions across the state.
- **Radar**, or radio detection and ranging, can be used to quantify the spatio-temporal dynamics of birds, bats, and insects in flight, offering valuable insight into the movements of organisms (Dokter et al., 2018; Hu et al., 2016). For example, radar-based monitoring has been used to analyze the feeding activity of bats in California's Northern Central Valley. There was higher bat activity over rice fields, where flying insects were more abundant, suggesting bats may play a role in agricultural pest control (Lee et al., 2025).
- **Hyperspectral imaging** combines spectroscopy and imaging and allows for the detection of high-resolution spectral signatures of different materials (Bhargava et al., 2024; Rajabi et al., 2024). This tool can allow for classifying vegetation, mapping vegetation and water conditions, assessing impacts of and recovery following fire and drought, analyzing soil, monitoring of water quality, and detecting stress in plants (Bhargava et al., 2024; Rajabi et al., 2024). For instance, Meerdink et al. (2025) used hyperspectral imaging together with thermal imaging, which creates visible images based on invisible radiation patterns emitted by objects, to look at three different plant communities in Southern California during the 2013-2015 drought. They were able to assess spatial and temporal patterns of plant stress among these communities and species, illustrating the potential of using these technologies to monitor natural landscapes, in particular areas that may be remote or difficult to access.

Radio Telemetry

Radio telemetry has long been a widely used tool for tracking wildlife movement, oftentimes used in combination with Global Positioning System (GPS) telemetry with collars attached to individual animals. Technological advancements, such as smaller and more powerful tags, coupled with the rise of collaborative networks, have contributed to the continued use of radio telemetry and enable the collection of more data with less effort and the tagging of smaller species, including invertebrates.

This approach is embodied by the Motus Wildlife Tracking System (Motus). Motus is a collaborative radio telemetry network of stationary receivers that automatically detect and log unique signals from tagged animals as they pass by. What makes this system unique is that any Motus receiving station, regardless of who established it, will detect and record data from tagged animals belonging to any registered project. This creates a large, open-access network that benefits all users.

Motus is highly effective for tracking small mobile species, including birds, bats, and flying insects. The data it provides on broad-scale animal migratory behavior, timing, direction, and speed of movement offer insight into phenological and habitat use changes that stem from human and natural pressures. Motus holds key advantages over traditional methods of understanding large-scale wildlife movements. Data collection is automatic, which reduces the need for manual tracking, and Motus tags are smaller, lighter, and far less expensive than GPS tags. This broadens the range of taxa that can be studied and allows researchers to increase their sample sizes.

Figure 4: Environmental scientists construct a Motus station at Shasta Valley Wildlife Area in Northern California.



Photo source: California Department of Fish and Wildlife.

An innovative development within this technology is the Blū Series tags from Cellular Tracking Technologies. Their BlūMorpho and Blū+ tags are the lightest radio tracking tags available, on the market, making them ideal for very small animals, including birds, bats, butterflies, bees, and other insects. These tags operate in the Bluetooth frequency range, and thus smartphones can act as receivers. This capability has enabled members of the public to get involved in data collection through community science initiatives, such as the Project Monarch app that helps track monarch butterflies with Blū+ tags.

Community Science

Community science engages members of the public in scientific research and monitoring by collectively making field observations and collecting data. This crowdsourcing approach is conducive to covering broader spatial scales that are typically difficult to achieve through more traditional monitoring methods, though community science projects tend to be biased toward areas of high human population density. The prevalence of smartphones has made community science increasingly mainstream, as individuals already possess the necessary equipment to easily collect data. Popular examples of community science apps include iNaturalist, eBird, and Nature's Notebook, while organizations like the California Academy of Sciences and the Xerces Society for Invertebrate Conservation provide guidance and resources for various projects for public participation. A robust protocol for data collection is critical in community science projects, helping to ensure that high-quality data are collected despite individual participants varying in terms of level of experience.

Integrating community science data with other types of data can provide a cost-effective way to understand species distributions and range dynamics while increasing the spatio-temporal scales at which changes are detected in ecological communities (Gillespie et al., 2024; Mason et al., 2025). Additionally, community science can even serve as a tool for addressing biodiversity challenges. For instance, some community science projects focus on the detection of invasive species. By allowing for early detection, these community science projects can help identify locations where containment or eradication of a newly detected invasive species is needed.

Outreach and education are also important aspects of community science, as participants often have non-technical backgrounds. In this way, these efforts serve as a gateway to fostering greater interest in science and nature conservation and can have the added benefit of building public literacy of the scientific process and subsequent trust between stakeholders and resource managers. Community science events like bioblitzes—where individuals gather to make observations of as many species as possible at a specific location—feature heavily in annual community

science campaigns, such as the City Nature Challenge and California Biodiversity Day. Additionally, many community science projects are ongoing throughout the year, such as the California Phenology Project, which uses phenology data to better understand resource responses to changing climates, and the Western Monarch Milkweed Mapper, which maps monarch butterflies and their host plants across the Western United States. California Reef Check, Snapshot Cal Coast, and the Long-term Monitoring Program and Experiential Training for Students are examples of long-running community science-driven programs that can inform resource management in marine and coastal ecosystems (Freiwald et al., 2018).

Figure 5: Bioblitz hosted by Earth Discovery Institute in celebration of California Biodiversity Day 2025.



Photo source: Veronica Cuadras.

Artificial Intelligence Technology for Data Collection and Processing

Automated camera traps and autonomous recording units for passive acoustic monitoring are powerful tools for monitoring wildlife behavior, species distributions, population demographics, and habitat use. Data they collect provides insight into biodiversity trends and the drivers of change over large spatio-temporal scales. These tools typically generate massive volumes of data, and the ability to use this information is typically limited by the intensive time and effort required to process

and analyze these data. To address this challenge, platforms that use AI to implement powerful machine learning approaches have been developed to streamline the data analysis workflow.

One example is the Wildlife Insights international online platform, which stores, identifies, analyzes, and facilitates the sharing of camera trap data. Wildlife Insights uses machine learning to automatically identify species and filter out blank images or camera misfires. This technology is continually retrained with new data and improved identifications, and users can review and manually verify the results. By using Wildlife Insights, researchers can more efficiently process camera trap data and integrate it with other data streams, such as environmental covariates, to analyze spatial and temporal changes in biodiversity patterns (Ahumada et al., 2020; Steenweg et al., 2017). The California Department of Fish and Wildlife (CDFW) has embraced this technology, uploading over 32 million images to the platform. In addition to CDFW, other state agencies, non-governmental organizations (NGOs), and universities in California are also using Wildlife Insights, centralizing data storage and ensuring data consistency standards across multiple datasets. Wildlife Insights' computer vision model has significantly expedited the processing of these photos, allowing for more holistic management and landscape-scale assessments of wildlife communities.

For processing acoustic data from autonomous recording units, multiple machine-learning based tools are available, such as Perch (van Merriënboer et al., 2025), and BirdNET (Kahl et al., 2021). BirdNET is a free analysis software that can automatically detect and classify over 6,000 sound classes, including bird, amphibian, insect, mammal, and human-produced sounds. CDFW staff have used BirdNET to process many terabytes of acoustic data, and combined with some human validation effort, this tool has vastly expedited the ability to detect species presence from acoustic recordings (Toenies & Rich, 2021). As of 2021, BirdNET could be run as a Python script executed from a console, used as a smartphone application, or accessed from an internet browser (Cole et al., 2022).

Genetics and Genomics

Advances in next-generation sequencing, computing technology, and analytical methods have given rise to new genetic and genomic tools for biodiversity monitoring. Landscape genomics is one such approach that integrates geographic and genomic data to test for spatial patterns of selection and adaptation (Storfer et al., 2018). Local populations and regions of high genetic diversity are thought to be genetically resilient with a high probability of responding to future environmental change. Areas with the greatest levels of genetic variation across taxa are especially important to consider when establishing conservation goals, such as those in the context of California's 30x30 initiative. Landscape genomics can shed light on the evolutionary and ecological histories of species while also providing insight

into connectivity corridors and barriers as well as patterns of climate resilience (Shaffer et al., 2022). A key example is the California Conservation Genomics Project (CCGP), a collaboration among California universities, government agencies, and non-governmental organizations that is working to produce a comprehensive, multispecies genomic dataset to help manage regional biodiversity.

Another powerful genetic tool for biodiversity monitoring is environmental DNA (eDNA), which is genetic material extracted from environmental samples like water, soil, air, plants, and even spiderwebs. eDNA provides a non-invasive approach for assessing the presence of species, and the method can be used to detect rare or endangered species that are difficult to observe. eDNA can be used for focused or targeted species monitoring, or in a metabarcoding approach to assess community composition across a broad range of taxa. Furthermore, eDNA monitoring can serve as an early warning system for tracking the distribution and spread of invasive species (e.g., golden mussel) and can be used to study the impacts of climate change by detecting changes in community compositions and species distributions over time (Bernatchez et al., 2023). In 2024, the California Department of Water Resources (DWR) released its eDNA Strategy (Resources, 2024) as a roadmap for operationalizing this technology to support water resource management in California. One notable application of eDNA by DWR is its use to detect the endangered Delta smelt—both to track wild individuals and those that are released by hatcheries. Another example of how eDNA is being used in California is the California Environmental DNA (CALeDNA) program, run by the UC Conservation Genomics Consortium. CALeDNA pairs community scientists with researchers to collect samples across the state, helping to provide a more complete picture of California's biodiversity across different habitats and seasons. The data from this effort have been used for various applications, including understanding the biodiversity of the Los Angeles River and tracking harmful algal blooms.

Examples of California biodiversity monitoring efforts that inform climate adaptation

Studying the impacts of climate change on biodiversity naturally requires both climate- and biodiversity-related datasets. Biodiversity monitoring alone is not always sufficient for measuring climate-related trends. Data must be analyzed for relationships to observed or modeled climate change to truly evaluate how the climate is impacting biodiversity. In this section, we provide a sampling of ongoing biodiversity monitoring projects in California that enable these climate impact analyses by providing the necessary biodiversity data component, and in some cases, climate-related data as well. In instances where climate-related data are not being directly collected, these projects have demonstrated a commitment to evaluating climate impacts through project design or through intentional analyses that are planned or already taking place. A couple of the project examples in this section are not currently performing ongoing monitoring at regular intervals but instead have generated or are currently generating important baseline datasets through an initial data collection effort. Though slightly different from a traditional long-term monitoring project, we included them here as they provide important opportunities for resurveys and future monitoring.

The goals of biodiversity monitoring projects vary, and project strategy and organization will ultimately depend on the purpose for monitoring (e.g., compliance monitoring, evaluating restoration success, evaluating species status). As evidenced by the initiatives described below, there is not a one-size-fits-all approach to successful monitoring; however, a few common themes emerged amongst the examples provided. One aspect these projects share is communal partnerships across varying spatial scales and even throughout time. They highlight the power of multiple people, organizations, and diverse skillsets working together towards a common goal. Utilizing consistent and reproducible protocols to ensure data are comparable across years and locations is also a common priority among these examples.

There are many biodiversity monitoring activities taking place in California, and this report does not include a comprehensive review of those efforts. Instead, we highlight a sampling of monitoring projects that have been established or accelerated since the Fourth Assessment was released in 2018, in addition to other monitoring projects that have demonstrated longevity, providing valuable information for years or decades. While the majority of the efforts below cover large spatial scales (e.g., statewide or regional), local studies are also vital, and the combination of fine- and broad-scale studies is necessary for gaining a comprehensive view of biodiversity.

Though not covered by this report, there are also many ongoing monitoring efforts at the national scale that encompass California and provide important contributions to our knowledge of biodiversity in the state, such as the US Forest Service's Forest Inventory and Analysis and the National Phenology Network.

All of the projects highlighted in this section have the ability to inform climate and conservation-related management decisions and policy at multiple scales. As discussed in previous sections, a range of climate adaptation strategies and conservation actions exist; the projects described here are collecting the data necessary to implement those strategies and actions successfully. For example, enhancing landscape connectivity to facilitate species range shifts requires an understanding of how species currently move across the landscape—information derived from monitoring. Similarly, prioritizing restoration activities aimed at increasing resilience to climate change depends on identifying degraded habitats, which may be indicated by declines in species abundance or condition as observed through monitoring data. Efforts to prevent or slow the spread of invasive species also rely on monitoring to determine the distribution, abundance, and rate of spread of the species in question. The summaries below do not capture every possible connection between the data collected and their application to management or policy. However, these projects share a common commitment to generating baseline data and, over time, detecting trends and changes that can inform a wide range of climate planning and conservation actions.

California Sentinel Sites for Nature

California Sentinel Sites for Nature (CA-SSN) is a monitoring collaborative established in California to create biodiversity and climate baselines and to assess change over time. Under the leadership of CDFW and University of California Nature, these sites are managed by a network of partners committed to biodiversity exploration and conservation under the increasing pressures of climate and land use change. Current partners include several state agencies, NGOs, and universities.

A Sentinel Site in this context is a location where standardized wildlife and climate monitoring techniques are being employed long-term for easy comparison of data across the network at various spatial and temporal scales. All organizations hosting Sentinel Sites have committed to using consistent field methods and data processing protocols to ensure data are highly comparable. The minimum set of protocols is highly scalable as the methods are intended to be simple and deployable regardless of expertise. Sentinel Site monitoring protocols are based on the California Environmental Monitoring and Assessment Framework, which was developed by CDFW in response to growing concerns regarding the impacts of land use change in California.

CA-SSN practitioners deploy a combination of wildlife cameras to detect small- to large-sized mammals, reptiles, and amphibians, and sound recorders to detect all vocalizing species, but especially birds and bats. Over the past four years, CDFW has established 42 total sites across California, primarily at CDFW Wildlife Areas and Ecological Reserves, totaling over 160 monitoring plots with varying levels of equipment. In 2026, another roughly 70 Sentinel Sites will be established by partner organizations, adding approximately 280 monitoring plots to the project. Partners organizations include the University of California Nature, Pepperwood Preserve, California State Universities, University of California Agriculture and Natural Resources, California State Parks, The Nature Conservancy, and more.

Most Sentinel Sites also include a Motus station and a weather station, and additional monitoring methods will be added in the future as the network grows and more methods become scalable. Time lapse cameras, eDNA, and invertebrate monitoring methods are already being piloted at several Sentinel Sites. This unique combination of both climate and biodiversity data collection at Sentinel Sites enables local tracking of climate change as well as the ability to study climate impacts on biodiversity at different spatial and temporal scales.

Data collected through the network by participating organizations will be accessible through established repositories. The CA-SSN emphasizes sharing data soon after collection to increase transparency and the likelihood of producing impactful data. Data will be used to support invasive species and disease detection, identify changes in species distributions, and evaluate shifts in species movement and migration patterns that may be associated with climate or land use change. Locally, the data collected through this effort can be used to assess the efficacy of management actions, such as restoration work, prescribed fires or forest thinning, and to inform land management planning. More broadly, Sentinel Site data can be applied to statewide climate planning initiatives, such as Safeguarding California, and conservation-related efforts, such as species recovery planning, species status assessments, State Wildlife Action Plan development, and much more.

The power of the CA-SSN is grounded in shared, highly scalable and reproducible monitoring protocols, an emphasis on widespread data sharing and availability for multiple uses, and a highly collaborative approach to implementation and growth.

Figure 6: Left: Weather station used for climate monitoring at a Sentinel Site. Right: Sentinel Site equipment for monitoring wildlife at Canebrake Ecological Reserve; the black drift fence corrals small animals into an enclosure at the end of the fence where their photo is taken before exiting.



Photo source: California Department of Fish and Wildlife.

California Marine Protected Areas

Established by the Marine Life Protection Act in 1999, Marine Protected Areas (MPAs) are discrete geographic marine or estuarine areas designed to protect or conserve marine life and habitat. This statewide network of 124 MPAs and 14 Special Closures spans from the Oregon border to Mexico, covering roughly 16% of the state's coastal waters. These areas are categorized by different types and levels of allowable uses—the two most common being State Marine Reserves (no take zones) and State Marine Conservation Areas (allow some take).

The MPAs are strategically located to protect a wide range of habitats, including kelp forests, rocky reefs, estuaries, and deep-sea canyons, and to help restore and sustain populations of marine species and enhance ecosystem resilience. In addition to helping conserve biodiversity, MPAs also provide scientific reference points to assist with resource management decisions, while enhancing recreational and educational opportunities.

To facilitate adaptive management of MPAs, the Marine Life Protection Act requires ongoing monitoring, research, and evaluation at specific locations. This research, conducted both inside MPAs and at nearby reference locations, is critical for tracking trends in marine life and ecosystems to understand how they respond to fishing and no-fishing conditions.

From 2007–2018, baseline monitoring occurred regionally within the network to establish a comprehensive benchmark of ecological and socioeconomic conditions at or near the time of MPA implementation. This serves as an important set of data against which future conditions can be measured. In 2018, CDFW and the Ocean Protection Council developed the MPA Monitoring Action Plan (CDFW & OPC, 2018) to inform next steps for long-term monitoring. Shortly thereafter, seven statewide long-term monitoring projects were funded in 2019.

These long-standing data collection efforts are crucial to supporting adaptive management of the MPA network and contribute to broader understanding of how marine ecosystems respond to protection and environmental stressors in California.

Figure 7: Pacific Grove in Monterey County.



Photo source: Matt Elyash (California Department of Fish and Wildlife).

California Cooperative Oceanic Fisheries Investigations

The California Cooperative Oceanic Fisheries Investigations (CalCOFI) is a long-term scientific program established in 1949 to monitor and understand the marine ecosystem off the coast of California. CalCOFI is a partnership between government and academic organizations, including the National Oceanic and Atmospheric Administration's National Marine Fisheries Service, CDFW, and Scripps Institution of Oceanography. Originally created to investigate the decline of the Pacific sardine fishery, CalCOFI has since evolved into a comprehensive oceanographic survey that collects data on physical, chemical, and biological properties of the California Current System with the goal of supporting sustainable marine management.

CalCOFI conducts quarterly cruises off Southern and Central California, collecting data from samples and observations at 113 different stations to track changes in ocean conditions and marine life over time. These data include temperature, salinity, oxygen, nutrient levels, plankton populations, larvae of harvested fish and invertebrate stocks, fish eggs, seabirds, and marine mammals. Overall, CalCOFI collects approximately 35 physical and chemical parameters and 2,500 biological parameters. Since 2014, water samples have also been collected for eDNA, and these efforts have recently expanded to incorporate detections of fish and marine mammal species.

By collecting both biodiversity and climate-related data, CalCOFI allows for evaluating status and trends in biodiversity, directly monitoring the environmental and ecological indicators of El Niño and climate change, and the opportunity to identify relationships between the two. CalCOFI operates in partnership with other observing programs and networks, including the California Current Ecosystem Long Term Ecological Research Program, California's Ocean Observing Networks (CeNCOOS and SCCOOS), and the Marine Biodiversity Observation Network (Southern California Bight MBON) in California.

CalCOFI's sustained efforts have been critical in studying the impacts of environmental and ecosystem variability, climate variability and change, and human activities on marine ecosystems. The data collected by CalCOFI support fisheries and marine management, ecosystem conservation, and scientific research, providing one of the longest continuous records of ocean dynamics in the world.

Figure 8: Scientists and ship crew deploy the CalBOBL (Bongo) net at sunrise on a CalCOFI cruise.

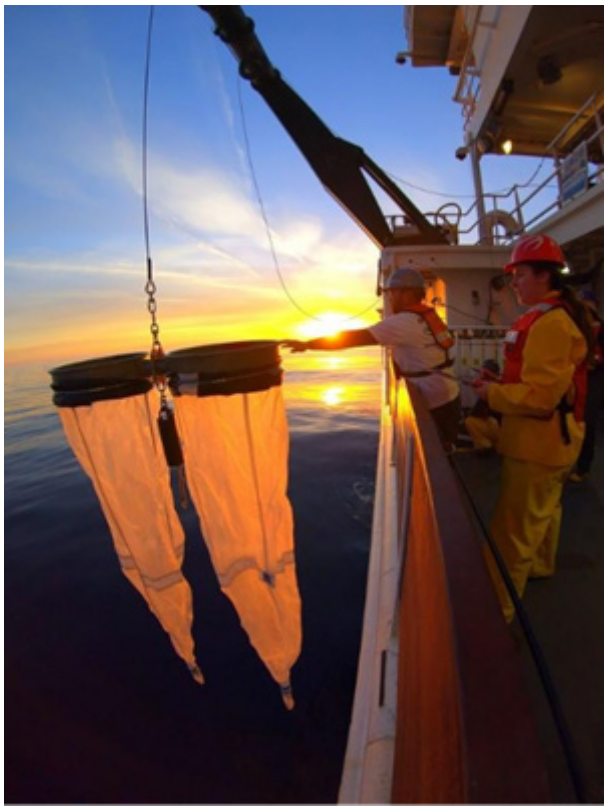


Photo source: James Wilkenson.

California Bumble Bee Atlas

Bumble bees are key pollinators of wild and crop plants, contributing to both ecosystem function and human agriculture. In California, eight of the state's 25 bumble bee species are classified as Endangered or Vulnerable by the International Union for Conservation of Nature; of these, one is listed as Endangered by the US Endangered Species Act, and four are candidates for listing under the California Endangered Species Act. Threats include habitat loss, pesticide exposure, and climate change. Despite their importance and imperilment, there is a lack of basic distribution and ecological information necessary to address bumble bee declines.

The Bumble Bee Atlas is a nationwide community science project whose goal is to characterize the distribution, diversity, and floral associations of bumble bees across the country. In 2022, CDFW and the Xerces Society for Invertebrate Conservation launched the California Bumble Bee Atlas (CABBA). In its first four years, CABBA trained and permitted 1,695 volunteers, who made more than 24,000 individual observations of 23 species and completed over 2,500 standardized surveys.

Community engagement is the cornerstone of the CABBA project. Anyone can participate, and all volunteers undergo training to ensure that data are collected correctly and safely. The project uses a standardized and effort-based survey protocol to ensure data consistency. Surveys are non-lethal, with bees being captured and chilled to allow high-resolution photography before they are released. Volunteers submit field data and photos to Bumble Bee Watch, where experts verify identifications. The data sheets include information on environmental conditions during the survey, such as temperature and wind speed. Volunteers also record any signs of recent fire, as well as which plants bumble bees are collected from. This information can be used to assess factors influencing bumble bee occurrence and foraging. The data can also be combined with other datasets to understand how climatic factors affect bumble bees. For example, preliminary analyses show drought as a factor in interannual bumble bee abundance. The project's data are also being used to guide conservation decision-making to better manage and protect these important animals.

In 2026–2027, CDFW and the Xerces Society will use results from the project to develop a statewide bumble bee conservation strategy, which will provide a roadmap for conservation action, including identifying opportunities for species recovery, best management practices, and key habitat types and host plants to support Species of Greatest Conservation Need. Concurrently, CABBA will begin a long-term monitoring program to better understand bumble bee occurrence across the state through time, with the goal of identifying specific threats that may result in further population declines.

The Bumble Bee Atlas is an example of how the community science model can be used to produce the data necessary for state, federal, and other scientists to protect imperiled wildlife. In doing so, the project has engaged thousands of Californians from all walks of life, educating the general public about the conservation needs of these functionally important invertebrates. CABBA data can be explored on its interactive dashboard tool.

Figure 9: Volunteers participate in a CABBA training at Lava Beds National Monument.



Photo source: Dylan Winkler.

California Conservation Genomics Project

Genetic diversity is the foundation of all biodiversity and is critical for the long-term evolutionary potential and viability of species. In 2019, the California Conservation Genomics Project (CCGP) was launched with the goal of producing the most comprehensive multispecies genomic dataset ever assembled to assess regional diversity and predict species resilience in the face of climate change. Conservation genomics, the use of whole-genome sequencing to understand the genetic diversity of different organisms, has been the subject of research in California for a long time. The CCGP, which is state-funded and led by the UCLA La Kretz Center for California Conservation Science, is one of the first efforts to complete work at this scale, moving beyond individual species studies.

To achieve genomic assessment at this scale, the initiative is being implemented by numerous principal investigators from across the state, including all 10 University of California campuses, carrying out projects focused on terrestrial, aquatic, and

marine species. Standardized DNA sequencing protocols are followed by all principal investigators who are funded through the CCGP to produce consistent and comparable datasets across all projects, including the first high-quality reference genomes for most species included in the effort. Based on information available in 2022, the CCGP has funded 78 projects comprising 148 unique genera and 235 species, spanning the tree of life as represented in California (Shaffer et al., 2022). Final sampling includes 29 marine species (13 invertebrates, 4 plants, and 12 vertebrates) and 206 terrestrial/freshwater species (54 invertebrates, 68 plants, and 84 vertebrates). These species span all ecoregions and habitats in the state, allowing for landscape-scale analyses and the identification of regions of high/low genomic diversity within California and the degree of landscape connectivity among these regions.

While the project does not include continued sampling within each project location, it lays important groundwork for future studies on genetic diversity by establishing baseline conditions and creating opportunities to resurvey sites at a later date.

Figure 10: Golden eagle takes flight at New Hogan Lake. The golden eagle is one of the species included in the CCGP.



Photo source: Tavis VanZant (California Department of Fish and Wildlife).

Southern California Wetlands Recovery Project: Coastal Wetland Sentinel Site Network

Created in 1997, chaired by the California Natural Resources Agency and supported by the California State Coastal Conservancy, the Southern California Wetlands Recovery Project brings together the directors and staff of 18 public agencies to coordinate regarding the protection, restoration, and enhancement of California's coastal wetlands and watersheds between Point Conception and the Mexican border. These wetlands, including salt marshes and tidal flats, serve as crucial habitats for diverse wildlife and plant communities, provide natural flood protection, filter and retain contaminants, and play a key role in carbon sequestration. Unfortunately, more than half of these low-lying coastal habitats have been lost in Southern California since the mid-1800s as a result of human development.

To reverse this trend and to ensure that the remaining wetlands are resilient to threats like sea level rise, climate change, and increasing human impact, the Southern California Wetlands Recovery Project defined a set of quantitative goals and management priorities in the 2018 Wetlands on the Edge: Regional Strategy (SCWRP 2018). A central component of that strategy is a regional monitoring program, of which the California Coastal Wetland Sentinel Site Network is a key element. The California Coastal Wetland Sentinel Site Network brings together scientists, resource managers, and local stakeholders to conduct standardized, long-term monitoring at selected wetlands along the California coast.

Thirty-seven coastal wetlands have been selected to act as sentinel sites through this effort. These sites are designated for long-term monitoring to track ecological conditions through time, evaluate the effect of regional trends in external conditions/stressors, and to track progress toward regional objectives, strategies, or plans. The network hinges on rigorously vetted methods and a set of standardized data collection that will take place at each site, allowing comparison across sites and regions. The sites span a gradient from least altered (reference sites) through restored and at-risk conditions, and are spread across different types of wetland habitats and geographic subregions. This thoughtful and intentional selection of sites enables tracking of ecosystem change over time—not just for individual wetlands or specific restoration projects, but regionally—so that agencies can assess whether the Southern California Wetlands Recovery Project's Regional Strategy objectives are being met. The data can be used to evaluate progress toward achieving regional goals, prioritize sites or stressors for intervention, evaluate the relative success of different restoration projects across Southern California, and provide early warnings of climate-related impacts to biodiversity. All data collected through the project are managed and accessible via a public data portal.

Although the California Coastal Wetland Sentinel Site Network has been established in southern California, the framework and approach are broadly applicable and could be used to establish networks in other regions along the coast (Walker et al., 2025).

Figure 11: Researchers fish the tidal creek at Goleta Slough Ecological Reserve as part of an annual estuarine monitoring effort.



Photo source: Jan Walker

The Grinnell Resurvey Project

Between 1904 and 1940, Joseph Grinnell, the founding Director of the Museum of Vertebrate Zoology (MVZ) at UC Berkeley, along with his students and colleagues documented and collected primarily birds and mammals and secondarily reptiles and amphibians from thousands of locations across California. This effort created a valuable snapshot of early vertebrate occurrences in California that contemporary researchers have reconstructed into a historical baseline that accounts for differences in the detectability of species. Specimens collected at the time of surveys serve as environmental monitors of ecological and environmental conditions that are reflected in body size, diet, genetic diversity, population connectivity, and accumulation of pollutants.

The Grinnell Resurvey Project aims to resample many of the original survey locations to assess how bird and small mammal distributions have been impacted over time by environmental changes, particularly habitat loss, climate change, and other threats that existed to a lesser degree or not at all when the original surveys were conducted. To date, bird resurveys have been conducted at 320 sites across all of California's terrestrial ecoregions. Small mammal resurveys have been conducted throughout the Sierra Nevada and Cascades ecoregions and the Mojave, Sonoran, and Great Basin Deserts at 305 sites.

Results from the Grinnell Resurvey Project have produced a remarkable portrait of ecological changes in California over the past century. Researchers have shown how small mammals and birds have predominantly moved upwards in the Sierra Nevada and Cascade ecoregions following climate warming, but that responses were extremely heterogeneous, differing among closely related species and varying spatially across montane regions, and were complicated by precipitation change (Moritz et al., 2008; Rowe et al., 2015; Tingley & Beissinger, 2013; Tingley et al., 2012). By comparing the calendar dates of bird detections, researchers demonstrated that birds in the Sierra Nevada and Coastal ranges now nest 10 days earlier than a century ago, tracking the earlier springs to remain in cooler conditions that promote breeding success (Socolar et al., 2017). Resurveys in California deserts found that the small mammal community has shown remarkable stability and resilience, while the bird community has collapsed in response to a century of drying and warming (Iknayan & Beissinger, 2018; Riddell et al., 2019). Sites today support about half the bird species that Grinnell encountered in the early 1900s, but the number of small mammal species per site is unchanged (Riddell et al., 2019). Physiological models showed that climate change over the past century increased the water needs of diurnally active birds by over 50 percent, but had little effect on small mammals, which are mostly active at night (Riddell et al., 2021).

Also, birds have responded differently to climate and land use change in California's most transformed landscapes: the Central Valley and Los Angeles region (Beissinger et al., 2023; MacLean et al., 2018). Urbanization and warming caused declines in more than one-third of bird species over the past century in Los Angeles, while agricultural development and the warmer and slightly wetter climate of the Central Valley had mixed impacts on bird diversity that balanced expanding and contracting species. Compiling these datasets together has allowed researchers the rare opportunity to test the ability of models to forecast species distributions over a century of climate and land use change (Clare et al., 2024; Smith et al., 2013). Researchers have also traced changes in body size and morphology (Holmes et al., 2016), diet (Walsh et al., 2016), and genetic diversity and population connectivity (Rubidge et al., 2012; Yang et al., 2011) of small mammals in the Sierra Nevada.

By resurveying these sites, MVZ faculty, students, and collaborators have not only been able to compare contemporary data to a historical dataset to quantify vertebrate changes and their causes in California, but they have established another benchmark for future comparisons.

Figure 12: Photos from the Lassen transect survey in October 1930 (top) and September 2006 (bottom).



Courtesy of The Museum of Vertebrate Zoology Archives, University of California, Berkeley

Vegetation Classification and Mapping Program

Vegetation is a surrogate for habitat and ecosystems, and as such, plays an important role in wildlife and natural lands conservation and management. Climate change has already caused shifting vegetation patterns as individual species distributions have expanded or contracted (OEHHA, 2022), and changes to vegetation communities will

undoubtedly impact the wildlife that depends upon them. Generating a complete picture of vegetation in all areas of the state is inherently challenging given the geographic extent and natural diversity of California, and tracking changes in vegetation is difficult by association. The Vegetation Classification and Mapping Program (VegCAMP) at CDFW was developed to maintain a standardized vegetation classification system for California and to implement and update the best methods of vegetation assessment, including sampling and mapping, at multiple scales. Their efforts are summarized as the Survey of California Vegetation Classification and Mapping Standards (SCV) and contribute to building a comprehensive understanding of vegetation distribution and status across the state.

To achieve these goals, VegCAMP employs a three-phase approach. The first phase is data collection utilizing standardized field survey techniques. The Rapid Assessment and Relevé protocol, developed by CDFW and the California Native Plant Society, provides clear instruction for completing field surveys in vegetation communities. Second, vegetation classification is developed through statistical analyses of the statewide field data. The Manual of California Vegetation online houses the statewide vegetation classification, which follows the National Vegetation Classification Standard, and region-specific vegetation classification reports are also available. Third, fine-scale vegetation mapping provides graphic visualization of the vegetation classification for researchers, conservationists, and other stakeholders. All three phases follow the SCV set forth by VegCAMP.

VegCAMP is completing each phase of the SCV by region in the state. To date, all three phases have been completed or are in progress for over 75% of the state and field sampling (phase 1) will have occurred in all ecoregions by the end of 2026. VegCAMP staff coordinate closely with other agencies and partners to complete this important work. Once initial maps are created, subsequent surveys can be conducted at various intervals, as capacity and funding become available, to detect change. All current SCV data (field surveys and maps) can be accessed through CDFW's Biogeographic Information Observation System (BIOS).

In addition to allowing for evaluation of the potential for climate-related megafires, having fine-scale vegetation mapping for the state is necessary to successfully evaluate climate-induced shifts in vegetation and the potential impacts to wildlife that rely upon vegetation for food and habitat. Furthermore, the data can be used to predict upslope movements of plants.

Figure 13: California goldfields in Butte County, CA.



Photo source: Travis VanZant (California Department of Fish and Wildlife).

Surface Water Ambient Monitoring – Bioassessment Program

The State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP) coordinates a variety of water quality monitoring efforts in aquatic ecosystems throughout California.

SWAMP's Bioassessment Program, led by CDFW's Aquatic Bioassessment Lab, monitors the health of California's freshwater ecosystems with standardized field surveys of biological organisms (benthic invertebrates and benthic algae) and associated environmental data (physical habitat and chemistry). Data analysts compare the ecological diversity and composition of the assemblages that were collected to what would be expected in a healthy stream. Scientists use this information to calculate quantitative indices of biological health, such as the California Stream Condition Index, which can be used with environmental data to interpret the health of a waterbody and monitor it over time.

The Bioassessment Program developed California's standard bioassessment protocols: Standard Operating Procedures (SOP) for the Collection of Field Data for Bioassessments of California Wadeable Streams: Benthic Macroinvertebrates, Algae, and Physical Habitat (Ode et al., 2025). The SOP describes procedures for biotic sampling and for assessing instream and riparian habitats and ambient water chemistry associated with biotic assemblage samples. These protocols are compatible with the US Environmental Protection Agency's National Rivers and Streams Assessment procedures and are used for most bioassessments in California.

CDFW's Aquatic Bioassessment Lab has been collecting bioassessment data since the mid-1990s, much of it in collaboration with SWAMP. The SWAMP Bioassessment Program generally collects data from three types of sites: 1) randomly selected sites, which are used for condition surveys, 2) high quality reference sites, which are used to establish expected conditions, and 3) targeted sites, which are used to address specific water quality questions or for enforcement monitoring. These data are accessible via the SWAMP Data Dashboard and the California Environmental Data Exchange Network. In addition, a large amount of compatible bioassessment data is being collected by federal agencies (US Environmental Protection Agency, US Forest Service, and National Park Service) and other state, local, and regional agencies. These data will become increasingly valuable as changes in climate impact aquatic environments through shifting precipitation and streamflow patterns, increasing water temperatures, and extreme drought and wildfire events.

The Bioassessment Program is an example of a long-term monitoring effort in the aquatic environment that supports evidence-based decision making and natural resource management and promotes widely available field survey methods and broad data accessibility.

Figure 14: Aquatic bioassessment monitoring in action at Upper Kirman Creek in Mono County.



Photo source: Connor Stewart (California Department of Fish and Wildlife)

Opportunities to Advance Biodiversity Monitoring and Assessment Research

While biodiversity monitoring and climate impact assessment efforts have grown in recent years, there are several key gaps that, if filled, could advance this important field and consequently the ability of monitoring data to inform policy decisions about responding to climate-driven impacts and planning proactive climate adaptation strategies. This section highlights opportunities to accelerate progress in monitoring biodiversity and climate change impacts to biodiversity in California. The topics discussed here—data, funding, and coordination—together represent a holistic view of the "needs" for successful biodiversity monitoring in the context of adapting to long-term environmental change. These opportunities were identified during the research process for this report and working group communications. These data gaps and funding- and coordination-related challenges do not constitute an exhaustive list of needs, but reflect some of the larger challenges in this space at the time of writing and therefore some of the greatest opportunities for progress. Targeted investment and action in these areas are essential for building the resilience of California's natural environment. For a deep dive on research and information needs related to biodiversity conservation and climate resilience in California, refer to Appendix D of the Pathways to 30x30 Strategy (CBN, 2022).

Data Needs

Vegetation Mapping. Vegetation is frequently cited as the best single proxy for characterizing habitat and ecosystems. While detailed, fine-scale digital vegetation maps exist for parts of the state, a comprehensive map covering the entire state is still under development (Bram et al., 2015; Gogol-Prokurat et al., 2022). The completion of a full vegetation classification and mapping effort is vital, as accurate baseline data allows researchers to detect and document incremental changes in vegetation patterns over time in response to changing temperature and precipitation trends, as well as responses to sudden, major events like wildfires.

Invertebrate Data. Multiple studies have identified a taxonomic bias toward vertebrates in research, despite invertebrates accounting for the majority of wildlife species (Clark & May, 2002; Titley et al., 2017). Invertebrates play key roles in ecosystem processes and often comprise the diet of vertebrate taxa; insufficient data on invertebrates across ecosystems undermine our overall understanding of biodiversity in California and how climate change is impacting biodiversity. The California All-Taxa Biodiversity Inventory (CalATBI) is one effort helping to increase invertebrate data in the state. This large-scale initiative seeks to document and archive the full range of biodiversity in California across all of the state's ecoregions and

includes an insect barcoding component. At a more regional scale, Dr. Art Shapiro of UC Davis has monitored butterfly population trends along a transect across central California, from the Sierras to the Coast, for three decades. This project demonstrates how data can be collected across varied landscapes over a long time period, which can contribute to our understanding of climate-related impacts to invertebrates (Forister et al., 2010). Additional studies that examine how stressors affect invertebrate biodiversity and how changes to their populations affect food webs and other key ecological processes are critical to develop and implement.

Figure 15: Umber skipper (Lon melane) on seaside daisy (Erigeron glaucus), a native coastal plant-pollinator interaction.



Photo source: Signe White.

Invasive Species. Invasive species pose a significant threat to biodiversity, potentially outcompeting native species, altering habitats, and disrupting ecosystem functions. Robust data on invasive species as well as baseline ecological data are important for determining how best to manage invasive species and prevent their introductions in the first place. The urgency for such data is growing as climate change alters species distributions and creates new opportunities for invasions.

Figure 16: An invasive bullfrog (Lithobates catesbeianus) at Gray Lodge Wildlife Area in Butte County.



Photo source: Travis VanZant (California Department of Fish and Wildlife).

Specimen Vouchers. There is an ongoing need for specimen vouchers, which are preserved samples of organisms that serve as a reference for scientific study. In particular, there is a need for responsibly collected specimen vouchers that can serve as permanent, reliable references for super-diverse and understudied taxonomic groups. These are essential for enabling validation of research findings and providing critical baselines for temporal and spatial studies. Specimen vouchers also enable the acquisition of DNA barcodes, which are critical for detecting species in eDNA monitoring approaches. For species where preserving a specimen may not be feasible, researchers can explore photo vouchers as an alternative approach for preserving information about an organism. In addition to new vouchers, existing specimens should be quantified and digitized to be easily discoverable and used by researchers in analyses.

Soil Biodiversity and Health. Soil health is intrinsically linked to soil biodiversity, yet measuring this biodiversity is a complex undertaking. Among the most biodiverse habitats on Earth, a variety of organisms inhabit soils, from microbes to nematodes

to earthworms. In 2023, the California Department of Food and Agriculture released Soil Biodiversity in California Agriculture, a report exploring soil biodiversity within California's agricultural systems (CDFA, 2023). The report presented information on the taxonomic and functional diversity of soil organisms, ecosystem services provided by those organisms, threats to soil biodiversity, assessment frameworks, and biodiversity indicators. The report also identified key opportunities for future research to advance knowledge about soil biodiversity in the context of California's working lands. These opportunities include: creating a dedicated monitoring program for the status and trajectory of soil biodiversity in California working lands; investigating the relationships between soil biodiversity and soil health; establishing causal links between soil biodiversity and human health; investigating climate and land use change impacts; and conducting further research on reliable soil biodiversity indicators.

Figure 17: A Point Blue Conservation Science staff member collects a soil sample for eDNA analysis, as part of a collaboration with the California Institute for Biodiversity to use soil eDNA to assess biological diversity.



Photo source: Chloe Latt (Point Blue Conservation Science).

Tracking of Management Activity. Tracking management activities related to land and water conservation across the state is a complex endeavor, but the ability to evaluate conservation effectiveness hinges on knowing what types of management activities are happening and where and when they are being implemented across California's landscape. A valuable addition to CA Nature, the online tool for accounting acres toward the state's 30x30 initiative and visualizing biodiversity, access, and climate opportunities, would be a statewide data layer that maps management activities, such as habitat restoration. Having such a layer, when cross-referenced with biodiversity monitoring data, would allow researchers to assess the efficacy of different management activities on biodiversity across the state and could assist with evaluating whether climate adaptation strategies are effective. This new layer could draw from existing efforts where applicable, such as the EcoAtlas Project Tracker, a data entry tool for uploading and editing information specifically on wetland restoration, mitigation, and habitat conservation projects throughout California. Another free decision support tool for land management is Planscape, which focuses on prioritizing landscape treatments to mitigate fire risk, maximize ecological benefits, and help California's landscapes adapt to climate change.

Monitoring in Under-surveyed Areas. Traditional monitoring methods have historically under-surveyed private lands (Hilty & Merenlender, 2003) and urban areas. Efforts are currently underway to address these key data gaps, particularly in the context of urban biodiversity. Community science, such as the annual international City Nature Challenge, represents a major opportunity to vastly improve biodiversity data collection in urban environments by enlisting the help of the public. On private lands, remote sensing can provide key information, complemented by ground truthing of similar data on public lands. Some natural environments are under-surveyed as well; additional investigation is needed to determine which ecosystem types are most under-surveyed for different taxonomic groups in order to prioritize monitoring efforts in these areas where possible.

Changes in Phenology. Phenology, which is the study of the timing and cyclical patterns of biological events (e.g., flowering, migration), provides crucial insight into how organisms respond to environmental cues. Some phenological changes that have been detected in California include butterfly species starting spring migratory flights earlier and shifts in the arrival times of long-distance migratory birds (Leicht-Young et al., 2013). Analyzing phenological changes requires multidisciplinary research over long timeframes, and as data from long-term studies continue to be analyzed, they will provide more insight into shifts in phenology that are linked to climate change. Use of timelapse cameras and imagery derived from existing monitoring methods can be used to assess seasonality and landscape change over time.

Impacts from Pesticides. There is a growing need for more research on the impacts of pesticides and pesticide adjuvants on biodiversity, in particular on pollinators, which are vital to ecosystem health and food security. Many commonly used pesticides, including neonicotinoids and other systemic chemicals, have been linked to declines in pollinator populations (Cibotti et al., 2025; Forister et al., 2016), yet there are limited data on their long-term and cumulative effects.

Detangling Responses to Climate Change vs. Other Stressors. Detecting the specific impacts of climate change is complex because ecological systems are simultaneously influenced by a multitude of human-caused stressors, including land use change, habitat fragmentation, and pollution. Without long-term monitoring, it will be extremely difficult to differentiate impacts from climate change, long-term climatological cycles (e.g., the El Niño Southern Oscillation and the Pacific Decadal Oscillation), and other physical drivers that operate on longer timescales. Further hindering predictive capabilities are gaps in knowledge regarding species' inherent adaptive capacity and unique physiological responses, such as thermal tolerances. The concept of adaptive capacity, the ability of a species to cope with or adjust to changes in climate, is essential for designing effective adaptation strategies. However, it is difficult to evaluate and apply in practice (IPCC, 2014; Thompson et al., 2015).

Funding, Coordination, and Data Sharing

Beyond foundational data needs, there are outstanding operational and structural gaps that impede the ability to carry out monitoring or effectively make use of monitoring data. These challenges can lead to duplicated efforts and misaligned protocols across entities. Resolving these issues is important to maximize the return on monitoring investments and successfully translate data into effective management actions. Coordinated monitoring efforts that have proven to be successful could be taken further by incorporating them into management plans or grant requirements.

While long-term monitoring is vital for resource management and durable conservation outcomes, funding opportunities are often scarce compared to resources allocated for ready-to-implement projects. Intentionally expanding funding that is dedicated to long-term, statewide biodiversity monitoring and assessment is the most direct solution. In the absence of this option, addressing the funding scarcity requires creative solutions centered on efficiency and collaboration. As mentioned previously, community science is one potential option for overcoming funding challenges by leveraging public participation for data collection, with the added benefit of fostering a sense of stewardship. Additionally, increased coordination on monitoring across different entities is essential to leverage capacity, avoid duplicative efforts, and build resilience to shifts in management priorities. Collaboration beyond the typical research/academic/conservation community is also vital and often overlooked.

This coordination must extend to the development of common field and data protocols and the sharing of resultant data. Coordination earlier in the data collection process can help to ensure that project results are more likely to be utilized. Standardized monitoring protocols are critical because they facilitate the analysis of data across space and time. Data collected using different field methods may not necessarily be comparable, which undermines coordination of monitoring between partners and limits the ability to aggregate data for analysis. Standardization helps ensure that data are comparable because they were collected using the same methodology, even if different individuals are carrying out the field protocols. Additionally, standardization of data formats and protocols allows for more seamless data exchange and the integration of datasets from multiple sources. Sharing data allows for comparison across different types of biodiversity data and integration with other relevant datasets (e.g., anthropogenic factors, climate models) and for maximizing the value of existing monitoring investments.

Data accessibility is often hindered by structural limitations, including legal restrictions, incompatible IT systems, and non-standardized data formats. However, pioneering efforts are successfully demonstrating effective pathways to overcome these barriers. Data portals compile and provide access to datasets from multiple sources. For example, California Natural Resource Agency's Open Data Platform provides an environment where underlying agencies and departments can publish and share data, increasing transparency and the accessibility of these datasets. At the national level, the Avian Knowledge Network is a noteworthy example, using a cloud computing system to store, manage, analyze, and share avian monitoring data across numerous organizations. An international example is the Global Biodiversity Information Facility, which aims to provide open access to data about all biodiversity, with roughly half of the data coming from community science platforms, such as iNaturalist and eBird. Successful monitoring projects, including those detailed earlier in this report, provide clear models for improving data sharing by employing open repositories and standardized collection methods across partners. AI holds valuable promise for helping to standardize data across disparate sources by detecting and correcting data quality issues. Crucially, for data sharing platforms to be most effective, they must be accompanied by visualization tools to improve access and ensure that data collection and analysis translate directly into practical application by natural resource managers.

While difficult to implement in practice, not taking the necessary steps to tie data collection to the appropriate resource managers and decision- and policy-makers will undermine our ability to meet California's conservation goals for biodiversity. Data is only meaningful in the context of climate adaptation if it is applied. There must be a mechanism and a willingness to analyze data and to connect it to management decisions and policies.

Concluding Thoughts on Monitoring for Biodiversity in the Context of Climate Change

California's ability to conserve its rich biodiversity and meet ambitious conservation and climate goals depends on robust, sustained monitoring across the state's varied ecosystems and taxonomic groups. The examples and approaches outlined in this report underscore that monitoring is essential for detecting trends, evaluating conservation effectiveness, and guiding strategies for adaptive management. Emerging technologies and community engagement offer promising opportunities to expand monitoring capacity, but success depends on addressing persistent data gaps, improving coordination, and ensuring long-term investment.

To maximize impact, biodiversity monitoring should be integrated into broader natural resource priority policies and programs across California. Embedding monitoring into these efforts will ensure that decisions are evidence-based and that progress toward statewide goals is measurable. By supplying information on how species and ecosystems are changing in response to climate change, monitoring efforts help policymakers identify emerging risks, evaluate the effectiveness of adaptation actions, and adjust strategies as conditions evolve. Investing in monitoring today ensures that we can make informed decisions to safeguard California's ecosystems for generations to come.

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