

CALIFORNIA'S FIFTH
CLIMATE CHANGE
ASSESSMENT

North Coast Regional Report

A Regional Report for California's Fifth Climate Change Assessment

Coordinating Agency

CA Governor's Office of
Land Use and
Climate Innovation

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.

Purpose of the Regional Reports

The Fifth Assessment Regional Reports bring together the latest climate science, community input, and adaptation opportunities to meet the needs of communities across nine California regions. These reports can inform regional and local vulnerability assessments, adaptation planning, and community resilience efforts. The Regional Reports include analyses of climate projections and impacts to natural systems, built systems, and social systems. They uplift case studies of adaptation solutions and highlight developments that have emerged since the Fourth Assessment was released in 2018. While climate impacts are felt across regional boundaries, the Regional Reports deepen our understanding of how climate change interacts with the unique communities, histories, waters, and landscapes across California.

Climate Modeling, Scenarios, & Time Periods

The Fifth Assessment Regional Reports consider the following climate models, greenhouse gas (GHG) emissions scenarios, and time periods:

- **CMIP6** (Coupled Model Intercomparison Project Phase 6) is the most recent version of a global collaboration that standardizes and combines the most advanced climate models to project how Earth's systems will react to our changing atmosphere. With CMIP6, we can see the most likely climate trends and the less likely, but still possible, extremes.
- **Greenhouse Gas Emissions Scenarios:** Current international climate models integrate two kinds of scenarios: Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs). The SSPs model how global society might evolve over the next century, including changes in population, policy, technology, and economic growth, while tracking the amount of heat trapped in the atmosphere. The RCPs correspond to GHG emissions and capture a quantifiable range of emissions and warming—how much do we expect the world will continue to emit, and the associated warming, throughout the century? Combined, these describe how global social conditions (e.g., population, technological, and economic growth) affect emission trajectories. This shift offers a more nuanced understanding of how our collective decisions today will shape the climate of tomorrow. The Fifth Assessment research primarily focuses on two RCP/SSP combinations:
- **SSP 2–4.5** (i.e., utilizing the second SSP narrative and RCP 4.5) describes an intermediate scenario indicating improvements toward meeting mitigation commitments. This scenario shows carbon dioxide equivalent (CO2e) emissions initially hover at current levels, then start to fall by mid-century.
- **SSP 3–7.0** articulates a high emissions scenario and less optimistic pathway, assuming current emission levels continue throughout the year 2100. This scenario shows CO2e emissions doubling by 2100.
- The Fifth Assessment also references a more aggressive emissions scenario (**SSP 5–8.5**), which describes a very high and unlikely emissions pathway that shows CO2e emissions tripling by 2075. The Assessment includes this scenario as a reference tool for a worst-case emissions outcome for informational and planning purposes rather than a plausible climate change future.
- **Global Warming Levels** (GWLs) ask "What happens to California once the world reaches a certain level of warming?" The focus is on adapting to a change in the expected climate, such as a 2°C (3.6°F) increase. While these models identify a range of years when these thresholds might be reached, the emphasis is on the intensity of the impact rather than the calendar date. This is a different and complementary approach to the previously used *date-based approach*.
- **Downscaling with Localized Constructed Analogues (LOCA) and Weather Research and Forecasting (WRF):** To make global climate models (GCMs) useful for local planning, scientists use a technique called downscaling. While global models provide a *big picture* view of the planet, the Fifth Assessment uses the LOCA2 statistical and WRF dynamical downscaling techniques and a hybridized version of these techniques, LOCA2-Hybrid, to focus on California's particular climate future.
- **Time Periods:** The Fifth Assessment uses a 30-year timeframe for analyses, as shown in the table below, alongside historical projections to draw comparisons between current and future time periods.

Descriptive Term	Time Range
Historical	1981–2010
Mid-Century	2041–2070
Late-Century	2071–2100

CALIFORNIA'S FIFTH
CLIMATE CHANGE
ASSESSMENT



Map of California

Climate Change Assessment Regions

Authors and Contributors

Coordinating Lead Authors

Rosemary Sherriff[1] and **Andrew Stubblefield**[1]

Lead Authors

Daniel Lipe[1], Jennifer Marlow[1], David Narum[2], Keith Parker[3]

Climate Science: Historical & Projected Trends

Lead Authors: Andrew Stubblefield[1] and Rosemary Sherriff[1] with Jeffrey Anderson[4], Chris Gressierer[1], Jeff Kane[1], Jason Patton[5]

Natural and Working Lands & Waters

Lead Authors: Rosemary Sherriff[1] and Andrew Stubblefield[1] with Eric Bjorkstedt[1], Kerry Byrne[1], Christine Davis[6], Whelan Gilkerson[7], Katy Gurin[6], José Marín Jarrín[1], Jeff Kane[1], Michael Kauffmann[8], Daniel Lipe[1], Justin Luong[1], Marisa McGrew[9], Keith Parker[3], Luis Santana[10], Darren Ward[1]

Built Systems

Lead Author: David Narum[2] with contributions from Craig Benson[11] and Christine Davis[6]

Social Systems

Lead Author: Jennifer Marlow[1] and Daniel Lipe[1] with Ana Alanis[12], Catriona Barr[1], Kayla Begay[1], Alec Brown[13], Mark Cederborg[14], Christine Davis[6], Jennifer Kalt[15], Erin Kelly[1], Kristina Kunkel[1], Lulu Mickelson[1], Evan Mills[16], Keith Parker[3], Brandon Quintana[17], Kaitlin Reed[1], Laurie Richmond[1], Eric Riggs[1], Wendy Ring[18], Cutcha Risling Baldy[1], Selena Rowan[19], Julie Sorfleet[20], Grace Woodmansee[21], Sylvia van Royen[15]

Author Affiliations

1 California State Polytechnic University, Humboldt

2 Blue Lake Rancheria

3 Yurok Tribe

4 Northern Hydrology & Engineering

5 California Geological Survey

6 California Trout, Inc. (CalTrout)

7 Coastal Ecosystems Institute of Northern California

8 Backcountry Press

9 Wiyot Tribe

10 Robinson Rancheria, Pomo Indians of California

11 City of Eureka and Humboldt Bay Harbor Commissioner

12 University of California, Los Angeles

13 44 Feet Project

14 Ecological Workforce Initiative

15 Humboldt Waterkeeper

16 Energy Associates and Research Affiliate, Energy & Resources Group, University of California, Berkeley

17 California Coastal Commission

18 Unaffiliated

19 Trinidad Rancheria

20 GIS Analyst

21 UC Cooperative Extension Siskiyou County

Community Advisory Board

Ana Alanis (University of California, Los Angeles), Craig Benson (City of Eureka and Humboldt Bay Harbor Commission), Vincent Brown (Northern Mendocino Ecosystem Recovery Alliance), Stephen Decatur (City of Dunsmuir), Skylar Fisher (Trinity County), Katie Koscielak (California State Polytechnic University, Humboldt), Lonyx Landry (California State Polytechnic University, Humboldt), Terre Logsdon (Lake County), Ron Reed (Karuk Tribe)

Technical Advisory Board

Catherine Brinkley (University of California, Davis), Michael Furniss (California State Polytechnic University, Humboldt), Karen Gaffney (North Coast Resource Partnership), Justin Garwood (California Department of Fish and Wildlife), José Marín Jarrín (California State Polytechnic University, Humboldt), Evan MacKinnon (California Department of Water Resources), Laurie Richmond (California State Polytechnic University, Humboldt), Wendy Ring (Climate Health Now), Mike Shaver (Potter Valley Tribe), Matt St. John (North Coast Regional Water Quality Control Board), Kelly Watson (California State Polytechnic University, Humboldt)

Associate Editor

Gregory Pasternack (University of California, Davis)

Acknowledgements

Many people contributed to the development of this report. We thank the authors that contributed sections and case studies. We thank the community advisory board and technical advisory board members that helped shape and inform the content and provided feedback to early drafts. We thank the county supervisors who met with us and shared their perspectives on climate impacts and resilience. We acknowledge the contributions and support of California Polytechnic University, Humboldt. We thank the members of the Climate Analysis Coordination Workgroup. We thank the Sea Level Rise Institute and the North Coast Resource Partnership. We thank the Tribal Advisory Group and the staff at the Governor's Office of Land Use and Climate Innovation (LCI). We acknowledge the contributions of our associate editor Greg Pasternak and three anonymous reviewers.

The Fifth Assessment team acknowledges the many advisors, contributors, and community participants who helped inform the research reflected in this report, including the Fifth Assessment Tribal Advisory Group for their review and guidance, which helped strengthen the report's discussion of Tribal priorities, Tribal expertise, and the climate impacts affecting California Native American communities.

Suggested Citation:

Sherriff, R., Stubblefield, A., Marlow, J., Lipe, D., Narum, D., & K. Parker. (2026). *North Coast Regional Report* (California's Fifth Climate Change Assessment). California State Polytechnic University, Humboldt. https://www.climateassessment.ca.gov/2799/

Disclaimer: The Fifth Assessment has been prepared as directed by Public Resources Code Sections 71340, et seq. and supported entirely by state funding allocated by the California Legislature in the Budget Act of 2021. The Assessment's reports summarize the best available information about potential climate futures, impacts, and adaptation approaches in California at the time of the Assessment's preparation. The authors of this report are solely responsible for their content and conclusions. The information presented here does not necessarily represent the views of the coordinating agencies of the State of California. Nothing in this Assessment establishes or modifies any binding rule, requirement, or legal obligation, nor is the Assessment an endorsement of any particular project, policy or response strategy. Specific response strategies will be developed by state, regional and local governments, and will likely involve policy trade-offs and funding considerations.

Any references in this Assessment to the lingering and compounding effects of racism and discrimination are drawn from academic literature and are not factual findings of, or legal determinations by, the State of California or any agencies of the State, of prohibited discrimination in any particular instance. Similarly, any descriptions of potential future harms are not findings of or admissions by the State of California or any agencies of the State.

The research was reviewed by expert reviewers, Tribal Advisory Group members, and approved by an external editorial board to ensure scientific rigor as well as appropriate representation of the practitioners and partners to whom each report applies.

Use of Artificial Intelligence (AI):

Development of this report used AI-based tools for secondary research assistance and for editorial review (formatting, proofreading, cross-referencing, glossary development) based on the Advertising Standards Council of India (ASCI)'s Draft Guidelines for Responsible Labelling of Synthetically Generated Content. AI tools conducted no original research and played no role in the community engagement, stakeholder consultation, or advisory board processes underlying this Assessment. All analytical judgments, interpretive conclusions, and policy options reflect the expertise of knowledge holders, collaborators, and contributing authors, who bear full responsibility for the content.

Executive Summary

At the confluence of four major ecoregions and the Pacific Ocean, the North Coast region holds an extraordinary diversity of life, ecosystems, and cultural legacies. Its steep mountains, fog-fed forests, serpentine outcrops, and verdant valleys form a rare mosaic of microclimates and habitats, many found nowhere else on Earth. The region provides numerous ecological, cultural, and economic values that are essential in sustaining wildlife and human communities for Northern California and beyond. Yet this biological and cultural richness remains undervalued and underserved in environmental investment.

The northern region of the North Coast comprises Del Norte, Humboldt, Lake, Mendocino, Siskiyou, and Trinity counties. The region is remote and distinctly rural. Roughly 45% of residents live in census-defined rural areas as compared to 6% statewide (US Census Bureau, 2020). All of the region's six counties are classified as nonmetropolitan under the US Department of Agriculture Economic Research Service (USDA ERS) Rural-Urban Continuum Codes (USDA ERS, 2024), with approximately 10% of the North Coast population residing in census tracts classified within the most remote category of USDA ERS Frontier and Remote (FAR) Codes, which measure remoteness based on driving time to nearby urban areas (USDA ERS, 2026). Small cities and towns are interspersed with huge areas of private timberland, ranches, agriculture, alpine zones, National Forests, and State Parks. Over 28 Tribes reside here, including the three largest Tribes found within all of California (Karuk, Yurok, Hoopa). Despite the many colonial impacts done to both the Indigenous Peoples and places they resided on before European contact (explained in more detail in Chapter 4), the Tribes within the Northern California region have continued to tend, shape, and be an intricate part of the ecosystems found here since time immemorial. Over generations, they have developed complex knowledge systems through their direct interaction with nature, often referred to as Traditional Ecological Knowledge (TEK). Thus, it is imperative to understand the role that Indigenous Peoples have in creating a more sustainable and resilient future. While efforts have been made to include TEK, there are opportunities to expand collaborative efforts to include more Indigenous leadership in both decision-making processes and on-the-ground restoration efforts in the future.

The North Coast is a model of myriad successes in conservation and restoration: Klamath River dam removal, reintroduction of extirpated species such as the California Condor, sustainable forest management and livestock production, cultural burning, maintaining diverse ocean and coastal habitats, ocean harvesting, and Indigenous stewardship. This unparalleled biodiversity and endemic species, productive and diverse ecosystems and wildlife habitat, provide a kind of "ecological insurance" for climate resilience and cultural heritage.

Climate change is already dramatically affecting the North Coast. Marine heat waves have decimated 230 miles (370 kilometers) of kelp beds offshore which has eliminated the primary food source for abalone, a culturally important species to Tribes in the region. This decline in abalone populations also led to the closure of a $44 million dollar abalone fishery. Humboldt Bay has seen 1 ft (0.3 m) of sea level rise (SLR) since 1970, which is the highest in the state. The Bay is experiencing damage to infrastructure and habitats, and the rate of SLR is accelerating. Wildfires have expanded in size and become more frequent, with Lake County having 70% of its area

burned by wildfires in the last 10 years. Down-scaled global climate model projections presented in Chapter 1 for the mid- and late-century show increased day and nighttime temperatures as well as increased heat wave occurrence and duration. While annual precipitation averages are not predicted to change, the warming will increase evaporation rates and increase the frequency and severity of droughts. Rain is projected to be more concentrated in winter months, with atmospheric rivers causing flooding, bridge failures, and landslides. Drier fall and spring weather is expected to extend fire seasons and increase fire activity. Chapter 2 outlines how changes to the climate will likely result in forest conversion, reductions in rangeland forage production and habitat, and altered freshwater, coastal, and ocean environments. Offshore, productive upwelling zones important for fisheries are expected to contract as ocean waters continue to warm, acidify, and have lowered levels of dissolved oxygen.

Most of the 380,000 residents of the region live in small towns and on rural properties and therefore are currently dependent upon fragile infrastructure systems that lack redundancy. These systems include single highways with no alternate routes, power lines with no backup sources, and water systems with no secondary supplies. When these systems fail—whether from intense rainfall, wildfire, extreme heat, or other climate-related stressors—the impacts cascade through every aspect of community life, from basic services to economic stability.

This report examines current lifeline vulnerability and chronic infrastructure degradation. It examines climate impacts on transportation and energy infrastructure, water and built structure infrastructure, and public health and emergency response failures. Community consultation for this report revealed clear infrastructure priorities. Rather than accepting centralized systems with single points of failure, residents expressed preference for distributed, redundant networks. Rather than imposing rigid structures on dynamic landscapes, they seek nature-based solutions that work with natural processes. And rather than treating infrastructure as separate systems, they recognize the interconnections—how transportation failures prevent evacuation, power outages disable water systems, and communication breakdowns multiply all other impacts—emphasizing the need for increased coordination and strengthened partnerships.

The region's extensive undeveloped land provides opportunities for nature-based infrastructure at significant scale. These "ecological uplift" approaches (processes that enhance ecosystem functions while meeting human needs) can generate local economic benefits while building resilience to climate impacts. Chapter 3 highlights numerous adaptation examples where these principles are already being put into practice on the ground and lists key considerations for policy. This report raises many questions—including how well nature-based approaches perform compared to engineered ones in different parts of the region, and whether large, centralized investments serve communities better than smaller local ones. Different places need different answers, and local conditions, available resources, and equity considerations should guide those choices.

With respect to social systems, Chapter 4 emphasizes how legacies of colonialism and genocide of Native Americans, extractive capitalism, high unemployment, a 17% poverty rate in the region compared to California's 12% (U.S. Census Bureau, 2023), housing unaffordability, health disparities, and pollution compound regional climate impacts. Despite these systemic inequities, Tribal leadership in the region is modeling pragmatic and transformative future-focused adaptation projects for the rest of the state.

Region-grown initiatives that prioritize investment, development, and long-term support are most effective. Policies written with primarily urban communities in mind will continue to deeply affect the more rural North Coast and impede climate progress in the region. The report provides policy options that can support state, Tribal, and local governments in finding ways to adapt and enhance resilience in the face of climate disruption. For the state government, these may include: supporting Tribal sovereignty, Indigenous leadership, and more collaborative work with Tribes—in ways such as expanding prescribed fire permitting for Tribes, and reforming finance and grant structures to better sustain long-term, multi-beneficial outputs. Updating metrics of success to adopt regional approaches will improve the identification of disadvantaged communities. Wildfire smoke, energy burden (the share of household income spent on energy costs, which falls disproportionately on rural and low-income households), and toxic sediment run-off and transport are factors important to the North Coast that standardized environmental justice screening approaches do not capture. Rural, coastal cannabis cultivation could provide superior climate resilience and related socio-economic and public-health benefits as compared to indoor industrialized operations in other parts of the state.

Community advisory board members felt that building out community-led planning, partnering regionally, and investing locally would be the most effective ways to support local governments in adapting to climate change impacts. Lasting climate adaptation depends on sustainable funding. Communities and governments must actively develop strategic revenue sources—including reformed grant structures, regional finance tools, and funding mechanisms tied to climate risk reduction—rather than relying on one-time or mismatched investments.

Table of Contents

Executive Summary **9**

Table of Contents **12**

Introduction **14**

Chapter 1. Climate Science: Historical & Projected Trends **17**

Key Message 18

1.1 Geographic Setting of the North Coast Region 18

1.2 Historical and Predicted Trends in the North Coast Region's Climate 21

1.2.1 Observed Temperature 21

1.2.2 Predicted Temperature Trends 21

1.2.3 Observed Precipitation 25

1.2.4 Predicted Precipitation Trends 26

1.3 Hydroclimate Droughts and Floods 28

1.4 Observed and Projected Fire 31

1.4.1 Observed Fire 31

1.4.2 Projected Fire 32

1.5 North Coast Sea Level Rise 33

1.5.1 Observed and Predicted Sea Level Rise Trends and Rates 36

Chapter 2. Natural and Working Lands & Waters **40**

Key Message 41

2.1 Enduring Wisdom for a Changing World 41

2.1.1 Cultural Fire as a Tool of Stewardship 41

2.1.2 Animals as Kin, Guides, and Resources 42

2.2 Terrestrial Systems 42

2.2.1 North Coast Biogeography 43

2.2.2 Forests and Woodlands 43

2.2.3 Grasslands 48

2.2.4 Rangelands and Grazing 49

2.2.5 Wetlands and Mesic Zones as Climate Refugia 51

2.2.6 Invasive Species and Ecological Disruption 53

2.3 Rivers and Lakes 54

2.3.1 Freshwater Seasonal Patterns 55

2.3.2 Freshwater Temperatures 56

2.3.3 Drought and Rivers 58

2.3.4 Flooding and Sea Level Rise Near Rivers 59

2.4 Ocean and Coasts 60

2.4.1 Impacts of Climate Change on Ocean and Coasts 61

Chapter 3. Built Systems in the North Coast Region **66**

Key Message 67

3.1 Built Systems in the North Coast Region 67

3.1.1 Transportation Infrastructure Impacts 70

3.1.2 Energy Infrastructure Impacts 72



3.1.3 Water Infrastructure Impacts....74
3.1.4 Buildings and Built Environment Impacts....76
3.1.5 Cross-Cutting Impacts: Public Health and Emergency Response Failures....77
3.2 Built Systems Adaptation Strategies....80
3.2.1 Strategy 1. Working with Natural Systems: Infrastructure as an Ecosystem....80
3.2.2 Strategy 2. Distributed Networks: Eliminating Single Points of Failure....83
3.2.3 Strategy 3. Adaptive Management: Right-Sizing Infrastructure for New Realities....85
3.2.4 Strategy 4. Integrated Multi-Benefit Solutions....86
3.2.5 Pathways for Infrastructure Transformation....88
3.3 Key Considerations for Policy....89
3.3.1 Assessment Limitations....90
3.4 Looking Ahead....90
Chapter 4. Social Systems and Cultural Resources....91
Key Message....92
4.1 Indigenous Knowledges....92
4.2 Education....94
4.2.1 Traditional Ecological Knowledge & Indigenous Science....94
4.2.2 Toward a PolyTEK for All....94
4.3 Governance....94
4.3.1 Tribal Governance....95
4.3.2 State and Regional Governance....96
4.4 Labor and Workforce Development....97
4.5 Finance....99
4.6 Insurance....100
4.7 Economics....102
4.7.1 Impacts on Ranching....103
4.7.2 Cannabis
4.8 Public Health....108
4.8.1 Physical Health: Extreme Heat....108
4.8.2 Physical Health: Wildfire....110
4.8.3 Mental Health....111
4.8.4 Limited Access to Care....112
4.8.5 Regional Strengths....112
4.9 Racial and Social Equity & Climate Justice....112
4.10 Human Displacement....114
4.11 Emergency Capacity and Rural Recovery....116
Conclusion....118
Glossary of Terms....121
Appendices....135
Appendix 1. Climate Science....136
Appendix 2. Natural and Working Lands & Waters....141
Appendix 3. Built Systems: Economic Framework for Climate-Resilient Infrastructure Investment....156
Appendix 4. Social Systems and Cultural Resources....173
Appendix 5. Lists of Tables, Figures, Case Studies, Appendices....189
List of Appendix Tables....191
List of Appendix Figures....191
References....193

Introduction



Our mandate was to report on how climate change will affect the North Coast region of California, how social, natural, and built systems can be developed to best respond to those changes, and what strategies there are to adapt and be resilient. The report authors, most of whom live in the North Coast, worked to include multiple perspectives from as many areas in the region as possible. Contributors were invited to provide input grounded in their lived experience and expertise, offering insights into how resilience can be strengthened across the region. In addition to multiple authors, the report includes input from online meetings and in-person workshops convened with a community advisory board and a technical advisory board. A lengthy Appendix is included, representing additional perspectives of the region, as well as a Glossary of Terms. The report does not expressly address the task of reducing our emissions of greenhouse gases, as this work is described in the State of California's Priority Climate Action Plan and other documents. However, it is important to the authors and advisory board members to state clearly that we cannot simply adapt our way out of the coming climate change impacts. It is critical to make rapid reductions in emissions to slow human-caused climate impacts and limit the disruptions that future generations will experience.

The North Coast region is a unique region of great natural beauty, forests, grasslands, rivers and estuaries, mountains, and rugged windswept coasts. It consists primarily of rural residents, small towns and cities, minimal industry, and a strong Tribal presence. The region has unique challenges and opportunities with respect to climate change adaptation and resilience, due to the drastic differences within it. As such, the report discusses concerns and issues for communities and ecosystems in coastal zones as well as the inland counties dominated by mountains or range environments.

A few of the many challenges our region faces include: remoteness in the face of natural disasters; small populations with limited capacity for disaster response; limited financial resources; few hospitals; and often limited access to evacuation routes. Economic disruption in communities supported by only a few sectors, such as forestry, fisheries, and government employment, is an ongoing concern.

Lower population densities (compared with California's urban regions) also mean that opportunities exist for adaptation and resilience that might not be possible in more urbanized areas. For example, minimal coastal development means that populations and ecosystems in those areas might have spaces to shift as sea levels rise. It means there is room to create fuel breaks around communities threatened by wildfire. Rural people often foster traditions of self-reliance, community support, and resourcefulness. Ancestral knowledge and perspectives from Tribal nations can inform land management, give insight into how we can live in balance with the natural world, and adapt to change. The Indigenous Peoples of Northern California have developed their worldviews around relational accountability founded upon three core values of respect, responsibility, and reciprocity. From a Tribal perspective, the climate crises results from colonization and the colonizer mindset. How do we change and reclaim our role of stewardship and relational accountability?

In September 2025, the National Academies of Sciences (NAS) published findings affirming that greenhouse gases are a danger that threaten public health and wellbeing (NAS 2025). The NAS report concludes that the endangerment finding by the US Environmental Protection Agency (EPA) has "stood the test of time and is now reinforced by even stronger evidence" (NAS, 2025, p. 1). Many of our authors have been working for decades to study and communicate the impacts of climate change. This report, situated in the voices, places, and peoples of California's North Coast, provides further evidence in support of NAS's findings, documenting publicly the ways in which climate change threatens and endangers our region.

The report pairs outlines of climate impacts alongside profiles of the climate economy emerging in our region and identifies valuable, region-grown resilience initiatives deserving of state attention and ongoing support. As Casey O'Neill from Happy Day Farms (Mendocino County) emphasized, the growing restoration economy is "a bright spot in a moment that often feels pretty bleak." The following report has been guided by our understanding and need for relational accountability to the many places and faces found within the Northern California region. It is grounded in our responsibilities and reciprocal relationships of caring for the lands and waters, and involving the future generations in climate resilience work.

Chapter 1.

Climate Science: Historical & Projected Trends

Authors: *Andrew Stubblefield and Rosemary Sherriff with Jeffrey Anderson, Chris Gressierer, Jeff Kane, and Jason Patton*

Key Message

Temperatures will continue to rise dramatically in the North Coast region. High temperatures mean that even though average annual precipitation is not predicted to change, the region will experience more frequent droughts. Rainfall is likely to be more concentrated in high-intensity events in the winter season, with less rainfall in the fall and spring, exacerbating flooding. Changes in rainfall and drying trends will increase wildfire frequency in the interior and southern portions of the region and eventually coastal regions. Sea level has risen and the rate of sea level rise (SLR) is accelerating. Because of land subsidence, Humboldt Bay is experiencing the highest rate of SLR and shoreline erosion in the state. Del Norte and Mendocino counties' tide gauges show a slower trend because of tectonic uplift. This chapter highlights the geographic setting of the North Coast region, observed and predicted climate changes (including temperature, precipitation, hydroclimate, and fire), and sea level rise.

1.1 Geographic Setting of the North Coast Region

The North Coast is a complex topographic region where major ecoregions converge, including the North Coast, North Coast Ranges, Klamath Mountains, the Cascade Range, and the Modoc Plateau (**Figure 1.1**). The region has a distinctive, Mediterranean-type seasonality characterized by wet, cool winters and dry, warm summers, with the region experiencing the greatest amount of precipitation of any region in California. Notably, the west-east atmospheric circulation from the Pacific Ocean and topographic variability produce the wettest conditions in the northwest, seconded by the northern interior, and the driest conditions in the eastern and southern areas of the region (**Figure 1.2**). Strong west-east, north-south, and low-high elevational climatic gradients create highly variable local temperature and precipitation patterns.

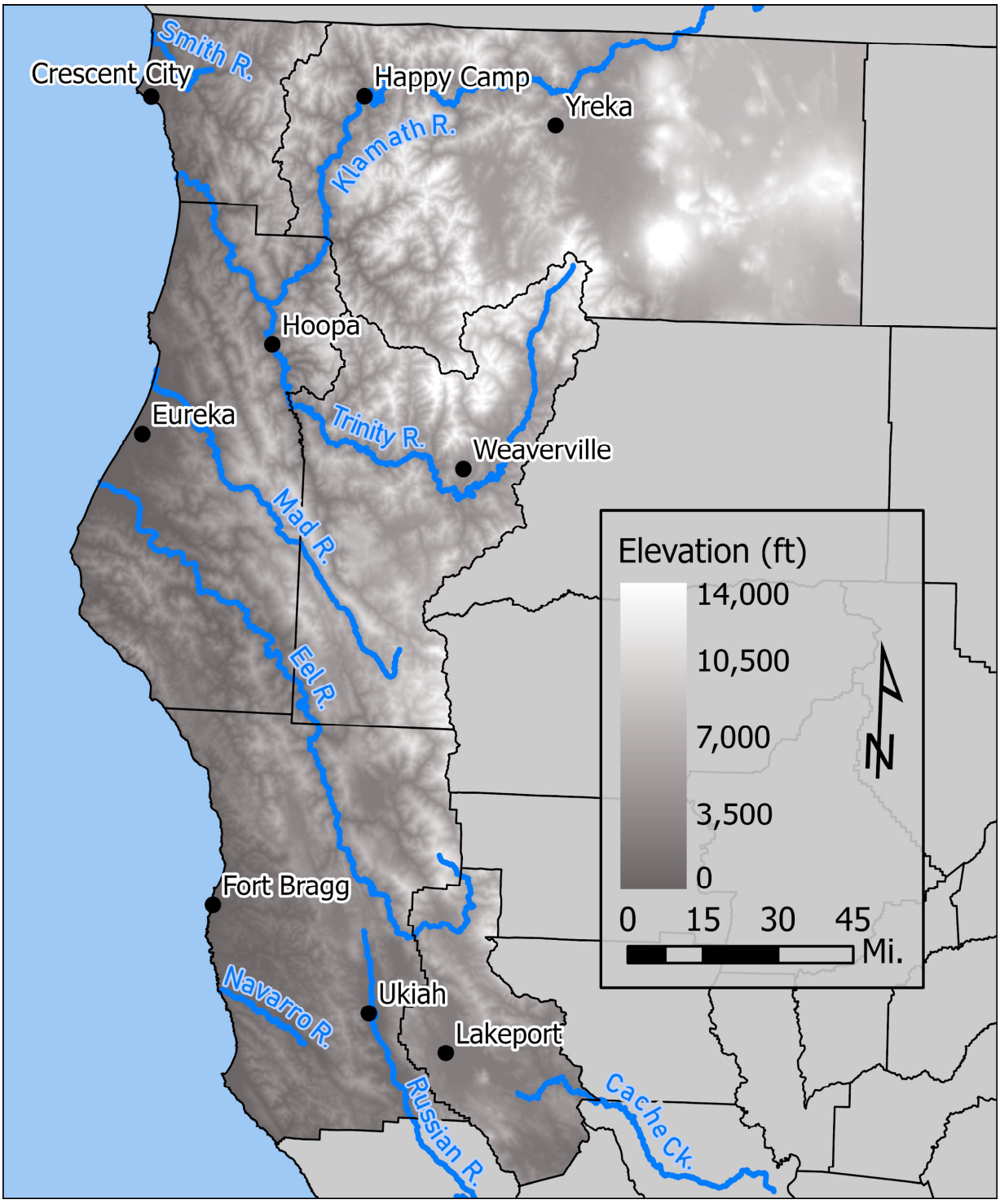


Figure 1.1: *Topographic variability across the six counties of the North Coast region, with the shade of gray representing elevation zones: darker shades indicate lower elevations and lighter shades indicate higher elevations. Contributor: Chris Gressierer*

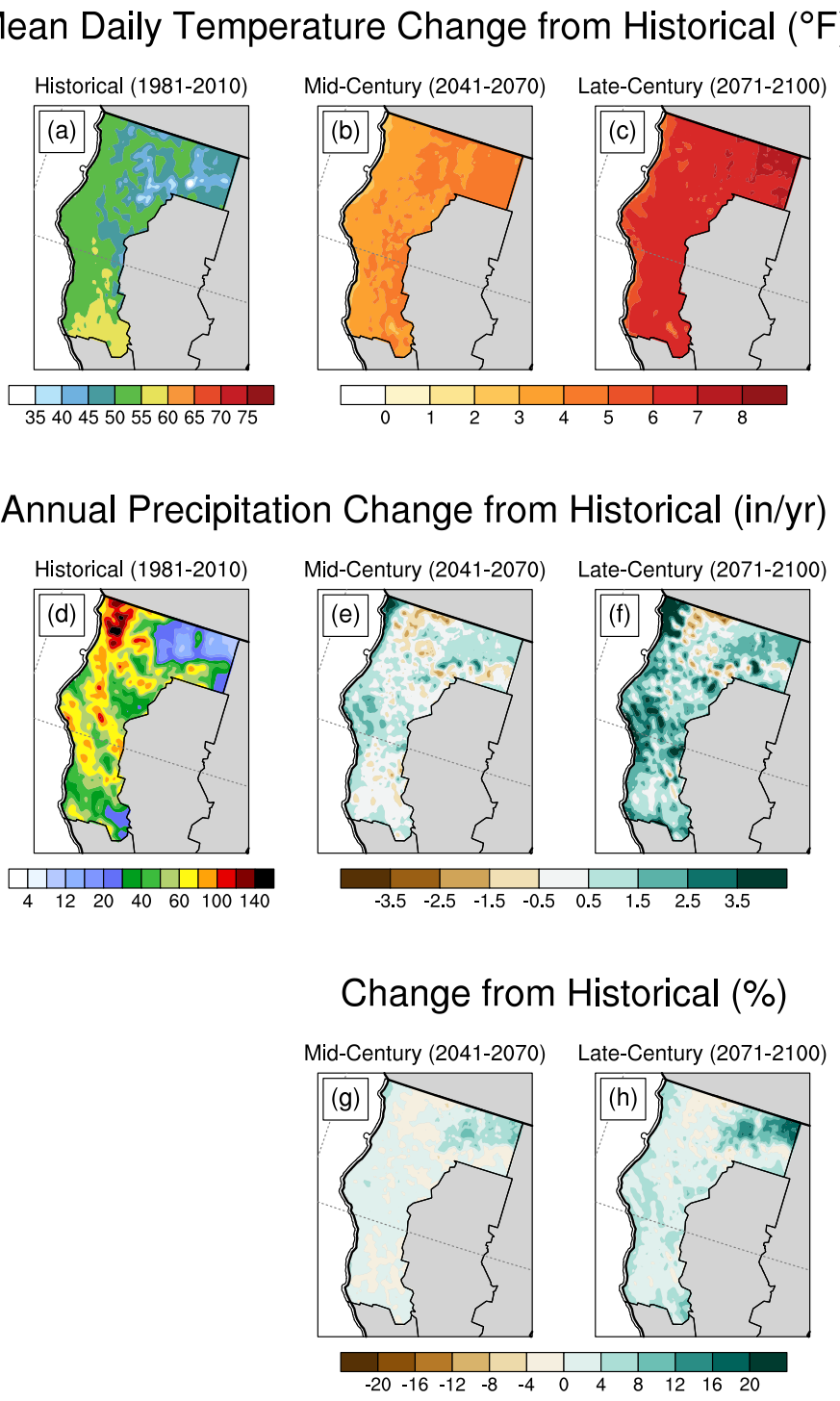


Figure 1.2: *Spatial patterns of changes in temperature and precipitation of the North Coast Region. Map of (a, d) historical (1981–2010) and (b-c, e-f, g-h) change from historical by mid-century (2041–2070) and late-century (2071–2100) for (top row) mean annual temperature (°F), (middle row) precipitation (in/yr), and (bottom row) percent precipitation under the SSP3–7.0 scenario. Contributor: Paul Ullrich*

1.2 Historical and Predicted Trends in the North Coast Region's Climate

1.2.1 Observed Temperature

Coastal temperatures are moderate throughout the year (average 52°F [12°C]) and range annually on average from 26–67°F (-3.3–19.4°C), whereas interior temperatures can fall below 10°F (-12.2°C) in the winter and exceed 85°F (29.4°C) in the summer (recorded period of time with the warmest and coldest daily average temperatures; **Appendix Table 1.A**). Average minimum winter and maximum summer temperatures are more moderate but show greater ranges in interior locations. Within the North Coast, the southernmost interior areas (Lakeport, Ukiah) are about 5°F (2.8°C) warmer than coastal areas (Crescent City, Fort Bragg) on average annually. Topographic variability throughout the region also has significant effects on local temperatures. Annual cooling degree days—a measure of the cumulative amount of time that daily average temperatures exceed 65°F (18.3°C), which is a proxy for energy for air conditioning—are much lower along the coast than the rest of the region. The number of days below freezing varies geographically, with a much higher number of freezing days in the northern interior portions of the region that also have the highest elevation ranges. In the northern mountainous areas, temperature inversions are not uncommon during the warm season due to their proximity to cool, moist air from the Pacific, the rugged mountain topography, fire weather, and trapped smoke (Sherriff et al., 2022). This can lead to considerable differential effects on temperature and fire behavior both below and above the inversion layer (often around 4,200 ft [1.28 km]; Estes et al., 2017), which is characteristic of and relatively unique to this region.

Over the past century, the North Coast Region has experienced a strong warming trend (**Figure 1.3**). This matches warming occurring across California and is largely due to anthropogenic (human-induced) climate change (e.g., Diffenbaugh et al., 2015). Mean annual temperature in the region has warmed by ~3°F (1.7 °C) during 1895–2024. Noticeable warming periods include 1920–1940 and 1980–2000. However, an acceleration of warming has occurred since 2008, with the rate of warming of the current period eclipsing any period since 1895. Five of the hottest years on record have occurred since 2014.

1.2.2 Predicted Temperature Trends

Global climate models allow us to predict how temperature and other climate variables will change over time as atmospheric concentrations of greenhouse gases and other factors influence the climate. The Intergovernmental Panel on Climate Change (IPCC) lists different outcomes based on which Shared Socioeconomic Pathway (SSP) humanity follows over the course of the century. The SSPs are different estimates for change in variables which are critical for predicting emissions, such as population growth, technological development, global integration of technology, and the rate at which carbon-free energy supplies are adopted. For this report, we are directed to consider a *high* emissions scenario, SSP 3–7.0, and how it will influence climate in the mid- (2041–2070) and late-century (2071–2100). SSP 3–7.0, as well as the optimistic *medium* emissions scenario SSP 2–4.5 and the pessimistic *very high* emission scenario SSP 5–8.5, are shown in **Figure 1.4**.

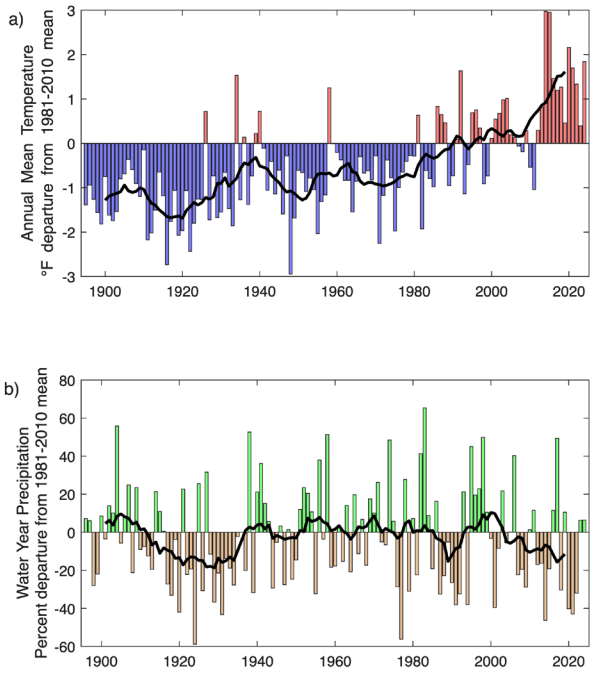


Figure 1.3: *North Coast region observed historical change in annual mean temperature and water-year precipitation. Historical change in (top) mean annual (Jan–Dec) temperature from nClimGrid for the region is reported as anomalies from the historical period (1981–2010); (bottom) water year (Oct–Sep) precipitation anomalies. The black line shows the 11-year centered moving average. Data from NOAA's monthly nClimGrid averaged across the geography of each region. Contributor: John Abatzoglou*

Temperature will continue to increase substantially by mid-century under all scenarios, from annual daily average temperatures of 51ºF now to approximately 54°F by mid-century across the region (**Figure 1.4**). By the end of the century, the *very high* emission scenario (SSP 5–8.5) leads to average annual temperatures in the North Coast being ~10ºF (5.5°C) higher than in 2015. If society is able to reduce emissions more quickly, the *medium* SSP 2–4.5 scenario would result in a still considerable ~5ºF (2.8°C) of warming by 2100. The *high* SSP 3–7.0 shows warming of ~7.5ºF (4.2°C). Over the short term, the next 15 years, little difference is observed between scenarios because of lags in the climate system and inertia in socio-economic systems. At that time scale, climate is more strongly influenced by decisions made in the past with respect to infrastructure and energy usage. By 2040, we start to see the *highest* emission pathway, SSP 5–8.5, diverging from the others with increases in predicted temperature relative to scenarios where fossil fuels are tightly restricted and the transition to carbon-free energy sources is promoted worldwide. The *high* and *medium* emission scenarios diverge from each other around 2070, resulting in 2.5ºF (1.4°C) more warming for the *high-range* scenario by 2100 as compared to the *medium-range*.

Warming across seasons is not even. Monthly average temperatures increase across the board (**Figure 1.5**). However, the warm season will show greater increases than the cool season. August and September monthly averages are predicted to be ~5ºF (2.8°C) hotter than the historical period by mid-century and ~8ºF (4.4°C) hotter by end-century according to the high-range SSP–3.70 scenario (and presumably much hotter for the very high-range SSP 5–8.5 scenario). Winter months, January through April, will be ~3ºF (1.7°C) hotter by mid-century and ~5ºF (2.8°C) by end-century.

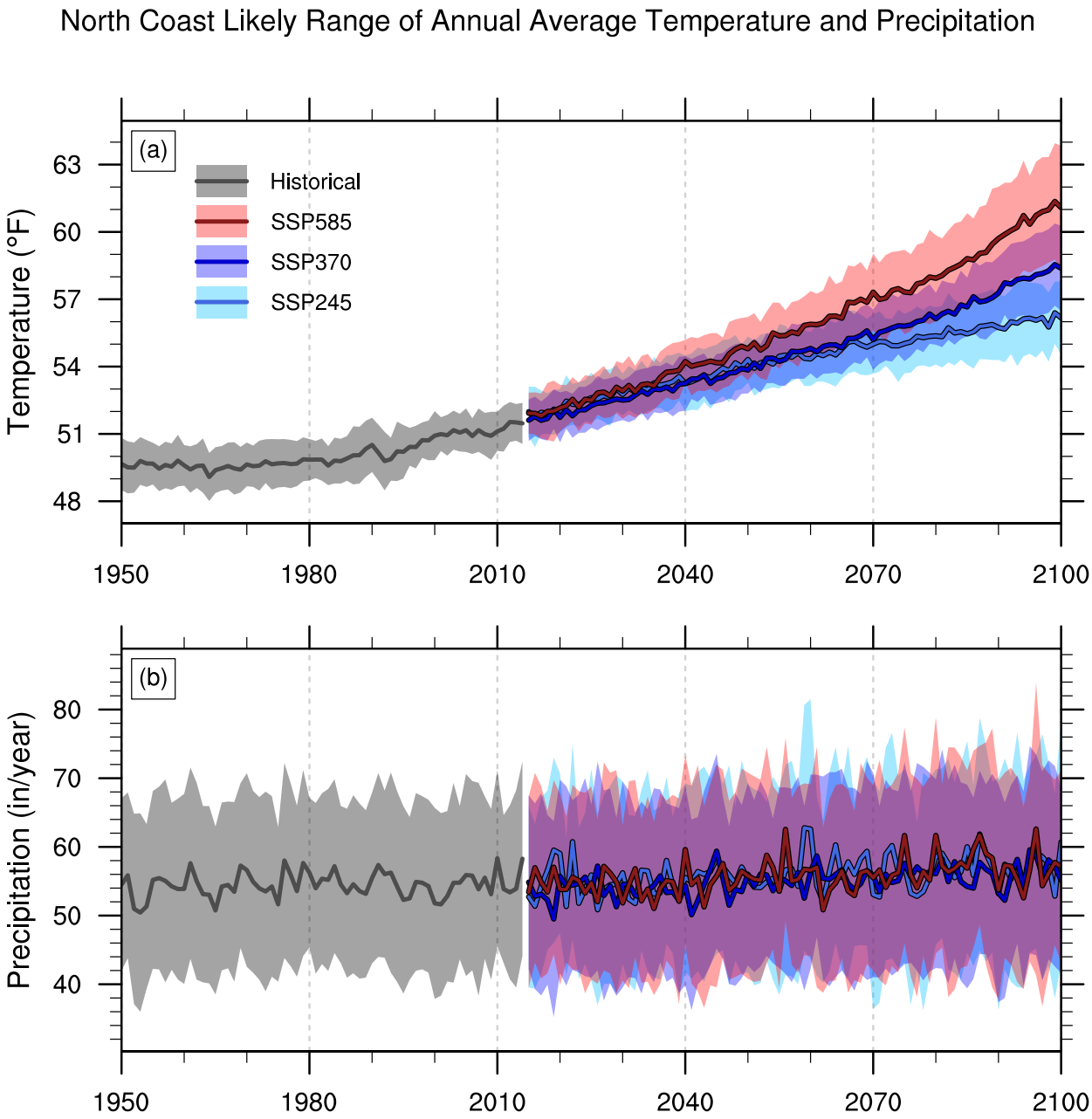


Figure 1.4: *North Coast region projected trends in annual temperature and precipitation. Mean annual (a) temperature (°F) and (b) precipitation (in/year) likely range estimated by LOCA2-Hybrid downscaled global climate models over the historical period (1950–2014; gray) and future periods (2015–2100) under three climate scenarios. SSP 2–4.5 (cyan), SSP 3–7.0 (blue), and SSP 5–8.5 (red) show three possible Shared Socioeconomic Pathway Scenarios (IPCC 2022), representing possible pathways societies and economies could take with respect to greenhouse gas emissions and land management. The "likely" values represent values within one standard deviation of the mean of the model runs. Contributor: Paul Ullrich*

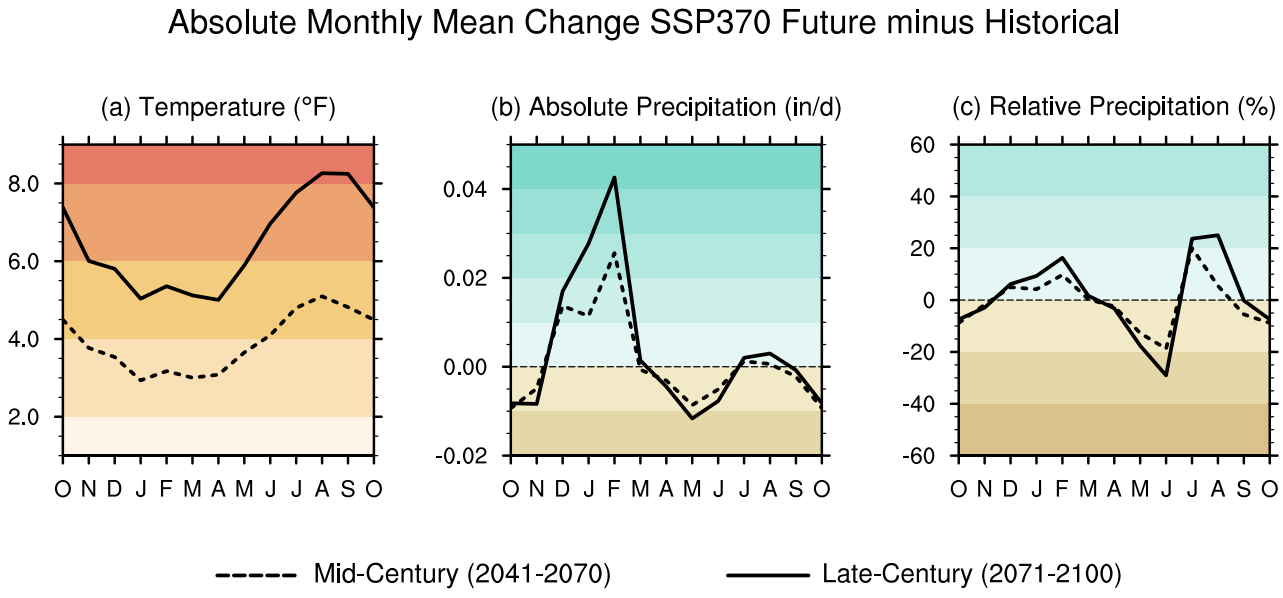


Figure 1.5: *North Coast projected changes in monthly temperature and precipitation. Seasonal change from historical (1981–2010) to future monthly (a) temperature (°F), (b) precipitation (in/day), and (c) precipitation (% of 1981–2010 in/yr) projected under the SSP 3–7.0 scenario. Contributor: Paul Ullrich*

Warming across the six-county region is pretty consistent as measured by maps of predicted Mean Daily Temperature Change (**Figure 1.2**) despite the geographic differences (**Appendix Table 1.A**). Slightly greater warming is predicted in eastern Siskiyou County and eastern portions of the inland counties at mid-century (~5ºF vs ~4ºF). By end-century, 6–7ºF mean daily temperature changes are projected across most of the region, with slightly cooler temperatures of 5–6ºF along the coast and slightly hotter temperatures of 7–8ºF in northern portions of Siskiyou County. Projections show mid-21st century summer temperature increases significantly higher in inland locations (**Table 1.1**). However, in coastal locations summer temperature increases are lower than average annual increases. Changes in winter minimum temperatures are slightly greater for interior cities compared to coastal locations. Likewise, cooling degree days increase and freezing nights decrease substantially, particularly in inland locations.

Table 1.1 *Projected changes in key climate statistics for nine cities in the North Coast region. Projected changes in climate for 2041–2070 relative to 1981–2010. All measures reflect annual averages for the period 1991–2020 using a multi-model averaging approach with SSP 3–7.0 LOCA2-Hybrid data. Measures were calculated as the average value of an approximately 15x15 km area centered around each city. Winter averages are calculated for December through February and summer averages for June through August.*

Climate Statistic	Crescent City	Eureka	Hoopa	Weaverville	Happy Camp	Yreka	Ukiah	Lakeport	Fort Bragg
Mean annual temp °F (°C)	+2.9 (+1.6)	+3.3 (+1.8)	+4.4 (+2.4)	+4.4 (+2.4)	+4.4 (+2.5)	+4.8 (+2.7)	+4.3 (+2.4)	+4.1 (+2.3)	+3.3 (+1.8)
Average winter max temp °F (°C)	+2.5 (+1.4)	2.8 (+1.6)	+3.6 (+2.0)	+3.4 (+1.9)	+3.4 (+1.9)	+3.2 (+1.8)	+3.6 (+2.0)	+3.2 (+1.8)	+3.0 (+1.7)
Average summer max temp °F (°C)	+2.2 (+1.2)	+2.9 (+1.6)	+6.2 (+3.4)	+6.2 (+3.4)	+6.3 (+3.5)	+7.0 (+3.9)	+5.0 (+2.8)	+4.8 (+2.7)	+2.7 (+1.5)

Climate Statistic	Crescent City	Eureka	Hoopa	Weaverville	Happy Camp	Yreka	Ukiah	Lakeport	Fort Bragg
Average winter min temp °F (°C)	+2.9 (+1.6)	+3.1 (+1.7)	+3.3 (+1.9)	+3.3 (+1.8)	+4.0 (+2.2)	+3.9 (+2.2)	+3.6 (+2.0)	+3.2 (+1.8)	+2.9 (+1.6)
Cooling Degree Days	20	7	83	70	67	79	69	65	9
Freezing nights (days)	-2.1	-2.7	-51.3	-37.7	-90.1	-33.1	-14.8	-20.3	-4.8
Annual precip (%)	8.1	5	2.8	0.4	0.7	3.3	-0.6	0.1	5

For readers seeking more detail for their area within the North Coast, we have prepared graphs (**Appendix 1.2**) showing climate model predictions (LOCA2-Hyrbid, SSP 3–7.0) for the same nine cities as **Table 1.1** for every year from now through 2100. Seven climate variables are shown: maximum relative humidity, minimum relative humidity, average absolute humidity, precipitation, windspeed, and maximum and minimum daily temperature. Averages across four seasons are also shown.

Extreme heat changes across the region can be understood by mapping the number of days above a threshold value during the historical period and predicted mid and end-century (**Appendix Figure 1.1.A**). These are time periods when working outside becomes difficult and heat exhaustion and death become more common, particularly among the elderly. While much of the region currently has 20–60 days a year with daily average temperatures above 90ºF, only some of the inland areas experience days above 100ºF (typically 5–10 a year). Note that the daily high temperatures can be much higher than the daily averages, which include cooler nighttime temperatures. By mid-century, those same inland regions—Lake County, southern Humboldt County, Trinity County, and western Siskiyou County—will experience 20–30 days a year with average temperatures above 100ºF. More parts of the North Coast will experience days over 100ºF. By end-century, the predictions give 40–60 days a year above 100ºF and 1–5 days above 110ºF for the hottest parts of the region. By end-of-century, the entire North Coast region will have at least 5–10 days a year above 100ºF except a sliver right along the coast of Humboldt and Del Norte counties, and 40–60 days a year above 90ºF. The number of warm nights (**Appendix Figure 1.1.B**) will also increase across the region, though it is not expected to cross critical thresholds by the end of the century (only a few nights above 80ºF even in the warmest part of the region). However, heat waves are projected to be longer as a result of climate change (**Appendix Figure 1.1.C**). Across the North Coast region, the average longest heat wave per year during the historical period lasted about three days. Under SSP 3–7.0, this is projected to increase by about five days by mid-century and nine days by end-of-century.

1.2.3 Observed Precipitation

High inter-annual variation in precipitation is the norm (**Figure 1.3**), with most precipitation occurring between November and April, followed by a prolonged dry season from May through October. As with other regions of California, the majority of precipitation occurs in a few major storm events annually, which is critical for water resources (Dettinger et al., 2011, Guirguis et al., 2019). However, predictability is low and water storage fluctuates widely year to year depending on the frequency and intensity of atmospheric river events. Single- and multi-year droughts are common (e.g., Griffin & Anchukaitis, 2014). The lack of instrumental stations along elevation

gradients limits our ability to evaluate specific trends by elevation, but there are clear and strong orographic (mountain) effects that consistently lead to less precipitation in valleys and canyons than at higher elevations and on the west side of the mountain ranges (Sherriff et al., 2022). The orographic uplift of moist air masses leads to high precipitation in the eastern portions of the region as the first major mountain range encountered by southwesterly winds moving from the Pacific Ocean. On average, the northern coastal areas receive over 60 inches (1.52 m) of annual precipitation, with the majority falling on the coastal mountains in the winter months. In contrast, some inland valleys receive as little as 18 inches (45.7 cm) annually (**Appendix Table 1.A**). The average snow line is ~4,500–5,000 ft (1.37–1.52 km), with accumulation highly dependent on annual and geographic variability. As storms move to the east, the higher average elevation means more snow that is less dense on average and has lower water content. This regulates the speed at which snowpack melts and how much water is released during winter warming events.

No clear trends have been observed for annual precipitation in the North Coast region since 1895 (**Figure 1.3**). We are currently in a 20-year drought that began in 2000. This is part of the millennial drought that has hit much of the southwest (Williams et al., 2022). However, for our region, the drought has not yet eclipsed a dry period of similar magnitude that began in 1905 and extended until 1938. Our current 11-year running average precipitation shows that we are about 18% below the 1981–2010 average. The 1905 drought was 20% below the 1981–2010 average. A cyclical pattern is evident over the century that may be tied to wetter El Niño years. The occurrence of multi-year periods of low precipitation has increased since the 1980s relative to the period of 1940–1980. Furthermore, summer streamflow reductions have been observed since 1953 across the North Coast region (Asarian & Walker, 2016).

Seasonal precipitation has changed significantly. A study of rainfall records since 1960 (Lukovic et al., 2021) indicates a delayed onset to the winter rainy season across California with a stronger trend in Northern California. November rainfall has decreased across the North Coast region, with particularly strong decreases in Del Norte County. This has been termed an increase in "seasonal sharpness", with less autumn precipitation (September–November) and more winter precipitation (December–March). Asarian & Walker (2016) noted a decline in September precipitation since 1953.

Fog is most prevalent in the northern coastal areas of the North Coast from late spring to early autumn (May–October). The timing is driven by the interaction of cool coastal temperatures related to upwelling water from the California Current (a cold, southward flowing Pacific Ocean current along the western coast of North America) and deeper ocean upwelling that meets warmer inland air. This creates a marine layer that buffers the coast and is particularly important for redwood forests during the dry summer months. The frequency and duration of fog vary significantly year to year, with some limited evidence of late 20th- and early 21st-century decline (Johnstone & Dawson, 2010) and uncertainty of how these trends may play out in the future.

1.2.4 Predicted Precipitation Trends

For annual average precipitation, no clear trend emerges from the aggregated climate model predictions (**Figure 1.4**). The range of likely annual precipitation from 40–70 in/yr closely matches the range in observed data since 1950. A slight increase in high-precipitation years by the end of the century is apparent (**Figure 1.4**) and illuminated more clearly by **Figure 1.6**. These trends are more pronounced along the coast than inland in the North Coast region (**Table 1.1**). However,

changes in predicted storm characteristics are of great concern. Atmospheric rivers, cyclonic events that bring moisture off the Pacific Ocean, deliver much of the annual totals of rain and snow to California and are responsible for much of the flooding, landslides, and damages that occur from winter storms. They are expected to increase in number, duration, and intensity over the course of the century even as the wet season grows shorter (Guirguis et al., 2019).

Seasonal differences in the timing of precipitation are predicted to continue trends already observed. In particular, winter precipitation (December–February) is expected to increase over the century (**Figure 1.5**). February precipitation will increase as much as 20% by end-of-century. July and August precipitation will increase by ~20% as well; however, this is a small absolute increase in water given how dry the region is at that time of year. The "seasonal sharpening" that has already been observed will continue, with predicted drops in precipitation for the shoulder seasons. Spring precipitation is predicted to show the sharpest declines, particularly May and June, with June showing almost a 30% decline by end-century.

Spatial differences in predicted precipitation are observed across the six counties (**Figure 1.2, Table 1.1**). At mid-century, areas across the North Coast are predicted to be slightly drier (0–4%) than the historical period, and then slightly wetter by end-of-century (0–4%, **Figure 1.2g**). By 2100, parts of southern Humboldt County, northern Del Norte, and Lake County are predicted to see 4–8% increases in annual precipitation (**Figure 1.2h**). While west Del Norte has a large end-of-century increase over historical precipitation (3.5 inch/yr, **Figure 1.2f**), this is quite small as a percent of the >100 in/yr (254 cm/yr) historical average (**Figure 1.2h**). Eastern Siskiyou County, a drier area in the region, is predicted to see 12–20% increases in precipitation over the historical period.

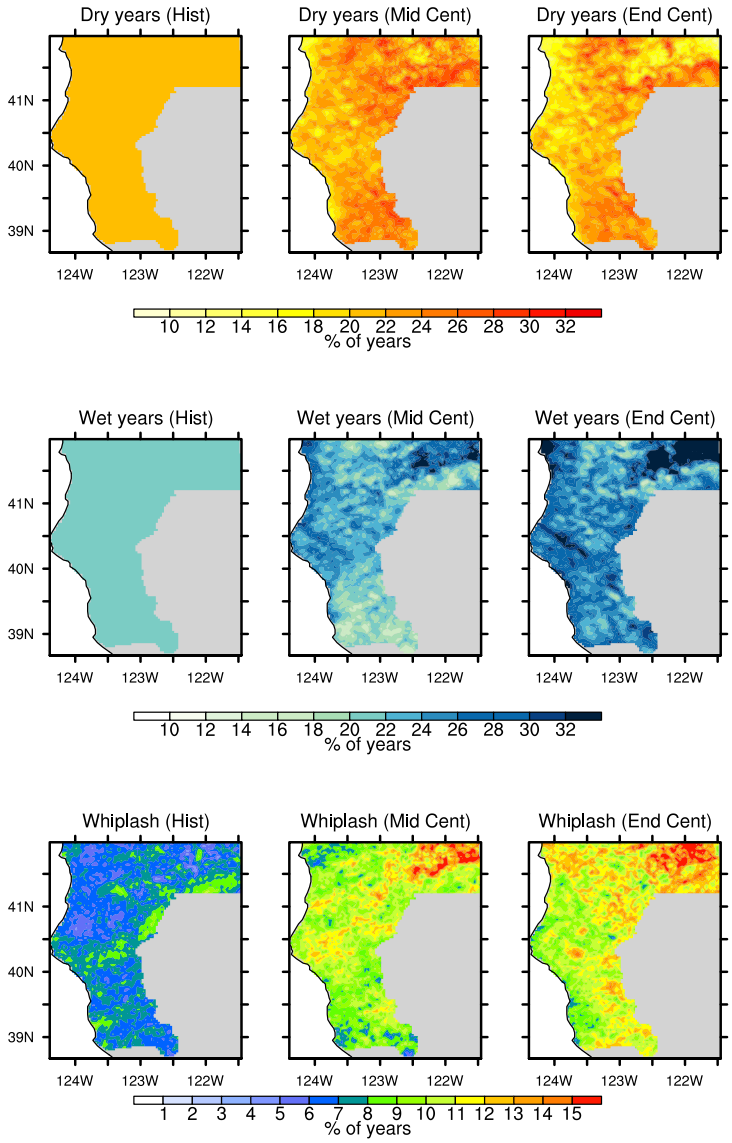


Figure 1.6: *Projected change in variability of precipitation under the SSP 3–7.0 scenario. Change in frequency of (a) dry years (below the 20th percentile of historical 1981-2010 precipitation), (b) wet years (above the 80th percentile), and (c) whiplash years (consecutive occurrence of wet and dry years, using same definitions). By definition, historical occurrence of wet and dry years is 20% everywhere. Contributor: Jesse Norris*

1.3 Hydroclimate Droughts and Floods

Some of the largest disturbances occur during climatic whiplash, when dry years alternate with wet years (Swain et al., 2018). Drought frequency will increase across the region (**Figure 1.7**). Model predictions indicate we will see an increase from 20% to 30% in the frequency of both dry and wet years for most of the North Coast region (**Figure 1.6**). By mid-century, the occurrence of whiplash years (when a dry year is followed by a wet year) will double for most of the region, increasing from ~5% of years to ~10%. Eastern Siskiyou County, and small portions of Humboldt and Trinity counties, will see the occurrence of whiplash triple in frequency.

Since average annual precipitation trends are not evident, an explanation is needed for why drought would increase. The answer is that the atmospheric demand for water increases with temperature. Hotter air temperatures increase evapotranspiration rates from land surfaces, and warmer air can hold more moisture. Thus, even mild droughts can become more severe as the climate warms. This is exactly what occurred during the 2000–2018 Southwest US megadrought (Williams et al., 2022), where climate change turned a moderate drought into the second worst drought in the last 1,200 years (also see Griffin & Anchukaitis, 2014). The Williams et al.(2022) study used climate modeling to determine that anthropogenic climate change resulted in greater evaporation and lower relative humidity and precipitation, increasing the drought severity by 46% as compared to model runs without anthropogenic climate change.

In the North Coast region, annual evaporation rates generally vary from 1.5–2.3 inches (40–60 mm) (**Figure 1.7a**). Droughts are water deficits that accumulate over time. Extreme drought (5th percentile for historical conditions based on the period 1951–2000) is 5–10% more likely across the region by mid-century even under the *medium-range* emissions scenario (SSP 2–4.5). A few areas in northern Siskiyou will have a 15% increased likelihood of extreme drought. For three-year droughts, which have much bigger impacts on water supplies and ecosystem health, increases in likelihood are similar at 5–10% for most of the region. However, Siskiyou County is predicted to be subject to greater changes in three-year drought frequency, approaching 20 or even 25% increased likelihood in portions of the northern part of the county. Duration of droughts is predicted to increase across the region, with the exception of the Lake and southern Mendocino counties where drought length decreases over the century (**Appendix Figure 1.1.D**).

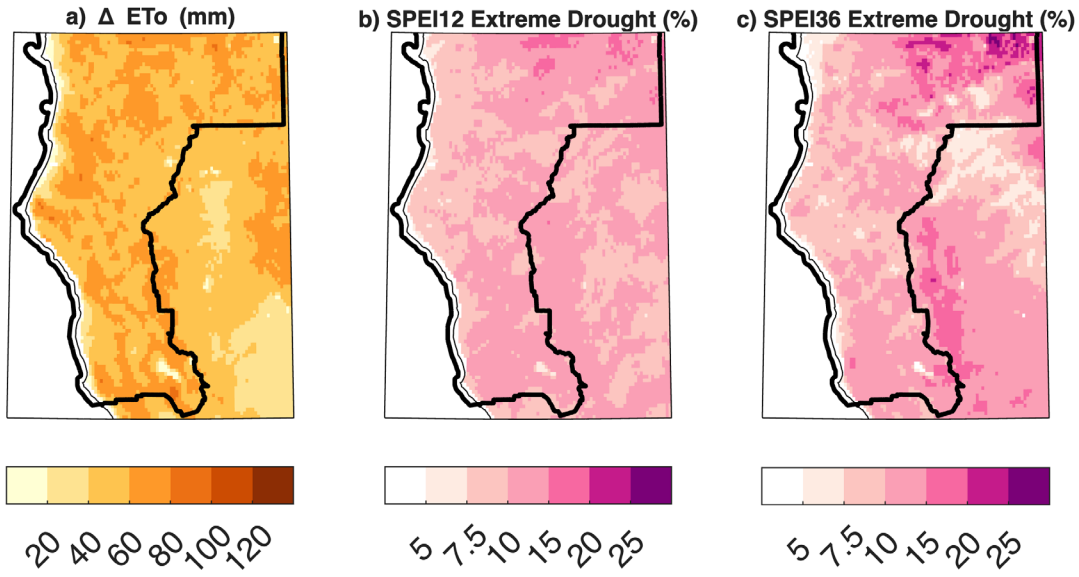


Figure 1.7: *Projected change in agricultural drought measures. Multi-model mean (a) change in annual evaporative demand (ETo), and the percent change in the annual likelihood of extreme drought for (b) 12-month Standardized Precipitation-Evapotranspiration Index (SPEI) and (c) 36-month SPEI for mid-century (2041–2070) under SSP2–4.5. ETo was calculated using the Penman-Monteith approach accounting for the influence of rising carbon dioxide concentrations on stomatal closure (Yang et al., 2017). Extreme drought was defined as the 5th percentile for historical conditions based on the period 1951–2000. Shown are the likelihoods of extreme drought—for example, a 10% likelihood of extreme drought by mid-century represents a doubling of historical likelihood. Contributor: John Abatzoglou*

In an ironic twist of physics, the same warmer air that contributes to drought intensity can also increase the frequency of extreme precipitation. This occurs because warmer air can hold more moisture, resulting in larger precipitation totals. Extreme rainfall events lead to flooding and associated damages. Globally, an increase in the severity of deadly flood events has been linked to changing climatic conditions (Kundzewicz et al., 2013). Model predictions indicate that our region will not be exempted from this trend. Daily maximum precipitation totals show noticeable increases across the region (**Figure 1.8**). Increases of 10–20% across the region are expected by mid-century, and by end-century, max precipitation is projected to increase by 20–40%. Particularly high increases are projected in Humboldt County. These results are supported by an analysis of 34 global climate models (Berg & Hall, 2015) that found statistically significant increases in extreme wet (3 times) and extreme dry years (1.5–2 times) in Northern California by end-century. Higher daily totals have the potential to hydrologically saturate larger areas and cause flooding on larger river basins. These changes are likely to result in more frequent landslides, road washouts, flooding, and increased erosion. Infrastructure designed for a milder climate—everything from roof gutters to culverts to sewage treatment and dams—is at greater risk of failure (see Chapter 3).

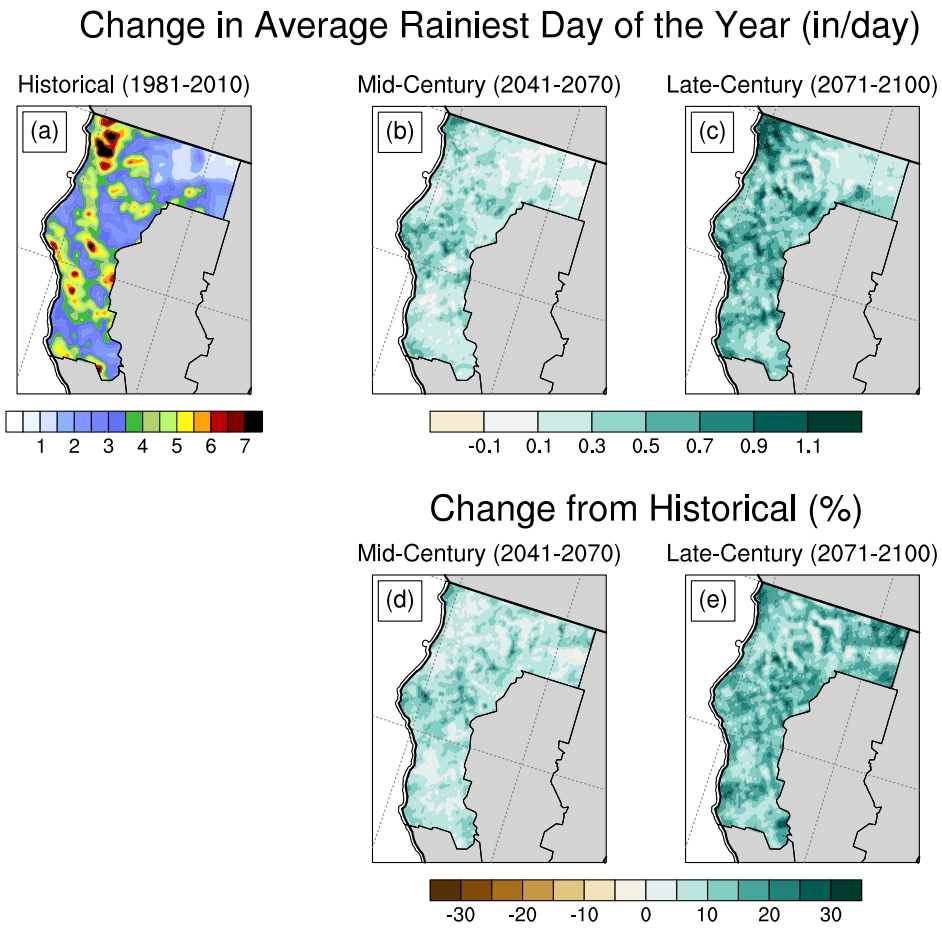


Figure 1.8: *Projected change in the rainiest day of the year. Map of absolute (top) and percent (bottom) change in the rainiest day of the year (in/day) from the (a) historical (1981–2010) to (b-e) future (SSP 3–7.0 scenario) periods. Contributor: Paul Ullrich*

1.4 Observed and Projected Fire

1.4.1 Observed Fire

Fire is both a natural and cultural process—shaping plant and animal communities, recycling nutrients, and maintaining ecosystem health (van Wagtendonk et al., 2018). Historically, fire operated as a stabilizing and regenerative force, guided by the rhythms of lightning, season, and Tribal stewardship (Anderson, 2005; Lake et al., 2017). Today, understanding the role of fire—and restoring Tribal use of fire—is critical for ecological resilience, cultural revitalization, and land management in a changing climate (Long et al., 2017). Native Peoples have been in relationship with these fire-adapted landscapes for millennia, stewarding the land through intentional burns that influenced everything from forest composition to traditional food availability and travel corridors (Anderson, 2005; Lake et al., 2017). With EuroAmerican settlement came widespread land dispossession and forced removal, causing a disruption of Indigenous fire practices (see Chapter 2). By the early 1900s, aggressive fire suppression policies—alongside extensive logging and replanting of dense, even-aged forests—further prohibited Indigenous Peoples' land management practices, resulting in a completely transformed fire ecology landscape (Stephens et al., 2018).

In the last half-century, the North Coast region has experienced increases in wildfire size and frequency. These changes are directly associated with warmer and drier climatic conditions (e.g., Abatzoglou & Williams, 2016; Westerling, 2016), coupled with other human-caused land management changes (Jones et al., 2022; Kreider et al., 2024). The magnitude of increase in fire activity has been variable across the North Coast, with interior and southern portions of the region experiencing large increases in fire activity (70% of Lake County has burned since 2015), while coastal areas have had substantially smaller increases in fire activity (Stephens et al., 2018). Patterns of change in fire severity (amount of vegetation change after a fire) are variable across the North Coast. Coastal areas have not shown a clear increase in high-severity fire and evidence of increases in more interior areas is mixed (Miller et al., 2012; Mallek et al., 2013; Estes et al., 2017; Parks & Abatzoglou, 2020; Downing et al., 2022; Harris & Taylor, 2022). Recent fires have had large patches of high-severity fire (e.g., 2020 Slater Fire, 2020 August Complex Fire).

The impacts of changes in fire activity may also be dependent on the occurrence of climatic events. For example, the 2022 McKinney Fire in the Klamath Mountains burned at high severity and was quickly followed by intensive rains, resulting in substantial erosion and river sedimentation that caused a major fish kill. Prior patterns may not represent current and future trends in high-severity fire for this area. Additionally, portions of the North Coast have witnessed some of the most extensive areas of recent repeated burns or reburns (i.e., a fire that occurs in a previously burned area) in California. Areas that reburn have a high likelihood of reburning at similar or higher fire severities as the initial fire (Grabinski et al., 2017), and the drivers of high severity reburns are shifting (Taylor et al., 2021). Despite increases in fire activity over the past few decades, the majority of our region is still experiencing a substantial fire deficit (less fire than prior to EuroAmerican settlement; Parks et al., 2025). While wildfires or portions of wildfires often have substantial benefits to many ecosystems, there are several patterns of fire changes that pose serious challenges to the North Coast (see Chapter 2).

1.4.2 Projected Fire

Interior and southern portions of the North Coast region represent areas with the greatest potential risks due to the rapid increase in fire activity over the last few decades. Of particular concern are wildfires that resulted in large, high-severity patches in places that historically (pre-colonization) experienced low- to moderate-severity wildfires. Fire weather conditions (i.e., dry, east winds) in the fall are projected to become more extreme, suggesting the potential for increased fire activity for large portions of the North Coast (Goss et al., 2020; Abatzoglou et al., 2021; **Figure 1.9**). As the climate continues to warm, fire size and frequency will also likely increase along the coast, especially if warming contributes to persistent reductions in summertime fog (Johnstone & Dawson, 2010).

Seasonal sharpness (shortened fall–winter precipitation period) is projected to continue, which will enhance fire activity and extend the fire season (Swain, 2021; Swain et al., 2025). Likewise, the projected decline in spring precipitation, particularly in May and June, would also contribute to lengthening the wildfire season and lead to greater stress on trees in late-summer due to the seasonal dry period beginning earlier and ending later. Seasonal patterns in thermal high- and low-pressure systems over the Pacific coast are expected to shift, which will further worsen air quality that is already impacted from fires, and may impact areas typically free of fire-related air quality issues (e.g., coastline areas).

Climatic whiplash (greater variability of climate conditions) will also affect fire activity and severity. For example, wet years can lead to abundant growth of grass and herbaceous vegetation, which can fuel wildfire in subsequent dry years. Similarly, storm events following dry, high fire years can result in landslides and erosion on bare, recently-burned slopes. It also complicates dam management. Dam operators might keep the reservoir below capacity to be able to handle high storm inputs, only to lack sufficient water in a subsequent drought (see Chapter 3).

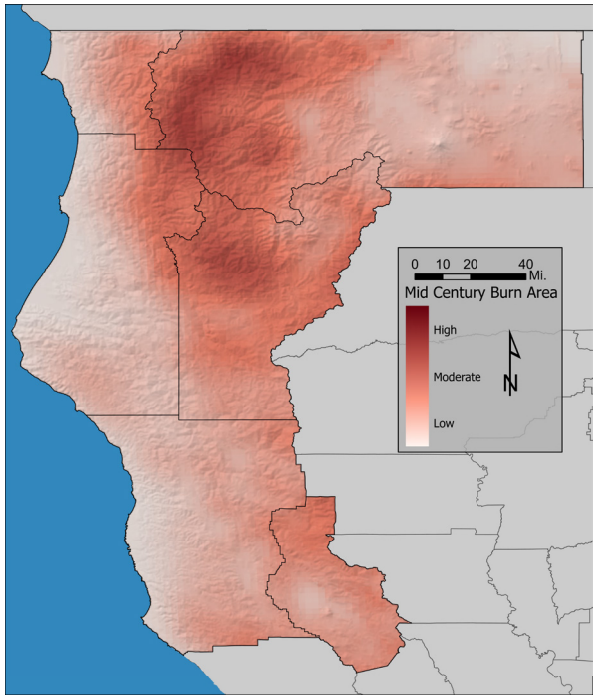


Figure 1.9: *Mid-century (2041–2070) predictions of burn area likelihood for the North Coast region. Sum of randomly modeled fire years (2000 per calendar year) that shows which areas of the North Coast region are likely to experience greater relative burn area (hectares) for the mid-century period (2041–2070) under the SSP 3–7.0 scenario. Darker shades represent larger likely burn area and lighter shades represent smaller likely burn area. Data modeling by the Pyregence team using the Fire Risk Simulation Model with inputs from WRF and LOCA2-Hybrid projections; data interpretation support by LCI Climate Services. Contributor: Chris Gressierer*

1.5 North Coast Sea Level Rise

Global sea level rise (SLR) is a direct consequence of climate change. Human activities have been the dominant cause for SLR since 1970, and they will be in the future (Fox-Kemper et al., 2021). SLR will have wide-ranging impacts on the Northern California coast, driving changes in water level that can lead to outcomes such as flooding, increased erosion, and changes in coastal circulation that will affect communities, ecosystems, and infrastructure. However, the timing (the "when") of these SLR impacts will differ from the rest of the state due to localized vertical land motion (VLM), driven primarily by regional tectonics and proximity to the Cascadia subduction zone or other fault systems (Patton et al., 2023). In addition to tectonics controlling SLR in the North Coast region, SLR will influence tsunami hazards and risks. For more on how SLR influences probabilistic tsunami hazards and risks across the state, see the Fifth Assessment report "Influence of Future Sea-Level Rise on Tsunami Hazards in California."

The 2022 Federal Sea Level Rise Technical Report (Sweet et al., 2022) and the California Sea Level Rise Guidance (OPC, 2024) are considered the best available sea level science for the United States and California, respectively, and reference to these documents can be made for a more detailed discussion. This section focuses on SLR and VLM specific to the North Coast counties of Del Norte,

Humboldt, and Mendocino and incorporates data generated by the local North Coast scientific community. National Oceanographic and Atmospheric Administration (NOAA) tide stations in the North Coast region are plotted in **Figure 1.10**. The Crescent City tide station is located along the Citizen's Dock, just west of the entry to the Boat Basin. The North Spit tide station is located near the US Coast Guard station along the North Spit, just north of the mouth of Humboldt Bay. The Arena Cove tide station is located along the fishing pier at Arena Cove.

The primary causes of global mean sea level (GMSL) rise are thermal expansion from heating the ocean and freshwater inputs from melting glaciers and ice sheets, both of which are driven by increased global temperatures from climate change. GMSL rise has been consistently accelerating since 1970 (Dangendorf et al., 2019; Frederikse et al., 2020). Satellites have accurately measured GMSL change since 1993, and recent analysis through 2023 (31-year span) clearly indicates that GMSL rise is accelerating (Hamlington et al., 2024). The GMSL rise rate has doubled from 0.8 inches/decade (2.1 mm/yr) in 1993 to 1.8 inches/decade (4.5 mm/yr) in 2024.

Regional and relative (local) rates of SLR differ from the GMSL rate due to (1) ocean temperature and circulation (sterodynamic) changes; (2) gravitational, rotational, and deformational changes due to ice sheet loss; and (3) VLM. Studies have shown accelerations in regional sea levels, although these can be obscured by natural climate variability (Wang et al., 2021; Hamlington et al., 2021, 2022). As part of the Sweet et al. (2022) study, a quadratic curve fit to satellite observations was used to develop a regional sea level trend. This trend revealed an apparent acceleration in SLR along California's coast over the 1970–2022 period.

Over short time periods, natural climate variability from the coupled atmosphere-ocean system can affect ocean dynamics (circulation) and regionally alter sea levels to be above or below GMSL rates. In other words, natural climate variability can mask or hide the climate-driven SLR rate, especially for short-period observations (Royston et al., 2018). The effects of the El Niño-Southern Oscillation and Pacific Decadal Oscillation climate variability on sea levels along the California coast have been well documented (e.g., Sweet et al., 2022; OPC, 2024) and can be observed in the North Spit tide station sea level observations (**Figures 1.11, 1.12**). We plotted observations from the North Spit tide station using a variety of trend analyses. The up-and-down pattern in the 5-year average plot follows the long-term average SLR rate and has been linked to the warm and cold modes of the Pacific Decadal Oscillation (Bromirski et al., 2011). Along the North Coast, SLR rates have been suppressed since 2016, and it is unclear when this trend will shift to a period of higher SLR rates.

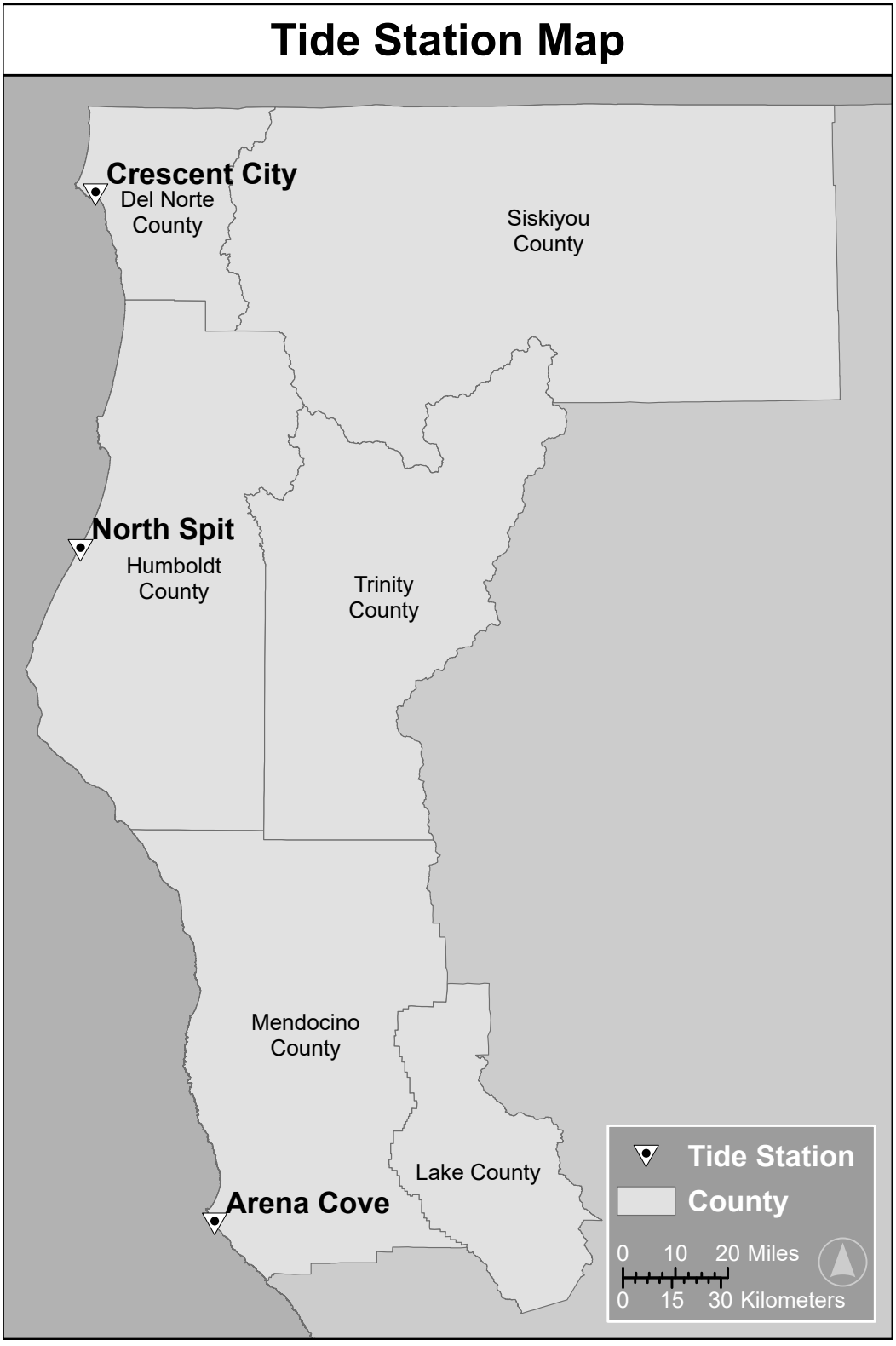


Figure 1.10: *NOAA Tide Station Map. Three NOAA tide stations (Crescent City; North Spit; Arena Cove) are plotted relative to the counties within the Fifth Assessment's North Coast region. Contributor: Jason Patton*

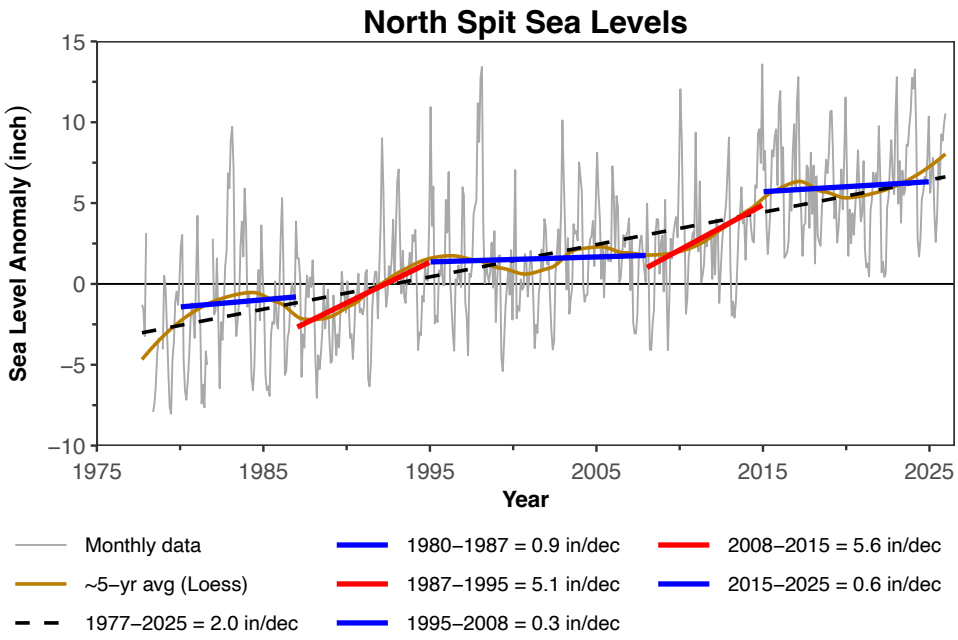


Figure 1.11: *North Spit tide station observations. Monthly sea level observations (gray line), long-term average trend (dashed black line), ~5-yr running average (gold line), and periods of SLR suppression (blue lines) and SLR acceleration (red lines) from 1980–2025. The source data are monthly mean sea levels with the seasonal cycle removed. We estimated the long-term average trend from a linear model, and an approximate 5-year running average from a LOESS curve for the entire record. We then calculated linear rates for short time periods (7–13 years) chosen by visual discrimination. Trends are reported in inches per decade (in/dec). Multiply in/dec by 2.54 to convert to mm/yr. Contributor: Jeffrey K. Anderson*

1.5.1 Observed and Predicted Sea Level Rise Trends and Rates

NOAA tide stations exist in the three North Coast counties: (1) Crescent City in Del Norte, (2) North Spit in Humboldt, and (3) Arena Cove in Mendocino (**Figure 1.10, Table 1.2**). These tide stations provide the longest record of sea level observations in the North Coast region, with Crescent City having the longest observation record of 93 years. To support this work, we update long-term average linear relative sea level (RSL) and vertical land motion (VLM) rates for the Crescent City, North Spit, and Arena Cove tide stations through 2025 (**Table 1.2**), following the approach of Burgette et al. (2013) and Patton et al. (2023). RSL change is the change in mean sea level relative to land and includes the effects of VLM. The three North Coast tide stations measure RSL change. Given the proximity of each tide station to one another, the dominant process driving the differences in RSL rates is VLM, which can cause SLR to vary significantly over relatively short distances. For example, the North Spit station has the highest rate of SLR of any NOAA tide station along the west coast of the United States as the land is sinking, contributing to the rise in sea level. In contrast, the Crescent City station, located 68 miles (109 km) to the north, has a negative RSL rate because the land has tectonically uplifted faster than SLR.

Table 1.2 *Long-term linear relative sea level (RSL) and vertical land motion (VLM) rates for the Crescent City, North Spit, and Arena Cove NOAA tide stations. VLM rates used in the OPC (2024) SLR scenarios are included for comparison and are from Sweet et al. (2022) and supporting information. Positive (+) rates indicate upward direction, and negative (-) rates indicate downward direction.*

Tide Station	Period of Record	This Report RSL Rate inches/decade [mm/yr]	This Report VLM Rate inches/decade [mm/yr]	OPC (2024) VLM Rate inches/decade [mm/yr]
Crescent City	1933–2025	-0.3 [-0.76]	1.1 [2.76]	0.9 [2.42]
North Spit	1977–2025	2.0 [5.12]	-1.2 [-3.13]	-1.0 [-2.50]
Arena Cove	1978–2025	0.5 [1.18]	0.3 [0.82]	0.2 [0.62]

Different methodologies exist for determining VLM rates from tide station observations. Since VLM can significantly affect RSL rates, having an accurate estimate of VLM is important to provide the best estimates of future SLR scenarios at a tide station or location. We provide two VLM rate estimates for the three North Coast tide stations (**Table 1.2**). The OPC (2024) VLM rates are determined at each tide station using a spatio-temporal statistical model (Kopp et al., 2014) that accounts for three components: 1) a global SLR trend, 2) a long-term linear VLM trend, and 3) a regionally varying sea level contribution. The long-term linear RSL and VLM rates determined in this report use a network adjustment approach (Burgette et al., 2013; Patton et al., 2023) between the three North Coast tide stations as follows. First, the linear rates of RSL change for the longest-record Crescent City station and the observation differences between pairs of stations (e.g., between Crescent City and North Spit and between Crescent City and Point Arena) are estimated accounting for time correlated noise (Bos et al., 2013, 2014). Differencing the observations between tide gauge pairs removes much of the sea level change and natural climate variability common to both stations. Next, these linear rates are used in a generalized least squares adjustment to provide refined RSL rates for each station (essentially the adjustment finds the most probable rates between the inputs). Finally, VLM rates were determined at each station by subtracting the refined RSL rate from the regional SLR rate of 1.99 mm/yr (Montillet et al., 2018).

The the localized network adjustment approach provides more accurate and precise VLM rates, and these VLM estimates are used to update the OPC (2024) SLR scenarios at each North Coast tide station. As noted in OPC (2024) changes in ocean dynamics are not expected to be significant for California, with ocean thermal expansion being the primary driver of sterodynamic SLR. Therefore, it is anticipated that California's SLR should track closely with GMSL rise into the future. This is advantageous as the GMSL trend described earlier can be combined with local VLM rates (e.g., **Table 1.2**) to provide an estimate of RSL without the influence of climate variability.

SLR trends for the Crescent City, North Spit, and Arena Cove tide stations are determined using data from the 1970s to 2025 by fitting a quadratic model to observations that account for the seasonal cycle, El Niño-Southern Oscillation, and Pacific Decadal Oscillation variability. Anticipating that each station's underlying SLR rate should track closely with GMSL, we generate another trend by subtracting each station's updated VLM rate (**Table 1.2**) from the GMSL rate (GMSL minus VLM). For each station, acceleration causes the SLR trend to increase over time and exceeds the long-term linear trend (**Figure 1.12**). As expected, the GMSL-VLM trend tracks closely to each quadratic fit trend, with the largest differences for the North Spit and Arena Cove stations, likely due to the shorter observation record. To avoid potential ambiguity between the two trends, we use the GMSL-VLM trend to provide estimates of climate-driven SLR at each station. Included on **Figure 1.12** are modified OPC (2024) SLR scenarios from 2020–2050. Each station's SLR scenario is updated using the revised VLM rate presented here, rather than the OPC (2024) VLM rate (**Table**

1.2). The SLR scenarios overlap reasonably well with the quadratic fit (red line) and GMSL-VLM trend (black line) lines. As noted in the OPC (2024) report, the *intermediate* scenario is the SLR most likely to occur through 2050.

As described above, the current SLR rate (**Figure 1.12**) is different at each tide station due to differences in VLM rates. Since 2000, the North Spit station has had an approximate 6.6 in (17 cm) increase in sea level, compared to 0.8 inches (2.0 cm) and 2.7 inches (6.8 cm) for the Crescent City and Arena Cove stations, respectively. The current RSL rates are approximately 3.0 inches/decade (7.6 mm/yr) for the North Spit station, 0.7 inches/decade (1.7 mm/yr) for the Crescent City station, and 1.4 inches/decade (3.7 mm/yr) for the Arena Cove station. Based on the *intermediate* SLR scenario, the Arena Cove station will reach the North Spit station RSL rate of 0.3 inches/yr (7.6 mm/yr) in the 2050s, and the Crescent City station won't reach this rate until the 2060s. Furthermore, OPC (2024) reported that the average California SLR rate will reach 0.3 inches/yr (7.6 mm/yr) around 2050.

It is clear that areas of Humboldt County, particularly the Humboldt Bay region, are experiencing high SLR rates that are already causing impacts to infrastructure and habitats in and around Humboldt Bay (Richmond et al., 2023; see also Chapter 4). Local, state, and federal agencies, along with Humboldt Bay communities, have conducted numerous SLR assessments and studies that include estimates of future tidal inundation (Anderson, 2015; Sullivan et al., 2022; Richmond et al., 2023). Implementation projects that provide SLR adaptation and resiliency have been challenging to permit and implement. While other counties in the North Coast region and statewide still have decades to plan and implement SLR projects, Humboldt County does not. The Humboldt Bay region has become the "canary in the coal mine" for SLR in California. Immediate action is required if the communities surrounding Humboldt Bay want to minimize the impacts from, or adapt and build resiliency against, SLR.

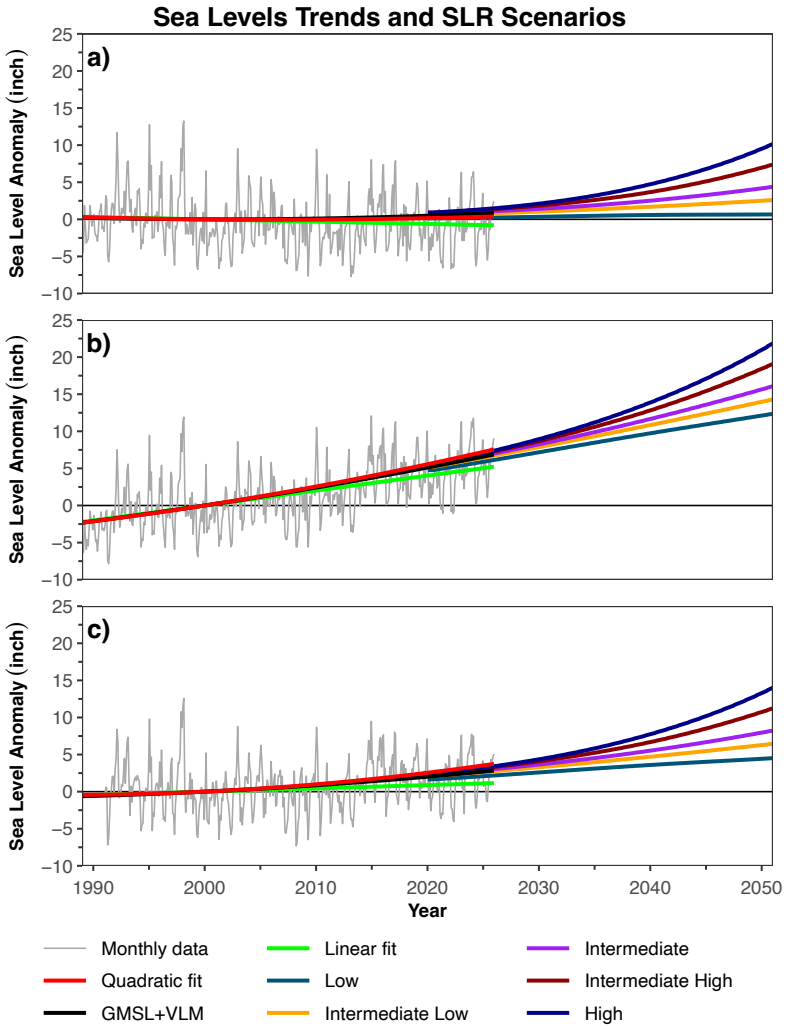
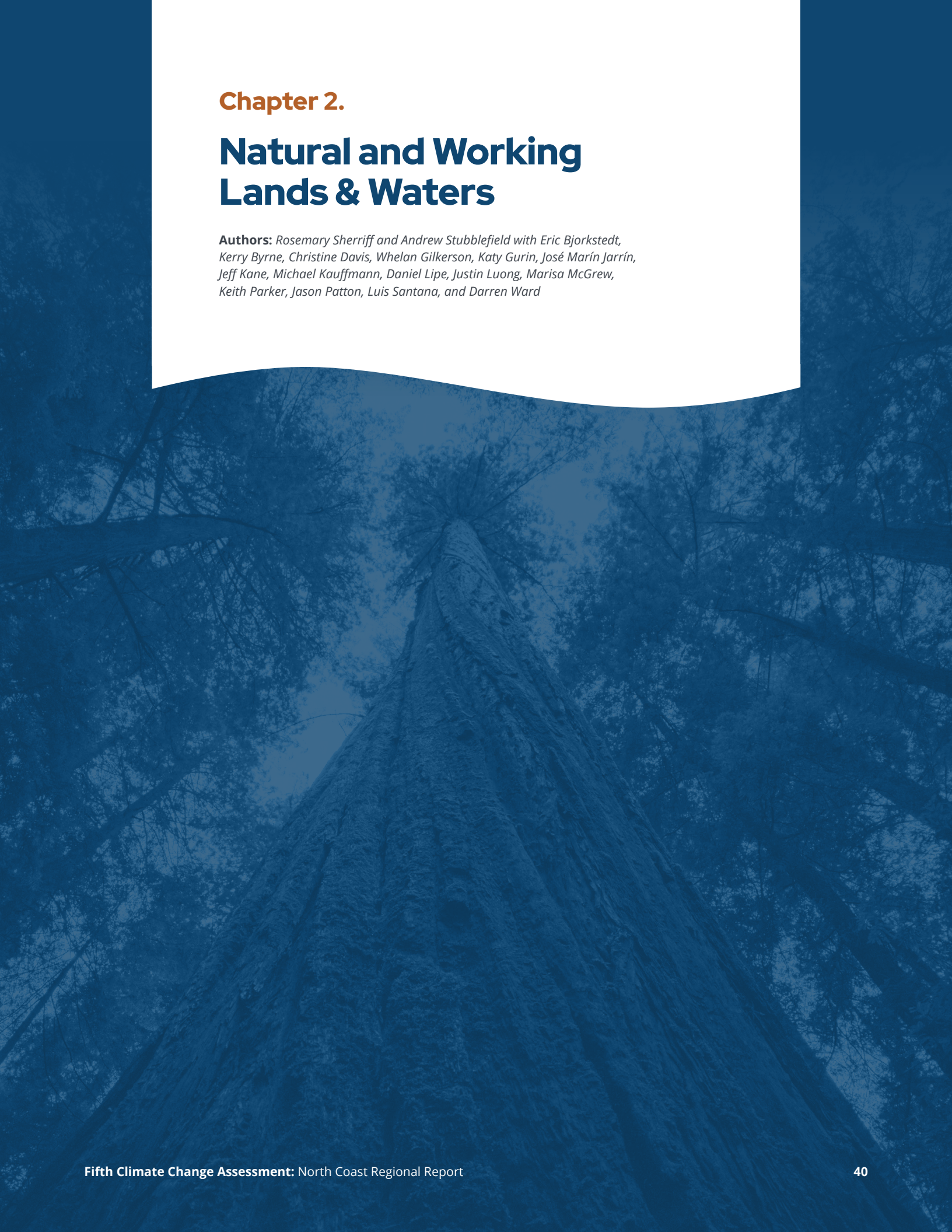


Figure 1.12: *Different SLR trends from 1990–2025; and the low, intermediate-low, intermediate, intermediate-high, and high sea-level rise scenarios from 2020–2050 for (a) Crescent City, (b) North Spit, and (c) Arena Cove tide stations relative to year 2000. Trends include linear rate, quadratic fit, GMSL-VLM, and modified OPC (2024) SLR scenarios. Scenarios have been adjusted with the revised VLM rates. Contributor: Jeffrey K. Anderson*

Chapter 2.

Natural and Working Lands & Waters

Authors: *Rosemary Sherriff and Andrew Stubblefield with Eric Bjorkstedt, Kerry Byrne, Christine Davis, Whelan Gilkerson, Katy Gurin, José Marín Jarrín, Jeff Kane, Michael Kauffmann, Daniel Lipe, Justin Luong, Marisa McGrew, Keith Parker, Jason Patton, Luis Santana, and Darren Ward*



Key Message

As climate change intensifies and ecosystems unravel, there is an increased need for collaborative approaches that are grounded in both Indigenous knowledge systems and western science. This work requires an increase in the number of Indigenous leaders and western scientists who have the ability to work with and across worldviews. This chapter highlights the natural and working lands and waters of the North Coast region with a focus on Indigenous Peoples' practices of land stewardship, terrestrial systems, freshwater systems, and ocean and coastal systems in the context of existing management, climate changes, and ecological resilience. Climate change concerns for the region include wildfire and drought impacts, forest and woodland conversions and biodiversity, reductions in grasslands, rangeland forage production and habitat, freshwater ecosystems, coastal changes (biodiversity loss, flooding control, erosion), ocean conditions, fisheries and habitat compression, loss of kelp forests, and SLR (highest rates in the state). We emphasize the importance of restoration and shared stewardship of ecologically and culturally important species and habitats, Indigenous Tribal knowledge systems, Indigenous management practices and shared stewardship with Tribes, landscape connectivity, climate/fire refugia zones, fuel and fire treatments, invasive species control, and nature-based solutions.

2.1 Enduring Wisdom for a Changing World

For thousands of years, Indigenous Peoples have practiced land stewardship from a worldview of interconnectivity. The cultural, ceremonial, and subsistence uses of land are all interwoven. Traditional Ecological Knowledge (TEK) is built on observation, ceremony, and adaptive practices that sustain biodiversity (Kimmerer, 2013; Lake et al., 2017). TEK offers time-tested, place-based approaches to conservation and balance that prioritize co-stewardship—not token inclusion, but structural partnerships embedding Indigenous leadership into land stewardship frameworks. For Indigenous Peoples, policy decisions are directly related to environmental justice because the loss of species and ecosystems represents not only a loss of biodiversity, but a loss of cultural heritage. The biodiversity and ecosystem structures of the North Coast are not merely natural—they are cultural legacies. Indigenous stewardship, through TEK and cultural fire, has actively shaped the region's resilience and richness (Lake et al., 2017). To maintain resilience of environmental systems and processes as climate change intensifies and ecosystems unravel, we need to recognize Indigenous Peoples who have co-evolved with and been an intricate part in creating and maintaining complex knowledge systems since time immemorial (Marks-Block et al., 2021; Kimmerer, 2013).

2.1.1 Cultural Fire as a Tool of Stewardship

Central to Indigenous land care is the use of fire (e.g., FireGeneration Collaborative). Cultural burning is applied by Tribes seasonally with specific goals, including but not limited to: increasing biodiversity, maintaining productive landscapes, and supporting human and non-human communities (Lake et al., 2017; also see **Appendix Case Study 2.1.C**). Over time, these fire regimes have shaped habitats at scale. Tribes manage forests and woodlands as living orchards, cultivating species like tanoak, black oak, chinquapin, hazel, and madrone. Meadows, prairies, and oak savannas were kept open with regular fire, promoting forage for wildlife and access for people

(Anderson, 2005). Fire-adapted plants like hazel, huckleberry, manzanita, and ceanothus were selectively burned or pruned to encourage vigorous regrowth for use in basketry, tools, and food (Marks-Block et al., 2021). Since European contact, Indigenous access and management of much of this region has been greatly reduced to Tribal-owned property.

2.1.2 Animals as Kin, Guides, and Resources

Animals have always held a spiritual and ecological importance in Indigenous lifeways. In the Northern California region, birds such as condors and other birds of prey, woodpeckers, waterfowl, and certain neotropical birds featured in regalia and ceremony serve as phenological markers and express what was once ecosystem abundance. Mammals like deer and elk provide food, hides, and cultural materials. Amphibians such as the Giant Pacific Salamander indicate the health of water sources. Ocean harvesting was also a component of a well-developed system of inter-Tribal commerce between the Yuroks, Karuk, Hoopa, Tolowas, Wiyots, Mattoles, Shastas, and Wintuns. The Yurok and Tolowa people harvested dried seaweed, smelt, and dentalia (small tubular mollusk shells used for money) from the ocean. They traded with the Hoopas in exchange for inland foods such as dried deer meat, pine nuts, and acorns. The Hoopas also traded with the Mattoles and Wiyots. The Hoopas supplied the two Tribes with inland foods and the Mattoles and Wiyots supplied them with seashells, abalone, dentalia, and ocean otters. The Hoopas traded some of the items they acquired from the ocean harvesting Tribes with inland Tribes such as the Shastas (Norton, 1979). Ocean harvested items were also used for other purposes such as medicinal use. The Yuroks collected kelp from the ocean as an ingredient in a poultice used for rattlesnake bite victims. The root of the kelp onion was pounded into a poultice, placed over the snake bite wound, and kept wet with pure ocean saltwater (Thompson, 1916). These relationships emphasize not just use, but reciprocity and reverence (Kimmerer, 2013; Pierotti & Wildcat, 2000). Indigenous stewardship has actively shaped the region's resilience and richness. The biological and cultural richness of the North Coast's terrestrial, freshwater, oceans and coastal systems remains undervalued and underserved. Below we highlight these systems and the climate change impacts.

2.2 Terrestrial Systems

Authors: *Rosemary Sherriff, Daniel Lipe, Michael Kauffmann, Jeff Kane, Marisa McGrew with Kerry Byrne and Justin Luong*

KEY TAKEAWAYS: TERRESTRIAL SYSTEMS

- Indigenous stewardship, particularly through their use of TEK and cultural fire, has actively shaped the region's resilience and richness.
- Natural and working lands and waters of the North Coast are ecological insurance for resilience and cultural heritage that includes unparalleled biodiversity and endemic species, productive and diverse ecosystems (forests, woodlands, grasslands and rangelands, wetlands and mesic zones), extensive wildlife habitat, and carbon sequestration.
- The North Coast is a model for adaptive management efforts: e.g., Klamath dam removal, sustainable livestock production, collaborative management, Tribal cultural burning, and Indigenous stewardship.

- Given the ecological, cultural, and economic (e.g., timber) importance of this region, there is a strong need to understand and anticipate impacts of climate change to inform adaptive management strategies.
- Major concerns of climate change include wildfire and drought effects, timber loss, tree mortality, reductions in wildlife habitat and native species, increases in non-native invasive species and pathogens, and loss of cultural resources and ecosystem services.

2.2.1 North Coast Biogeography

California's North Coast is not merely a place of ecological interest—it is a national treasure and biodiversity hotspot. At the confluence of four major ecoregions, this region holds an extraordinary diversity of life, ecosystems, and cultural legacies (DellaSala & Gianoli, 2012). Its steep mountains, fog-fed forests, serpentine outcrops, and verdant valleys form a rare mosaic of microclimates and habitats, many found nowhere else on Earth (Kauffmann & Garwood, 2022). Yet this biological and cultural richness remains undervalued in environmental policy and conservation investment. At the northern heart of this region lies the Klamath Mountains, one of the most geologically and botanically intricate mountain systems in North America (DellaSalla et al., 1999) that has served as a refugium during past glacial cycles, harboring relict lineages and facilitating the persistence of endemic species (Olson et al., 2012; **Appendix Case Study 2.1.A**). To the northeast, the Cascades with their volcanic soils hold diversity that supports rare plant assemblages. There, cooler temperatures, snow-fed streams, and alpine ridgelines provide refuge for boreal species at the southern edge of their ranges. The region's volcanic past not only shapes its soils but also contributes to its rugged topography and unique hydrology (**Figure 1.1**). From the east, the dry interior of the Great Basin has open shrublands, intense sunlight, and wide temperature swings. These harsh conditions create niches for drought-adapted, sun-loving species—plants with deep roots and thick cuticles, reptiles that thrive in heat, and pollinators evolved for sparse floral resources. Isolation in this arid landscape often drives evolutionary specialization, generating endemic species adapted to life on the ecological edge. The woodlands of the interior California Coast Ranges, spanning parts of Lake, Mendocino, and Humboldt counties, form a distinctive transition between the redwood belt to the west and the hotter, drier Sacramento Valley to the east. Dominated by oaks, these woodlands create a patchwork of savannas, mixed forests, and dense shrublands that reflect the interplay of soils, fire history, and seasonal water availability, creating a rich mosaic that supports both ecological diversity and cultural traditions tied to the land.

2.2.2 Forests and Woodlands

The biogeography of the North Coast includes the most productive forests in the state and beyond (e.g., Sillett et al., 2020), providing substantial economic and cultural value, wildlife habitat, carbon sequestration, and recreation. In the northern portions of the region, the Klamath Mountains and North Coast Ranges host one of the highest diversities of conifers on Earth—over 30 species, including several that grow nowhere else on Earth, and up to 18 species in one square mile (Kauffmann, 2012; Kauffmann & Garwood, 2022). Given the ecological, cultural, and economic (e.g., timber) importance of this forested region, there is a strong need to anticipate impacts of climate change to inform adaptive management strategies. Continued warming (**Figures 1.2–1.4**) and drought (**Figure 1.7**) will likely result in the loss of important forest and woodland species

in the region (**Appendix Case Study 2.1.A**). Potential impacts may include increased forest loss due to increased fire activity (**Figure 1.9**; Zald & Dunn, 2018; Levine et al., 2022), accelerated tree mortality (Preisler et al., 2017; Desiervo et al., 2018; Jules et al., 2022), reduced productivity of trees and seedling regeneration (Robinson et al., 2023; Lemmo et al., 2024), and conversion of forests to shrublands (Coppoletta et al., 2016; Grabinski et al., 2017; Taylor et al., 2021). Biogeographically, coastal forests and woodlands are often more buffered from extreme drought, temperature increases, and wildfire events (Chapter 1) compared to interior portions of the region (**Figure 2.1**). **Appendix 2.1.A** lists potential impacts of climate change for vegetation ecosystems of the North Coast.

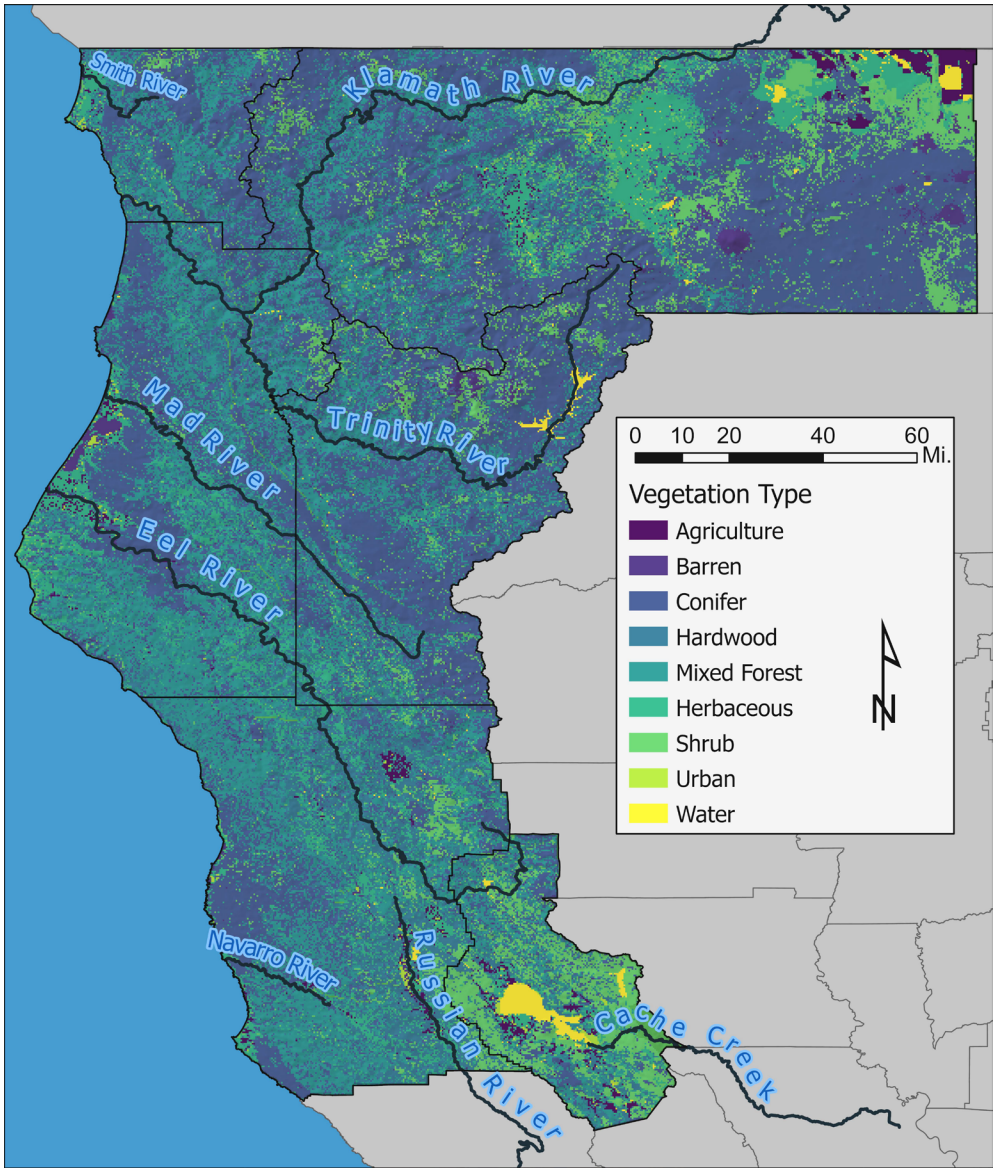


Figure 2.1: *Vegetation cover across the North Coast Region. CalVeg data layers. Contributor Chris Gressierer.*

COASTAL FORESTS

Along the coast, the relict redwood trees, with extraordinary sizes and heights, contain more aboveground carbon than any other forest type on Earth (Van Pelt et al., 2016; Sillett et al., 2020). These ancient trees have in fact been showing a significant growth increase over the last century, presumably due to warmer temperatures and longer growing seasons (Carroll et al., 2014). These forests also have other magnificent co-dominant tree species including Douglas fir, Sitka spruce, and western hemlock, among others. However, these old-growth redwood forests represent only 3% of their historical range. The dominant coastal redwood forests (previously logged) often have dense, even-aged stands composed of redwood and Douglas fir trees that impede the development of old-growth characteristics without active restoration treatments. Despite this, younger redwood forests (~150 years old or less), particularly those stands with restoration thinning, store substantial amounts of carbon and can accumulate biomass faster than old-growth redwood stands as they mature (Iberle et al., 2020; van Mantgem et al., 2016).

Coastal fog provides a substantial amount of a redwood's annual water intake. Thus, the strength of the continued buffering along the coast is in part reliant on the persistence of fog (Johnstone & Dawson, 2010) in addition to high precipitation (Chapter 1). Reductions in fog over time could result in changes in productivity and carbon sequestration with expected differences from the northern to southern margins of the range. However, the strength, duration, and geographic patterns of this potential effect need further study and more validation.

Coastal areas have experienced less fire activity in recent decades compared to more interior areas (see *Section1.4.1 Observed Fire*). While redwoods are highly resilient to wildfire (Berrill et al., 2020; Peltier et al., 2023), evidence from recent wildfires indicates higher potential for crown fires, substantial loss of forest canopy, and elevated mortality in Douglas fir (Woodward et al., 2020; Biblin et al., 2025; Kane & Carrasco, 2025), with potential impacts to important wildlife habitat and timber species. Furthermore, there is a critical gap in knowledge for coastal redwood and mixed-evergreen forests (see *Interior Forests* below) related to uncertain potential for shifts in habitat, biodiversity, timber, and carbon storage with climate changes.

At mid-elevations, coastal mixed-evergreen forests are structurally diverse forests that serve as transitional habitats, supporting northern spotted owls, Pacific fishers, amphibians, and pollinator communities (Sawyer & Thornburgh, 1977). Historically, frequent, mixed-severity fires—caused naturally by lightning and intentionally put on the ground through Tribal cultural burning—maintained diverse successional stages. A few notable tree species include Douglas fir, Port Orford cedar, tanoak, chinquapin, madrone, grand fir, and red alder (along riverbanks and streams), with a wealth of varied shrub and understory species that are culturally and ecologically important. Fire-suppressed and logged forests now show increased density, fuel loads, and wildfire risk (see *Section 1.4.1 Observed Fire* and *Interior Forests below*).

INTERIOR FORESTS

Inland of the coast, forests have a mix of ecologically and culturally important conifer, oak, and other hardwood species that are common in similar elevations with important distinctions among major watersheds (**Figures 1.1** and **2.1**). Some common and dominant lowland trees include Douglas fir, ponderosa pine, California bay, tanoak, incense cedar, and sugar pine, intermixed

with many other oak and hardwood species. In the eastern and southern areas, knobcone pine becomes more prevalent intermixed with chaparral ecosystems. Historically, frequent, mixed-severity fires—caused by lightning and cultural burning—maintained diverse successional stages. Even more so than coastal forests, these forests have higher density, fuels, and wildfire risk. Restoring fire, especially Indigenous cultural burning, is critical for restoring ecological resilience as described further in sections above and below.

The Klamath Mountains and southern Cascade Range have the highest elevations (**Figure 1.1**) and are shaped by longer winters, shorter growing seasons, and less frequent but influential fire (Sherriff et al., 2022). The species composition is distinct and globally significant. The conifer diversity of these highlands is unmatched—more than 30 native species co-exist in the region, many of them range-restricted. Shasta red fir dominates subalpine zones; Western white pine occupies ridgetops; and Jeffrey pine thrives on ultramafic soils. Iconic sugar pine, with its long cones and fire-adapted traits, also appears across this belt. These forests provide refuge for snow-adapted fauna, specialized pollinators, and rare lichens and bryophytes. They also serve as long-term climate refugia, buffering temperature extremes and retaining snowmelt into summer. Fire regimes at these elevations tend to be low- to mixed-severity. However, the ecological roles of fire remain critical.

OAK WOODLANDS

Blanketing interior valleys and foothills, oak woodlands form a vital ecotone between conifer forests, chaparral, and grasslands, and are renowned for their ecological and cultural importance. Oak woodlands are biodiversity hotspots. These semi-open landscapes are structured around oak species that vary by elevation, soil type, and moisture. Their layered structure—mature trees above, shrubs and grasses below—supports nesting birds, browsing deer, foraging insects, and sheltering amphibians (Kauffmann & Garwood, 2022). Seasonal variability in acorn production, insect blooms, and flowering herbs draw both migratory and resident species. These woodlands were widely sustained by frequent, low-intensity fires through Indigenous cultural burning and periodic lightning (Anderson, 2005; Lake et al., 2017). With the onset of fire suppression, oak stands have been invaded by conifers, reducing light availability and degrading habitat quality (e.g., Cocking et al., 2012). Restoring fire to these landscapes is essential—not only for ecological balance, but for the continuation of traditional lifeways centered around oaks. Oaks are cultural keystones as much as ecological anchors, sustaining entire food webs and community traditions (Anderson, 2005; Kimmerer, 2013).

WILDLIFE IN FORESTS AND WOODLANDS

Terrestrial habitats of the North Coast region host abundant mammals, birds, reptiles, amphibians, mollusks, and insects. Many of the species are endemic to the region, some of which are rare, threatened, or endangered at the state or federal level (e.g., Trinity Bristle Snail, Franklin's Bumblebee, Scott Bar Salamander, Humboldt Marten). At the same time, there are many other species of concern in our diverse ecosystems that have broad geographic ranges (e.g., Western Bumblebee, Willow Flycatcher, Fisher). Wildlife responses to the changing climate are varied, with greater shifts in species distributions occurring at higher elevations (e.g., Rowe et al., 2015; Halsch et al., 2021). Indirect impacts will largely be from climate change-exacerbated disturbances such

as human land uses, non-native species, drought and heat waves, insect pests, pathogens, wildlife diseases, and fire, which impact habitat, corridor connectivity, food resources, and breeding success. Impacts of the large 2018 Mendocino Complex Fire on mammals in the oak woodlands of Mendocino County found high resistance, recovering to levels comparable to adjacent unburned sites within three years of the fire and increased species richness in areas with limited reduction to canopy cover (Calhoun et al., 2023). However, areas impacted by high-severity fire had negative impacts on many bat and bird species. A high proportion of nesting habitat (60%) for the federally threatened northern spotted owl in redwood forests is at very high risk of experiencing high-severity wildfires (Hysen et al., 2023). Within the Klamath Mountains, wildfire was found to cause negative impacts on northern spotted owls in high-severity patches (Rockweit et al., 2017). If high severity increases as expected, populations of northern spotted owls may decline.

MANAGEMENT FOR RESILIENCE: FORESTS AND WOODLANDS

Generalizations that tree susceptibility and decline increase with distance from the coast is oversimplified. Severe drought leads to rapid reductions in tree growth in some coastal species (e.g., Sitka spruce, western hemlock), particularly in denser forests and those located at the southern extent of their distributions in Mendocino County (Robinson et al., 2023). Some inland montane tree species show greater resistance during severe drought, although large trees and denser stands show greater vulnerability. Another important exception is in long-fire-excluded oak woodlands (e.g., Oregon white oak, California black oak) that have been encroached by conifers. Encroachment has resulted in the substantial loss of oaks and other hardwoods (Schriver et al., 2018; Knight et al., 2020), which can be exacerbated by drought (Beckmann et al., 2021).

In inland areas, increased fire activity has the potential to expand certain species and/or lead to shrub conversion. Areas that burn repeatedly at short intervals and at high severity can be predisposed to type conversion from forests to shrublands (Odion et al., 2010; Coppoletta et al., 2016), local loss or contraction of native and culturally important species, and facilitate non-native plant invasion (Reilly et al., 2020). Inland (e.g., Siskiyou and Trinity counties) and southern areas (e.g., Lake County) are at particular risk of repeated burning (**Figure 1.9**) and conversion of forests and woodlands to shrublands. Current evidence in the Klamath Mountains suggests that fires that burn at high severity commonly reburn at high severity (Grabinski et al. 2017; Taylor et al., 2021). Increased fire activity in higher elevation forests also poses threats to regionally rare and culturally important species, given their limited extent in the region (see **Appendix Case Study 2.1.A**).

RESTORATION TREATMENTS

Mitigating impacts of climate change involves restoration that improves habitat for ecological and culturally important species, habitat connectivity, and climate/fire refugia to facilitate the movement of wildlife species. Managing endemic species that have small ranges requires land management to be implemented on small scales. Thus, the specifications of effective vegetation management treatments need to vary. Additionally, all treatments require periodic follow-up treatments to maintain effectiveness (van Mantgem et al., 2016; Fineran, 2024). Treatments that include a combination of thinning and burning have consistently demonstrated the most fire resilience and ecological benefits (Kalies & Yocum Kent, 2016; Davis et al., 2024). The effectiveness of thinning-only treatments is varied (e.g., Raymond & Peterson, 2005; Glebocki, 2015; Vernon et

al., 2018; Bernal et al., 2023; Davis et al., 2024). Prescribed fire-only treatments are highly effective at reducing impacts from wildfire but often have limited ability to sufficiently reduce the stand density necessary to promote wildlife habitat, reduce drought and insect impacts, support cultural restoration, and foster understory diversity (Knapp et al., 2017; Bernal et al., 2023). In ecosystems adapted to a high-severity fire regime, active management may not be suitable outside of built environments as they can have limited benefits and contribute to undesired ecological outcomes.

The pace and scale of implementing ecosystem management treatments focused on ecological or cultural restoration and fuel reduction has increased. Some regional highlights include expansive redwood restoration thinning across national and state parks in collaboration with non-governmental organizations and communities. However, there is an opportunity to extend the benefits of these restoration treatments by reducing slash through prescribed fire, pile burning, or other methods as the risks of fire continue to increase. In the western Klamath area, communities and agencies are collaborating on large-scale restoration and fuels reduction projects to promote resilience of human communities and ecosystems (**Appendix Case Study 2.1.B**). Other communities in the North Coast are also engaged in similar partnerships to implement fuel treatment strategies to reduce impacts from fire and other climate change impacts. Reducing forest and woodland density in many ecosystems has the advantage of reducing water stress and increasing growth that can promote greater resilience to compound and cascading impacts of drought, heat waves, fire, and biotic disturbances across a wide range of ecosystems in the North Coast (e.g., Vernon et al., 2018; Dagley et al., 2018; Soland et al., 2021; Lalemand et al., 2024; Goff et al., 2025). While these advances are encouraging a substantial proportion of forests and woodlands will require active forest management as climate change contributes to continued increases in and compound effects of drought, insect outbreaks, and wildfires in the North Coast region.

While there is evidence supporting active management to reduce negative impacts of climate change and past management decisions, direct evidence within the North Coast region is limited. The effectiveness of management treatments will require that enough area is treated to reduce impacts related to climate change. Current evidence indicates that treating 20–40% of a given landscape within 10 years may sufficiently reduce wildfire severity (McKinney et al., 2022; Ott et al., 2023). However, research specific to the North Coast has not been conducted to estimate the desired pace and scale of implementing management treatments. The existing pace and scale of forest and woodland treatments within the North Coast (~1–2%/year) is currently insufficient to promote landscape-level effectiveness. There is also a need for restoration of ecotonal areas, such as woodland-grassland transition areas, that support high biodiversity (see *Section 2.2.3 Grasslands* below).

2.2.3 Grasslands

Northern California grasslands are some of the most complex and diverse in the world. Indigenous Peoples created, maintained, and enhanced a mosaic of local grassland and meadow environments for a multitude of reasons including maintenance of open habitats that support elk, deer, and other species; reducing wildfire risk; and cultivation of food, medicines, materials, and other culturally important species (Kauffmann & Garwood, 2022). Maintenance of grassland and meadow environments was accomplished seasonally through a variety of approaches,

times, and levels of intensity. It is important to understand that not all species and/or habitats were maintained in the same way or for the same reasons. In Kat Anderson's book, "Tending the Wild" (2005), she describes Indigenous cultivation of such areas as a process being carried out through a complex set of understandings and knowledges of life forms, species, plant properties, environmental site criteria, cultural uses, and strategies of cultivation. Utilizing multiple approaches that were specific for each place and time created a mosaic of grassland type habitats, each supporting a diversity of species. Cultural burning is one of the main approaches Indigenous Peoples used to maintain open areas.

Through European expansion and colonization came the forced removal and suppression of Indigenous Peoples and, therefore, their practices and ancestral homelands. Over the past 300 years, grazing by non-native species has replaced much of the native grazers including elk and black-tailed deer. These once abundant species are not only important food sources for Indigenous and other local community members, but they also hold great cultural and ecological importance. In addition, the introduction of non-native grazers and land practices has led to a shift from native perennial species to non-native annual grasses and forbs. While the role of grazing remains controversial around native grassland restoration, many of the remaining grasslands are now dependent on grazing as the main management strategy.

2.2.4 Rangelands and Grazing

Authors: *Justin Luong and Kerry Byrne*

Rangelands occupy approximately a fifth of the land area in the North Coast region (**Appendix Table 2.1.A**). North Coast rangelands are a patchwork of habitats (**Appendix Table 2.1.B**) that provide climate-resilient carbon storage, flood attenuation, cultural resources, recreation and livestock (Eviner, 2016), and wildlife habitat with high levels of plant and bird diversity (Johnsen et al., 2020). North Coast rangelands are important contributors to California's agricultural economy and are one of few regions that can support sustainable beef production (**Appendix Case Study 2.1.E**). Rangelands in the region are susceptible to woody invasion without ongoing land management. The recent passage of Senate Bill 310 (SB 310, 2024) will further allow access and legal coverage to support more managed fire on the landscape, including cultural burning by Tribes (Haggerty, 2025). Fire helps limit woody encroachment, increases native plant germination, and reduces litter (Ratajczak et al., 2012; Saler & Jules, 2021). Site-specific management strategies that take into consideration collaborative approaches, multiple purposes, and varied conditions of grasslands provide opportunities for diverse perspectives in restoration.

Enhanced climate changes (Chapter 1) such as climatic water deficit (CWD) will reduce plant and forage production in most of the North Coast region (Liu et al., 2023), increasing grazing pressure and potential for overgrazing, impacting both livestock and native ungulate species (Woodmansee et al., 2021). Drought and CWD can decrease forage palatability via increased plant investment in drought adaptations (Shi et al., 2019). Higher CWD can indirectly reduce shade cover (Allen et al., 2021) and increase soil drying, resulting in shorter growing seasons and higher fire risk (Swain, 2021). On the other hand, extreme precipitation events and extended flooding (**Figure 1.8**) will also increase soil erosion, nutrient loss, and leaching (Mastrocicco et al., 2019); stunt plant productivity (Liu et al., 2023); reduce suitable stocking times due to longer soil saturation periods; and contribute to higher soil compaction (Milazzo et al., 2023). Flooding (see *Section 2.3 Rivers and*

Lakes below) can also create vectors that contribute to the spread of novel pathogens and invasive seeds that can result in species turnover, novel species invasion, and reduced ecosystem function (Diez et al., 2012). These climate changes (i.e., drought, flooding, and increased temperatures) can all result in compositional plant shifts (Keddy & Laughlin, 2022; Sandel & Dangremond, 2012) that limit more sensitive species, like wildflowers (Prugh et al., 2018; Zhu et al., 2024), and increase the abundance of invasive grasses (Sandel & Dangremond, 2012). These shifts typically result in biotic homogenization, or reduction and dominance of a limited number of species, which can have cascading effects to pollinator networks and culturally important plant species and can result in an overall truncation of ecosystem services (Holl et al., 2022). Compositional shifts that reduce forage for wildlife and livestock can increase human-wildlife conflict. **Appendix Case Study 2.1.F** highlights climate responses by grassland and rangeland type.

MANAGEMENT FOR RESILIENCE: GRAZING AND LIVESTOCK PRODUCTION

Increased precipitation extremes causing droughts and floods (**Figures 1.5–1.9**) will reduce forage, likely forcing producers to purchase supplemental feed and/or reduce stocking rates, decreasing ranching profitability (Woodmansee et al., 2021). Climatic changes will also cause biotic homogenization of plant communities, reducing the diversity and mineral composition of available forage, impacting animal health that is naturally supported by high plant diversity (Prigge et al., 2024; Zanon et al., 2022). Producers may have to compensate for these rangeland losses by providing more mineral and protein supplements. Increased water scarcity will require additional investment into water infrastructure (Chapter 3) to support livestock production and local wildlife populations (Rosenstock et al., 1999); however, increased water use (Woodmansee et al., 2021) and diversion could result in declines for wildlife elsewhere from where water is imported (Huntsinger et al., 2017). Increased CWD may also decrease shade cover, which, when compounded by more arid conditions, may require strategic range developments or tree plantings that can provide animal rest areas (Veissier et al., 2018). To limit loss of important biodiversity, drought-sensitive species could receive supplemental management (e.g., monitoring or watering). Culturally important plants may benefit from grazing exclosures in areas with reduced forage production to help prevent overgrazing.

FIRE AND RESTORATION IN RANGELANDS

Many North Coast rangelands host perennial species that retain live green tissue most of the year (Barbour et al., 2007), a natural deterrent to fire due to the high moisture content that live tissue contains compared to dead tissue (Bond & van Wilgen, 1996). However, increasing invasion of annual grasses (Diez et al., 2012; Luong et al., 2023) leads to heightened fire risk. Preemptive management through prescribed fire, prescribed grazing, or Indigenous cultural burns can help lower fire risk by removing fuel, making wildfire behavior more manageable (Siegel et al., 2022; Ratcliff et al., 2022). In Sonoma County, grazing also helped create a safe zone in the landscape that did not burn where livestock and wildlife were able to retreat and survive wildfires (M. Halbur, personal communication, November 5, 2024). A review also found that prescribed fire was effective in reducing California wildfire risk (Jose et al., 2023), which may provide important opportunities for partnerships with Tribal governments. Regulatory and risk-averse barriers still limit implementation of prescribed fire, which could be addressed with additional outreach to the public and local communities (Miller et al., 2020). Tribal cultural burning and prescribed fire

can support biodiversity, protect cultural species (Hopkinson et al., 2020; Young et al., 2015), and increase floral densities that are important for native pollinators (Mola & Williams, 2018). The Karuk Tribe is employing "Pirish fire," or good fire, to steward grasslands, manage invasive species, and promote native wildflowers.

Grassland restoration has been successful in the North Coast, but allocating more resources would improve biodiversity and support the maintenance needed for desirable outcomes (Luong et al., 2023). This is especially prudent as California rangelands are experiencing passive biodiversity loss over time (Lesage et al., 2022) and are prone to reinvasion after restoration without maintenance (Tang et al., 2023). Projects such as those completed by the Mattole Restoration Council and Bureau of Land Management in the King Range National Conservation Area help illustrate these successes. In such cases, controlling native woody encroachment was a key management goal to limit habitat loss to Douglas fir. Douglas fir control rangeland plant community recovery, oak growth, and regeneration and recovery of avian diversity (Goff et al., 2025; Stephens et al., 2020). Alpine meadow restoration can improve baseflow and groundwater recharge (Hunt et al., 2018). Sagebrush and shrub-dominated rangelands often recover poorly from post-fire restoration efforts, especially with competition from invasive annual grasses (Brabec et al., 2015).

2.2.5 Wetlands and Mesic Zones as Climate Refugia

Amid the shifting seasonal rhythms of drought and fire, wetlands and mesic zones (providing relatively consistent moisture levels)—found in springs, seeps, shaded canyons, north-facing forest slopes, and beaver-modified valleys—function as natural climate refugia (also see *Section 2.3 Rivers and Lakes*). They buffer temperature extremes, moderate fire behavior in adjacent uplands, and sustain continuous water availability through dry summers (Olson et al., 2012; Morelli et al., 2016). In an era of increasing climate volatility (e.g., **Figure 1.6**), these areas provide essential ecological insurance. Wetland and mesic zones buffer climate shifts, with inherent complex physiography, that enhance their capacity to protect diversity, connectivity, and ecosystem services.

Cold water habitats within these zones are especially vital for amphibians, which are highly sensitive to desiccation and thermal stress. Example streams that provide critical cold-water habitat include the Big Springs complex in the Shasta River and Cedar and Elder Creek tributaries to the South Fork Eel River. Púfpuuf, the Pacific giant salamander (*Dicamptodon tenebrosus*), is a highly regarded riparian and freshwater cultural indicator species for the Karuk Tribe and thrives in the cold, oxygen-rich waters of forest streams (Welsh & Hodgson, 2013). "Púfpuuf is a spiritual being who transformed into a salamander to monitor spring and creek water quality and quantity. Their presence is indicative of a healthy riparian and aquatic freshwater system" (Page VII–108 Karuk Tribe, OEHHA, 2022). Southern torrent salamanders (*Rhyacotriton variegatus*), relics of cooler climatic epochs, are dependent on the coldest seeps and heavily shaded habitats (Nussbaum et al., 1983; Welsh, H.H, Jr., 1990). *Ensatina* and other slender salamanders represent an extraordinary radiation of lungless salamanders across the Klamath and North Coast ranges, where mesic forest floors provide both shelter and moisture (Petranka, 1998). The coastal tailed frog (*Ascaphus truei*), one of the few frogs adapted to icy, fast-flowing streams, offers a glimpse into ancient amphibian lineages shaped by these watery refuges (Corn & Bury, 1989). The region's diversity of mollusks—both aquatic and terrestrial—adds further texture to these ecosystems.

Tiny aquatic snails in headwater seeps and spring-fed creeks serve as bioindicators of pristine water quality, while moss-dwelling slugs and litter-layer snails contribute to decomposition and nutrient cycling, forming an often-overlooked component of the forest food web (e.g., Frest & Johannes, 1995).

Future resilience in wetlands and mesic zones will depend on protecting and restoring these habitats as critical climate refugia; safeguarding springs, seeps, riparian corridors, and beaver-influenced valleys through conservation easements; hydrological restoration; and shading from native vegetation. Vegetatively, these areas act as lifeboats in an increasingly seasonal landscape. Moisture-dependent plants such as sedges, mosses, willows, and shade-loving ferns complete their life cycles even during severe summer droughts. Some of the region's most disjunct (fragmented) or endemic plant species persist only in these microclimates, retreating here as the broader landscape warms and dries (Sawyer et al., 2009).

As the region faces unprecedented droughts (**Figure 1.7, Appendix Figure 1.1.D**), heat waves (**Appendix Figures 1.1.A–C**), and erratic precipitation (**Figure 1.6**), beaver restoration is emerging as a powerful climate adaptation strategy (**Appendix Case Study 2.1.C**). The Karuk Tribe has long understood the importance of sahpihnîich (beaver), as explained in their Impacts of Climate Change on the Karuk Tribe report from 2022, "Sahpihnîich can play a role in drought mitigation by storing water and maintaining areas of open water. Their dams can moderate stream temperatures, reduce peak flows in flooding events, create complex aquatic habitats for many other species, trap suspended sediment, and restore incised streams to more complex channel and ponds systems" (P.VII–109 Karuk Tribe, OEHHA, 2022). Collaborative restoration of beaver and other culturally important species led by Tribes, conservation organizations, state and federal agencies, private landowners, and watershed practitioners, aims to restore not just a charismatic and culturally important species, but the processes that stabilize ecosystems—slowing and storing water, recharging groundwater, shading streams, and spreading moisture across valley bottoms (Reeves et al., 2014). Reintroducing or mimicking beaver activity to slow water flow—removing barriers to cold-water connectivity, and enhancing structural diversity with downed wood, boulders, and plantings that maintain cool, moist microclimates for sensitive species—would further protect these ecosystems (**Appendix Case Study 2.1.C**). Long-term monitoring of amphibians, mollusks, and moisture-dependent plants will serve as early indicators of climate stress, with special attention to stronghold populations. Collaborative Tribal-led projects that utilize TEK—such as Tribal fire stewardship and cultural plant use in wetland restoration—ensures management decisions that reflect both Indigenous and western science priorities. Finally, maintaining habitat connectivity, anticipating species range shifts, and engaging communities in monitoring and restoration will help these life-sustaining anchors persist amid increasing drought and fire.

The Wiyot Tribe recently acquired a coastal parcel of land called Mouralherwaqh with SLR and climate refugia in mind. From a bird's eye view, the 48-acre parcel appears as a food forest island surrounded by residential development. The site overlooks King Salmon and Wigi (Humboldt Bay), and its rises in topography support Sitka spruce forest with ample native understory vegetation like redwood manzanita, salmonberry, thimbleberry, red huckleberry, hazel, and more, essentially providing a rich food forest. Two adjacent wetlands were historically connected to Humboldt Bay but were disconnected with the construction of Highway (Hwy) 101. Wiyot citizens and recorded stories share how the wetlands were prime for hunting waterfowl. Today, the wetlands still host

egrets and great blue herons with their rookeries overlooking the wetlands on the property but have become overgrown with slough sedge and cattails. Since buying this land back, the Wiyot Tribe has been looking to the past to help guide current and future restoration efforts, which include a management plan to restore the wetlands through and with culturally important species and habitats.

2.2.6 Invasive Species and Ecological Disruption

As climate change accelerates and disturbance regimes shift, invasive species (e.g., pigs, turkeys, bullfrogs, medusahead, barbed goat grass) are becoming a growing threat to the integrity of native ecosystems in Northwest California. Nowhere is this more evident than in high-elevation mountain lakes and grassland valleys, where invasive species intersect with native biodiversity in increasingly disruptive ways. As snowpack declines and seasonal drought intensifies (e.g., **Figures 1.2–1.8**), the duration and extent of breeding habitat for amphibians shrinks (Corn, 2005; Lee et al., 2015). *Batrachochytrium dendrobatidis*, chytrid fungus, and other emerging amphibian diseases further stress populations already pushed to the brink by habitat loss and invasive predators such as nonnative trout and American bullfrogs (Rachowicz et al., 2006; Pilliod & Peterson, 2001; Doubledee et al., 2003).

In response, land managers are now embracing climate-informed restoration strategies. In select alpine lakes, efforts are underway to remove invasive trout and thus restore historical hydrological ecologies—including improving the reproductive success of native amphibians (**Appendix Case Study 2.1.D**) (Knapp et al., 2007; Tiberti et al., 2021). Protecting and enhancing refugial waters ensures permanent breeding habitat for sensitive species, allowing populations to persist and recover even as climatic conditions shift. These actions are part of a larger movement toward adaptive restoration—reconnecting species to suitable habitats as ecological baselines change (Morelli et al., 2016).

Further east, in the clay-rich soils of the eastern Siskiyous, another invasive challenge is emerging. The annual grass ventenata (*Ventenata dubia*) is spreading rapidly, overtaking areas that once resisted cheatgrass due to soil constraints (Tortorelli et al., 2020). Ventenata and other invasive grasses alter fire regimes by increasing fine fuel loads, making fires more frequent and intense, and displace native forbs and perennial grasses that many native herbivores and pollinators depend on (e.g., Maestas et al., 2016). In addition, supplemental hay feed for livestock production in mountain valleys in the east part of the region has resulted in invasion by Dyer's woad (*Isatis tinctoria*) (Stapleton & Orloff 2017).

Managing these invasions requires both early detection and integrated action, mapping invasion fronts, prioritizing vulnerable habitats, and combining fire management, targeted grazing, and native plant restoration (Davies & Johnson, 2017). These efforts increasingly align with climate adaptation frameworks, recognizing that invasive species control is essential to maintaining biodiversity, habitat integrity, and ecosystem function in a warming world (Millar et al., 2007; Morelli et al., 2016).

2.3 Rivers and Lakes

Authors: *Darren Ward, Christine Davis, Andrew Stubblefield, Luis Santana*

KEY TAKEAWAYS

- Flow management and habitat restoration promotes fish life history diversity. In dammed rivers, modified flow releases could mimic natural river flows and temperatures to support fish populations. However, to date, releases are a small fraction of historic flows. Creation of off-channel habitats has been successful to create flow refugia during peak winter flow conditions. Targeted mitigation strategies to reduce populations of non-native fish improves resilience of native species.
- Minimize water temperature increases by maintaining or increasing riparian shading, increasing summer flow, enhancing groundwater connection, and managing reservoir releases.
- Strategies for supporting fish during drought are 1) protect and restore groundwater-supplied habitats; 2) relocate fish; 3) reduce predatory fish populations; 4) implement strategic restoration projects that increase the extent and biodiversity of riparian vegetation; 5) ensure timber harvests upslope of rivers and streams are managed responsibly; and 6) forest thinning, which has potential to increase summer low flows.
- Recommendations for restoration: 1) allow natural processes and riparian forests to absorb impacts of increased hydrology; 2) focus on tributary to floodplain connectivity, physical processes and flood control, levees, tide gates; 3) use strategic and comprehensive science systems to plan and implement the restoration of ecological and ecosystem function; and 4) support an integrated regional approach at the full continuum of scales and resolutions.

The North Coast region of California has an incredible variety of freshwater ecosystems and microclimates, driven by proximity to the ocean, topography, and geology (**Figure 2.2**). The largest aquifers in the region are the Eel River and Van Duzen River lower floodplains. Groundwater also supports agriculture in parts of the North Coast. Overall, the North Coast has high-quality freshwater compared to many other regions of California. However, the highly erodible soils and shifting climate, combined with current and past timber harvest practices, have resulted in numerous rivers that are listed as impaired by US EPA, predominantly for high sedimentation and increased water temperatures. The rivers and lakes of the North Coast region support a culturally and economically important fish community. The North Coast is a stronghold for anadromous fish species in California, including the most productive remaining wild populations that are less impacted by habitat alteration and climate stress than populations to the south. Clear Lake, high alpine lakes, and reservoirs in the region support unique communities of freshwater resident fish, including rare endemic species, introduced species with high recreational value, and invasive introduced species that come with detrimental effects.

Ongoing and projected changes to rivers and streams include larger and more variable winter flows and reduced summer flows, as well as longer, drier dry seasons (**Figure 1.5**), particularly in watersheds historically dependent on snowpack (Patterson et al., 2022) and those with little groundwater storage capacity (Dralle et al., 2023). Inland areas are projected to experience higher temperatures and intensified drought conditions (**Table 1.1, Appendix 1.2**). In lakes, projected seasonal shifts include longer ice-free periods for alpine lakes (Woolway & Merchant, 2019) and longer periods of thermal stratification in all lakes (Woolway et al., 2021). Wildfires and

more intense wind and rain will increase the flux of large wood into rivers which are harmful to civil infrastructure and may cause flood breakouts where models do not otherwise predict them. In regulated river systems, additional hydrologic changes may arise from reservoir storage and management practices that change in response to climate. Shifts to seasonal temperature and flow regimes have profound implications for freshwater species biodiversity, including changes in fish assemblages—potentially favoring invasive species, altering flow-dependent habitats, and intensifying pressures from agricultural water withdrawals. Anadromous fish face cascading and compounding impacts from the wide range of changes to marine and freshwater conditions. Further discussion of rivers, lakes and dams is found in **Box 2.2**, the Water Infrastructure Impacts and Adaptive Management sections of **Chapter 3**, and **Appendix Case Studies 2.1.C, 2.2.A**, and **2.3.A**.

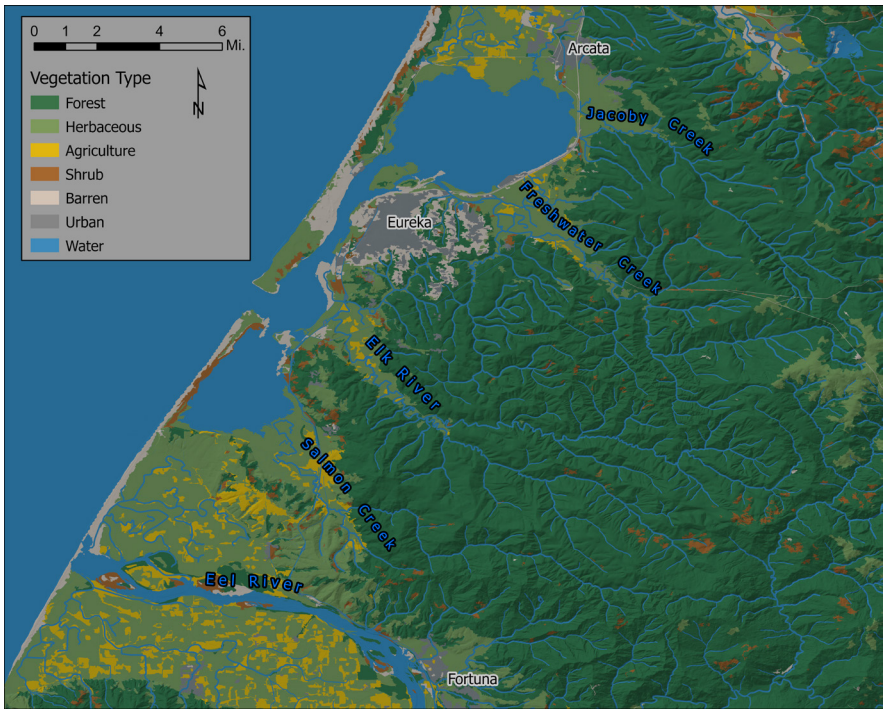


Figure 2.2: *Humboldt Bay, major rivers, and vegetation types. Contributor: Chris Gressierer*

2.3.1 Freshwater Seasonal Patterns

Altered flow and temperature regimes pose a challenge to fish and other organisms that evolved in response to historical climatic patterns. Changes in seasonality can lead to a mismatch between the timing of events in organisms' life histories (phenology) and the habitat conditions they encounter. These mismatches, such as dissolved oxygen depletion in the water, can reduce survival or growth rates, constrain the spatial distribution of populations, or even lead to the sudden loss of entire populations. For example, the timing of adult salmon's return to freshwater to spawn in fall and winter coincides with reduced temperatures and precipitation events that increase flows and allow access to small tributaries that are their preferred spawning habitat. In

severe drought conditions during the winter of 2013—2014, extremely low winter flows prevented migrating salmon from accessing tributary breeding grounds, constraining their distribution to larger mainstem habitat in large watersheds and completely eliminating reproduction in smaller coastal watersheds where all spawning habitat was rendered inaccessible (Carlson et al., 2025). Altered flows also cause river mouths to close up preventing fall-run Chinook and Coho salmon from entering. The Klamath River mouth has consistently closed up each September (2015 to present), forcing Yurok fisherman to create a new channel manually. In September 2025, the Klamath River mouth closed due to low flow.

MANAGEMENT FOR RESILIENCE: FRESHWATER SEASONAL PATTERNS

Flow management (Sturrock et al., 2020) and habitat restoration (Roddam & Ward, 2017) can promote fish life history diversity. Maintaining life history diversity in the face of uncertain changes in seasonal flow and temperature regimes increases the chance that populations will include some individuals that can succeed in the new conditions (Cordoleani et al., 2021). In dammed rivers, modified flow releases could mimic natural river flows and temperatures to support fish populations as conditions change (Yarnell & Thoms, 2022). However, dam flow releases have done a poor job of mimicking natural flows. For example, on the Trinity River, environmental flow releases, designed to restore fluvial processes, maintain floodplains, and transport gravel for spawning, are only 10% of historical peak flows. There are long period cycles of snowpack, precipitation, ambient temperatures, and other factors which impact fish populations that cannot be duplicated by humans. Habitat restoration can focus on expansion of habitat that promotes expression of successful life histories and supports their success. For example, high winter flows and rapid spring recession are associated with early downstream movement of juvenile salmon followed by extended rearing in estuaries (Sorel et al., 2022); if this flow pattern increases with climate change, then restoration efforts that focus on estuarine habitat for juvenile salmon could be effective. Creation of off-channel habitats has been successful to create flow refugia during peak winter flow conditions. Targeted mitigation strategies to reduce populations of non-native fish can improve resilience of native species.

2.3.2 Freshwater Temperatures

Water temperature will continue to increase across the region as a result of increased air temperature, reduced summer streamflow, and in some cases increases in winter streamflow (e.g., **Figures 1.2–1.7**; Liu et al., 2018). Temperature gradients from downstream to upstream constrain seasonal distribution of many fish species, with juvenile salmonids and other heat-intolerant species in interior watersheds limited to small headwater tributaries during summer and a heat-tolerant community of fish in larger mainstem habitats. Warming will affect species distribution, isolating heat-intolerant species in interior watersheds to shrinking headwater refugia (Krochta et al., 2025). As they become increasingly isolated in thermal refugia, heat-intolerant species may lose access to food-rich mainstem habitat during summer (Brewitt et al., 2017), and they may need to move long distances to access these habitats during cool seasons (Armstrong et al., 2021) or for migratory species to complete their lifecycles.

Unlike interior watersheds, some North Coast waters near the coast are buffered from the most severe temperature increases by maritime influence (**Table 1.1; Appendix 1.1-1.2**; Lewis et

al., 2000; Madej et al., 2006). These coastal waters potentially provide additional area for heat-intolerant organisms for species that can complete their lifecycle in coastal habitat or migrate during cool seasons to other required habitats such as headwater spawning areas for salmonids.

In lakes, warming increases the duration and intensity of thermal stratification, during which resources like nutrients and oxygen cannot mix throughout the water column (Woolway et al., 2021). Extended periods of stratification lead to reduced oxygen in deep waters, forcing fish to occupy warmer surface water and potentially eliminating habitat for species that need cool water and high oxygen concentrations such as salmonids in alpine lakes. Further, persistent anoxia in deep water can stimulate nutrient release from the sediments, compounding issues with eutrophication (excess nutrients) in hyper productive systems like Clear Lake (Smith et al., 2023).

Strategic conservation and restoration of land adjacent to riparian climate refugia (riparian areas that may temporarily buffer species from impacts of climate change) must be prioritized in watershed planning. An example is the creation of a Yurok Salmon Sanctuary after 47,000 acres of the Blue Creek watershed was returned to the Yurok Tribe in the largest land back project in California history. Also, connectivity of habitats will be one of the most important factors to mitigate the effects of the temperatures and support species biodiversity (Heller & Zavaleta, 2009). Thus, landscape changes in riparian areas, such as large commercial or housing developments, roads, and vegetation cover changes from logging, should be minimized near riparian buffers, or done in a way that lessens the impacts of landscape fragmentation. Increasing anadromous fish spawning populations will also increase riparian growth by delivering marine-derived micro-nutrients from carcasses post-spawn.

MANAGEMENT FOR RESILIENCE: FRESHWATER TEMPERATURES

Maintaining or increasing riparian shading, increasing summer flow, enhancing groundwater connection, and managing reservoir releases can all help minimize water temperature increases. Shaded headwater streams in watersheds with sufficient groundwater storage capacity to support summer flows and larger spring-fed streams will provide an important safeguard against losses of heat-intolerant aquatic species (Lusardi et al., 2023). Fish and other mobile organisms can shift their habitat use in response to increased temperatures by moving into thermal climate refugia. This behavioral response can allow populations to persist as long as they still have access to migratory corridors and specific habitats (e.g., spawning areas). Maintaining habitat quality and access in habitats that are temporarily unsuitable due to summer temperatures is critical, as these areas are often key migration pathways and provide high-quality habitat in cool seasons (Armstrong et al., 2021). In rivers with regulated flows, release of water from reservoirs can dramatically alter the temperature regime. Releasing cold water from the bottom of reservoirs during summer has been used as a management strategy to support fish that require low temperatures (Yates et al., 2008). Removal of dams can open up hundreds of miles of headwater cold-water refugia (see case study about proposed decommissioning of PG&E's Potter Valley Hydroelectric Project, **Appendix Case Study 2.2.A**).

2.3.3 Drought and Rivers

Increased heat index and ambient air temperatures will result in increased drought, which may alter both stream flow amounts and fire regime intensity (**Figures 1.2–1.10** and **Appendix Figures 1.1.C–1.1.D**). Increased drought will intensify forest edge habitat drying out and degrading due to timber harvests and development. Intensified fire regimes may result in reduced riparian vegetation, which in turn may affect the temperature of freshwater tributaries. In tributaries that are already at the high end of optimal temperatures for fish habitat, a one- to two-degree change in stream temperature may significantly reduce the possibility for fish to survive. However, in many systems fish have co-evolved with fire. For example, most major fires in the Klamath Basin have caused a lowering of the water temperature and a corresponding move upstream of salmon with intense smoke cover blocking sunlight.

Prolonged drought results in some streams disappearing or becoming intermittent. Even when water remains in the channel, low flows lead to reduced dissolved oxygen levels and increased water temperatures (Obedzinski et al., 2018). Fish mortality during drought can be very high, particularly during extended periods of disconnection (Vander Vorste et al., 2020). Small tributary habitats that support high survival and growth of fish during wetter years may have the highest mortality during droughts (Obedzinski et al., 2018; Vander Vorste et al., 2020).

Although the North Coast has higher precipitation than some regions in California (**Appendix Table 1.A**), it is still subject to ecosystem-altering drought. Climate predictions indicate that precipitation may increase in some parts of the region with altered temperature regimes (**Appendix 1.2**). If rainfall does increase, it will likely occur in unpredictable patterns of intensity that may contribute to compounding situations of high rainfall, flooding and scouring, erosion, and SLR (**Figures 1.11–1.12, Appendix Figure 2.3.C**). For example, precipitation may fall as rain instead of snow in some scenarios, thus decreasing precipitation holding capacity in the form of snowpack in higher elevations and altering seasonal water flows.

MANAGEMENT FOR RESILIENCE: DROUGHT AND RIVERS

Increasing streamside vegetation, managing land use, and using restoration projects such as beaver reintroduction to increase groundwater storage can increase the resilience of streams to drought. Groundwater supply can support flows and reduce water temperatures during extended dry periods, maintaining resilience in habitat conditions. Small streams in watersheds with low groundwater storage foster unique life histories of fish with faster growth and earlier migration (Dralle et al., 2023), traits that may contribute population resilience. Protecting small tributaries from excessive or illegal diversions and unmonitored groundwater pumping can help maintain flows and cool temperatures. Current reporting of water use is inconsistent or inaccurate. Strategies for supporting fish during drought are 1) protect and restore groundwater supplied habitats; 2) relocate fish; 3) reduce predatory fish populations; 4) implement strategic restoration projects that increase the extent and biodiversity of riparian vegetation; 5) ensure that timber harvests upslope of rivers and streams are managed responsibly; and 6) forest thinning, which has potential to increase summer low flows (Keppeler et al., 2024).

2.3.4 Flooding and Sea Level Rise Near Rivers

Flooding is expected to increase in magnitude and frequency as rainfall becomes more concentrated in more intense storms. Severe flooding could be further increased if drought, heat, and fire reduce soil holding capacity, leading to more rapid surface runoff and less groundwater storage. High magnitude floods can directly affect fish populations. In coastal watersheds with high winter precipitation, limited slow-water habitat during high flows is thought to be a primary constraint on survival and abundance of juvenile salmon (Solazzi et al., 2000). Large floods can cause mortality and displace fish from preferred habitats. In addition to short-term, direct effects on fish, flooding can have long-term effects by altering fish habitat. Large floods reconfigure stream channels through erosion and deposition. Some level of flooding is essential for habitat creation, for example to maintain scouring to produce pools and sort fish spawning gravel. However, extreme floods transport massive amounts of sediment, exacerbated by legacy input from historic logging, potentially filling pools, covering riparian areas, and widening and homogenizing channels (e.g., **Appendix Case Study 2.2.B**).

Rivers are living, dynamic systems that do not always stay in defined corridors. Sea level rise is reclaiming many diked agricultural lands and mixing salt water with freshwater at the mouths of rivers during high precipitation events (**Figure 2.2**). These compounding factors bring new challenges as high sediment loads cannot always cycle out of the relict slough channels, causing increases in flooding that can harm residential and commercial infrastructure and convert agriculture lands back to salt marsh. However, these processes often do not return naturally and need restoration actions (e.g., **Box 3.1** and **3.2, Appendix Case Study 2.2.B**).

MANAGEMENT FOR RESILIENCE: FLOODING AND SEA LEVEL RISE NEAR RIVERS

Good forest management can help control the impact of floods by delaying and spreading flood peaks and increasing infiltration. Healthy forests and riparian zones, with a minimal and well-maintained road network, are more resilient in the face of intense rainfall. Restoration actions aimed at restoring ecological and ecosystem function are powerful interventions when designed as part of a strategic, comprehensive, science and systems-based approach to planning and implementation. For example, projects that improve tributary-to-floodplain connectivity can improve flood response. Tidivates and levees that are upgraded and maintained will better protect infrastructure, but they can often be reconfigured to maintain or improve habitat function and maintain sediment transport (e.g., levees set back to allow floodplain inundation and a larger tidal prism, sediment and excess in-stream vegetation removed from channels to improve drainage and the flushing of flood sediments). An integrated regional approach at the full continuum of scales and resolutions is more successful than piecemeal projects (e.g., reach by reach, watershed by watershed).

2.4 Ocean and Coasts

Authors: *Eric Bjorkstedt, José Marín Jarrín, Whelan Gilkerson, Keith Parker, Marisa McGrew, Andrew Stubblefield*

KEY TAKEAWAYS:

- Ocean conditions are influenced by global factors beyond local influence. Decarbonizing the global economy as rapidly as possible is our most effective tool to give ocean environments their best chance of maintaining vitality.
- Nature-based solutions can benefit resilience to climate impacts in numerous ways. Using dredge materials to build up berms to create salt marshes between Arcata and Eureka would attenuate waves threatening the Highway 101 corridor, while creating productive habitat. Humboldt County has reclaimed hundreds of acres of tidelands through dike-breaching and recontouring poor-quality agricultural land.
- Reducing other stressors on aquatic ecosystems will support resilience. This includes limiting habitat loss to development, buffering agricultural and urban runoff, and maintaining well-managed fisheries through adaptive fisheries management, including support for fisheries transitions. Changing ocean conditions may require investments and infrastructure such as cold storage or freezing facilities to help local fishermen adapt. Maintaining and expanding networks of marine protected areas will enhance conservation and resilience of aquatic ecosystems.
- Freshwater and terrestrial conditions such as quantity of river discharge and water quality, temperature, and sediment load are strong drivers of coastal habitat conditions. As a result, the management of coastal habitats will be most effective if it is done in concert with management of contributing/associated watersheds, not in isolation.
- Tribal perspectives bring a wealth of knowledge, perspective, and experience that can help guide restoration and management (**Box 2.2**). Continuing support of Tribes to manage coastal lands significant to their people and histories through land back and collaborative Tribal-led coastal restoration efforts builds on demonstrated successes. This means protecting and enforcing Tribal sovereignty, including culturally important coastal places, fisheries, and shellfish fisheries identified by Tribes.
- Providing resources to fisheries and coastal habitat managers to engage with and guide local and regional efforts that contribute to decarbonizing the energy system (e.g., wind and wave energy development) will increase the ability to understand, reduce, and mitigate ecological impacts.

The North Coast region is dominated by the influence of ocean conditions and food webs on our climate and the habitats created by the interaction of wind, waves, and sea level with rivers and landforms (**Figure 2.2**). In this section, we describe the coastal environments and fisheries and share Tribal perspectives. We detail impacts from climate change and present management strategies for resilience.

The open ocean in this region of the coast is driven by the California Current System, El Niño Southern Oscillation (ENSO), and Pacific Decadal Oscillation (PDO) (Checkley & Barth, 2009). Strong seasonal winds from the northwest upwell nutrient-rich water from deeper areas of the ocean, mostly during the spring and summer. This nutrient-rich water fuels high productivity, and thus

productive fisheries, primarily rockfish, salmon, and crab. This region also supports small-scale, data-poor fisheries including true smelts, surfperches, and shellfish.

A wide diversity of coastal wetlands reflects the influences of ongoing tectonic activity and erosional processes. Ecosystems include rocky intertidal zones and kelp forests, coastal lagoons with intermittent connectivity to the ocean, and river mouth estuaries and bays with daily fluxes of freshwater and sea water, all influenced by the nearshore ocean. A 350-km-long stretch of kelp forests was wiped out during the 2013 marine heat wave, resulting in a phase shift to barren sea floor populated only by sea urchins, and the loss of the $44 million abalone fishery (**Appendix Figure 2.3.A**; Rogers-Bennett & Catton, 2019). Please see the Fifth Assessment report "Identifying Climate Change Refugia in Coastal and Pelagic Ocean Habitats" for further information on refugia for sardines and red abalone.

Sandy beaches and surf zones are the most common coastal habitat. Influences from the ocean include tides, swells, wind, and waves, while influences from the land side include wind, sand movement, and rain runoff from dunes. Many species of animals and plants are found, including those harvested since time immemorial (e.g., smelt, surfperch, gulls, seals, and sea lions).

2.4.1 Impacts of Climate Change on Ocean and Coasts

Though large-scale modes of climate variability such as El Niño continue to drive ocean dynamics, warming trends are now the dominant mode of change in sea surface temperature (Cluett et al., in review) and large-scale, persistent heat anomalies—marine heat waves—are increasingly frequent and extensive. Changes in atmospheric patterns have shifted storm tracks and the timing and intensity of upwelling winds, leading to greater stratification in some regions and a trend toward stronger upwelling in northern parts of the California Current Ecosystem (CCE) (Garcia-Reyes et al., 2015; Sidemen et al., 2014.). How these trends affect coastal waters off Northern California will reflect their position within the broader CCE and are shaped by regional structure, e.g., the influence of Cape Mendocino and other headlands on coastal ocean dynamics (Lagier et al., 1993). Coupled with these dynamics, increased anthropogenic carbon dioxide drives ocean acidification, increasing baseline exposures and leading to more intense acidification events in areas strongly affected by upwelling of deep waters (Desmet et al., 2022).

Distributions and abundances of coastal fishes and invertebrates in California are expected to respond to ocean warming and stratification, direct and upwelling-related intensification of ocean acidification and deoxygenation and shifts in the timing and patterns of primary productivity. Superposition of warming trends on seasonal patterns and long-term modes of climate variability (e.g., PDO) makes understanding ecological responses (e.g., anchovy booms; Thompson et al., 2024; Swieca et al., 2025) challenging. Rising sea levels and changes in ocean swell may also impact critical coastal habitats for important species.

One key concern is habitat loss resulting from "coastal squeeze" and altered sediment dynamics in estuaries and sandy beach surf zones. For example, changes in sediment transport may lead to the loss of troughs or runnels—features formed by sand bars migrating toward the shore—that are known aggregation sites for certain juvenile fish species in the Pacific Northwest. Alternatively, sediment accumulation may smother rocky reef habitats, threatening sedentary invertebrate species.

Several fish species in the Pacific Northwest rely on a range of interconnected coastal habitats to meet their needs for food, shelter, and growth. Fall-run juvenile Chinook salmon use estuaries as nursery habitats upon first entering the marine environment. However, SLR will reduce the size and warming waters will reduce the habitat quality of estuaries. This may force juvenile salmon to migrate into the coastal ocean earlier and at smaller sizes, increasing their risk of mortality. Such effects may already be observable in estuaries like the Eel River in Northern California, where water temperatures exceed 68°F (20°C) as early as April.

The upwelling system that fundamentally defines the CCE exhibits both along-shore and cross-shelf responses to warming events that foreshadow potential responses under continued climate change (e.g., **Appendix Figure 2.3.B**). Warming events, especially strong El Niños, commonly lead to the temporary presence of southern species in coastal waters off Northern California (Winnacott, 2021). Analogously, onshore advection during marine heat waves has been shown to bring species from warmer offshore waters closer to the coast (Sanford et al., 2019).

While many of these shifts in species distributions appear to be temporary, evidence for more persistent shifts has emerged from studies of rocky intertidal assemblages, indicating that some changes in planktonic assemblages may be persistent, at least in terms of repeated or more frequent detections (e.g., krill species, pyrosomes, *Vellela*, etc.). Pelagic species' distributions are projected to shift northward or coastward (e.g. Lezama-Ochoa, 2024), but predictions can be highly uncertain due to novel environmental conditions (Ash et al., 2022). For demersal species (groundfish), responses to marine heat waves are uncertain (Fredston et al., 2023) and regional persistence might be supported by a shift to deeper habitats.

Changes in currents flowing across the continental shelf have also given rise to emerging concerns about habitat compression (Schroeder et al., 2022)—the compression of cold, productive upwelling conditions into narrow bands along the coast, especially during relaxations from upwelling leading to incursion of warm waters into the coastal zone that reduce the extent of productive, upwelling-associated habitats (**Appendix Figure 2.3.B**). Such habitat compression has the potential to drive whales that pursue prey, dependent on upwelling habitats, into shoreward habitats, thus increasing risks of interactions with coastal fisheries (Santora et al., 2020). Predictions of future dynamics of habitat compression reflect the tension between the presence of warmer offshore waters and the persistence (and possible intensification) of upwelling that holds these waters at bay for at least part of the year.

The mechanisms that drive the growth of phytoplankton blooms and subsequent shift of these blooms to toxin production is an area of active research, but there is a sense that mild enrichment (weak upwelling) coupled with periods of stratification—conditions that provide just enough nutrients to sustain a bloom under consistent stress—are likely to be drivers of intense harmful algal blooms (HAB), such as was observed in 2015. The North Coast appears to be especially susceptible to such events, especially in regions north of Cape Mendocino (Largier et al., 1993; Trainer et al., 2020). HABs are expected to intensify under future conditions (Moore et al., 2008), a dynamic that is likely to exacerbate overlap between fisheries (e.g., Dungeness crab) and migratory whales, leading to stark economic consequences and a need for active, adaptive management to reduce conservation risks.

Box 2.2: *Tribal Perspectives on the Gifts from Rivers and Oceans*

Author: *Keith Parker*

Native People have sustainably fished for many species of fish (e.g., salmon, trout, lamprey, sturgeon, smelt, surfperch, flatfish, rockfish), mollusks (mussels, clams, abalone), and crustaceans (crabs) for subsistence since time immemorial. The knowledge acquired throughout this time has provided Indigenous peoples with guidance and understandings on the responsibilities that humans have to take care of the places where they live. Indigenous scholar Dr. Robin Wall Kimmerer (2013) describes this knowledge as the "original instructions." Indigenous original instructions are used like a compass; they provide an orientation for where we need to go but do not provide a map of how to get there. Guided by these original instructions, each generation has to figure out their own roadmap to sustainability that will encompass the ever-changing environmental conditions and issues of the day. Since their arrival, European American fisheries have been far less sustainable, often resulting in dramatic reductions in fish abundance. Lands under Tribal management are a fraction of what was once accessible to Tribal members. As climate change continues to decrease availability of the minimal resources currently available to Tribal peoples, the need for policies that create collaborative cross-boundary relationships becomes more and more important.

The North Coast region hosts many resources important for Indigenous communities and the overall health of the environment. Pacific lamprey, commonly referred to as eels, and Green Sturgeon are ancient anadromous fish that share similarities to salmon. Eels and sturgeon are a significant food source for many of the Northern California Tribes as well as many other northwest Tribes. They fill a critical niche in the food calendar when salmon typically are not running upriver anymore, and other high lipid food sources are scarce. The Wiyot Tribe shares its name with what is now known as the Eel River, or Wiya't, and feel that the health of the river reflects the health of the Tribe. Sturgeon are also an important cultural icon for Yurok people with the sturgeon back design found in Yurok jewelry, art, tattoos, and home/office trim. Indigenous communities have been the primary eyes for observing and vocalizing a significant decline in Pacific lamprey and sturgeon populations, with agency biologists focused on other species.

One of the many impediments to native fish recovery in the Eel is the introduction of the invasive Sacramento pikeminnow (*Ptychocheilus grandis*). Pikeminnow populations in the Eel River have exploded. Pikeminnow directly compete with native fish as well as acting as predators on native species. Warming temperatures will create more suitable habitat for pikeminnow, further threatening culturally important species. While invasive in the Eel River, pikeminnow are native in Clear Lake, and have been nearly extirpated due to largemouth bass. Clear Lake pikeminnow are seen as a culturally important fish for Pomo Indians of California like the Robinson Rancheria.

Climate change is expected to shift the distribution of commercially valuable ocean fish, pushing them northward or into deeper, cooler offshore waters. Tribal fishers who rely on traditional fishing grounds, may need to adapt to targeting new or different species to sustain their cultural and economic practices. Early indications show that the removal of the Klamath Dams will be very positive for salmonids and eel populations, however the Klamath River estuary is facing sedimentation from the released dam sediments. A perspective on the Klamath estuary is found in **Appendix Case Study 2.3.A**. Follow these links for examples of coastal restoration projects by Wiyot, Yurok, and another Yurok effort.

SLR (**Figures 1.11–1.12**) will have wide-ranging impacts on the Northern California coast, driving changes in water level that can lead to flooding, increased erosion, changes in circulation, and other outcomes that will affect communities, ecosystems, and infrastructure. In Humboldt Bay, SLR and climate change are already affecting the estuary's interlinked physical environment and ecological communities. The expansion of the tidal prism driven by SLR, in conjunction with a reduction in anthropogenic sediment loading following the end of large-scale soil disturbance driven by 20th century industrial logging, are contributing to widespread erosion, expansion, and enlargement of the bay's tidal channel network. In turn, the bay's salt marsh habitat is becoming more fragmented with increased erosion being observed along the bayward margin in many locations. Since most of the bay's salt marsh habitat is backed by levies and shoreline revetment that currently prevent landward transgression of marsh habitat in response to increasing sea level, the bay's salt marshes are being squeezed by increasing inundation and hydrodynamic energy, resulting in transition of low marsh habitat into unvegetated mudflat (Richmond et al., 2023).

At lower tidal elevations, Humboldt Bay's eelgrass beds experienced relatively dramatic declines in cover in response to a historically unprecedented marine heat wave and coupled extreme drought conditions that occurred between 2013 and 2016 (**Appendix Figure 2.3.A**). Since 2017, a return to more benign ocean conditions and lack of extreme and prolonged drought conditions have resulted in substantial recovery of the bay's intertidal eelgrass beds; however, as climate change proceeds, the upper margins of eelgrass beds are likely to face increasing thermal stress during low tide. SLR may cause the lower margins of eelgrass beds to recede, as increasing water depth decreases available sunlight. As SLR progresses, it is anticipated that the negative effects of increased thermal stress on intertidal eelgrass will be moderated by increasing inundation and reduced atmospheric exposure during low tide conditions, allowing for shoreward migration where extensive intertidal mudflats may accommodate an expansion of intertidal eelgrass habitat.

SLR in conjunction with changes in nearshore sediment supply and transport may alter the configuration of barrier sand spits on Humboldt Bay as well as coastal lagoons throughout the North Coast (e.g., **Figure 2.3**; Richmond et al., 2023). These features are shaped by wind, waves, freshwater runoff, and sediment supply, adjusting dynamically over time in response to changing conditions. It is unclear how these features will respond to the effects of climate change and SLR; however, it is anticipated that barrier spits may transgress shoreward and/or may become more prone to breaching or fragmenting if nearshore and fluvial sediment sources are insufficient to keep pace with rising water levels. Many of these systems are located in relatively undeveloped watersheds and have some capacity for landward transgression of estuarine conditions. However the generally steep, mountainous terrain of the North Coast region results in rapid increase in stream valley gradient moving inland, suggesting that many of our region's estuaries may contract as SLR progresses.

Several areas of the North Coast, including the Eel River Delta, Humboldt Bay area, and the lower Smith River, provide exceptions to this general paradigm, where extensive low gradient agriculturally dominated landscapes, often created through reclamation of former tidelands, provide substantial opportunities for estuarine restoration and expansion as SLR proceeds. The strategic importance of these areas with respect to coastal wetland resilience is likely to grow as climate change progresses and coastal squeeze limits adaptive capacity in more developed areas of coastal central and Southern California.



Figure 2.3: *Rapid Shoreline retreat and Freshwater Wetland Conversion at Elk River Spit Humboldt Bay. A freshwater wetland has persisted for decades on the Elk River Spit, first appearing in 1954 aerial imagery. Its position relative to the shoreline was nearly unchanged between 2009 and 2018. Saltwater intrusion and wetland conversion initiated in 2022. The spit is now overtopped regularly during King tides. Image Credits: Google Earth*

Over the next century, changes in ocean waves, in addition to impacts from SLR, will drive changes in beach habitat, coastal erosion, and extreme flooding with storms. Projections from Global Climate Models (Chang et al., 2012; Priestley et al., 2022) show storm tracks may shift northward and associated extreme waves are projected to slightly decrease in comparison to observed records (Erikson et al., 2016; Erikson et al., 2022). However, changes in wave direction, related to shifts in storm tracks, may also shift hazard-prone areas. Storms and waves can drive increased coastal erosion and potential loss of habitat beyond changes by SLR. Considering approximate mid-century changes consistent with 0.5 m SLR (1.64 ft), projections show beaches across the region may erode an average 55.1 m with a 20-year storm (**Appendix Figure 2.3.C**; Vitousek et al., 2023). Over 22% of beaches in Northern California may erode completely with storms of that intensity.

Cumulative effects from waves, storms, SLR, and other climatic changes are expected to increase erosion rates of coastal bluffs and cliffs, impacting adjacent infrastructure and communities. Long-term projections of cliff retreat show an average retreat distance of 17.4 m across the region with 0.5 m SLR (**Appendix Figure 2.3.D**; Barnard et al., 2022). Similarly, storms and waves compound and intensify flooding hazards from SLR. Ocean-driven flooding with 0.5 m (1.64 ft) SLR alone may drive flooding across 37 km^2 of coastal Northern California, but impacted areas expand by almost 300% and 350% when considering effects from a 20-year storm and 100-year storm, respectively (Barnard et al., 2022).

Chapter 3.

Built Systems in the North Coast Region

Author: *David Narum with contributions from Craig Benson and Christine Davis*



Key Message

North Coast transportation, energy, water, and building infrastructure face interconnected failures from intensifying climate impacts, and communities across the region are already demonstrating a path forward. The region has demonstrated adaptation through nature-based solutions, distributed networks that eliminate single points of failure, adaptive management, and integrated multi-benefit approaches that design infrastructure to serve multiple functions simultaneously, reducing costs and unlocking diverse funding streams. This chapter documents those approaches, the evidence behind them, and the structural barriers that prevent them from scaling to match the pace of intensifying climate impacts.

3.1 Built Systems in the North Coast Region

Built systems in the North Coast region exemplify rural vulnerability to climate change. The six-county region covers 19,000 square miles (49,000 sq km), with over 380,000 residents that are dependent on infrastructure that lacks redundancy: single highways with no alternate routes, power lines with no backup sources, and water systems with no secondary supplies. When these systems fail—whether from intense rainfall, wildfire, extreme heat, or other climate stressors (**Figures 1.2–1.10** and **Appendices 1.1–1.2**)—the impacts cascade through every aspect of community life, from basic services to economic stability.

The 2022–23 atmospheric river sequence demonstrated this at regional scale: nine storms in three weeks cut power to over 200,000 homes and businesses (California Office of Emergency Services, 2023), disabled communications networks, contaminated water supplies, and closed multiple access routes (Redheaded Blackbelt, 2022; NOAA California Nevada River Forecast Center, 2023). Chronic stressors degrade infrastructure between acute events as well: at Last Chance Grade in Del Norte County, for example, Hwy 101 crosses an active landslide where deterioration has accelerated over the past decade, requiring frequent pavement repairs during heavy rainfall and forcing lengthy detours with each closure (Caltrans, 2018).

Where infrastructure failures erode connectivity over time, wildfires force more immediate ruptures. Each wildfire evacuation makes it harder to return. As Stephen Decatur from Dunsmuir City observed, “People usually just have to leave and don’t come back…people leave after fires because repairs are too costly” (Community Advisory Board, 2024). After 10 days of mandatory evacuation from the 2018 Mendocino Complex fires—the fourth evacuation in three years, and in a county (Lake) where 70% of the land has burned since 2015 (Lake County Office of Emergency Services, 2024)—Lake County resident, Terre Logsdon, joined this exodus and moved to North Carolina. She later moved back and became the county’s Chief Climate Resilience Officer.

“Besides wildfire,” she observed, “flooding from atmospheric river storms is not being looked at enough. Lake County is a bowl” (Community Advisory Board, 2024). Her observation reflects what climate models project: more frequent, interrelated hazards demand different infrastructure designs.

The region's building stock introduces its own vulnerabilities. Coastal structures built without air conditioning increasingly face dangerous heat exposure as marine fog decreases and heat waves intensify (**Appendix Figures 1.1.A–C**), while foundations designed for stable moisture conditions crack under new cycles of extreme wet and dry conditions. These risks fall disproportionately on nearly half of the region's population that live in disadvantaged communities where older, poorly insulated housing amplifies climate exposure for elderly residents, people with chronic health conditions, mobile home residents, farmworkers, and unhoused populations (Chapter 4).

Current infrastructure is already failing under today's climate stress. Mid-century projections (Chapter 1; **Appendix 1.1–1.2**) suggest that these systems will face conditions far beyond current design thresholds. The California Fifth Climate Change Assessment's LOCA2-Hybrid downscaling—a statistical method for translating global climate model output to local geographic scale—reveals stark differences in projected warming across the North Coast under various emissions scenarios. These differences translate into distinct infrastructure challenges and call for context-specific adaptation approaches (Chapter 1; **Figure 1.2; Table 1.1**).

Priorities. Community engagement and consultation for this report revealed infrastructure priorities clustered around four recurring strategies: distributed, locally-controlled systems over centralized infrastructure; nature-based solutions that work with ecological processes rather than against them; adaptive management approaches that adjust to changing conditions rather than optimizing for fixed assumptions; and integrated multi-benefit designs that serve many functions simultaneously while reducing costs and unlocking diverse funding streams. The underlying driver is the same across all four—existing systems leave communities exposed to preventable health and safety consequences.

This move toward distributed, adaptive infrastructure aligns with the North Coast's particular circumstances, where the same characteristics that create vulnerability—low population density, geographic isolation, and limited resources—also present opportunities for transformation. The region's extensive undeveloped land supports nature-based infrastructure at significant scale, while communities with deep experience in self-reliance are well-positioned to pioneer distributed systems. These "ecological uplift" approaches—infrastructure that enhances ecosystem functions while meeting human needs—also often generate local economic benefits as they build climate resilience. **Table 3.1** summarizes these four strategies and the priority examples documented throughout this chapter.

Table 3.1 *Community-identified climate resilience strategies organized by recurring themes, with priority examples for each.*

Community Identified Strategy	Core Principle	Priority Examples Across Systems
Distributed, locally-controlled systems	Decentralized systems under local or Tribal governance reduce the risk of single-point-of-failures and keep decisions close to the communities that are served.	**Energy:** Rural microgrids (BLR; TERAS), battery backup, community solar (Crescent City Harbor) **Transportation:** Redundant evacuation routes (Brooktrails Second Access; Redemeyer Rd.; Great Redwood Trail) **Water:** Small system partnerships (Ukiah Valley merger), shared operators (Round Valley, RCAC circuit riders)
Nature-based solutions	Infrastructure aligned with ecological processes enhance ecosystem function while meeting human needs.	**Water treatment:** Arcata Marsh wetlands (4 decades, 2.3M gal/day, 300+ bird species) **Slope stabilization:** Bioengineered slopes at ~half the cost of conventional approaches (Hwy 299) **Coastal:** Living shorelines and salt marsh restoration (Humboldt Bay) **Buildings:** Passive design (Cal Poly Humboldt LEED Gold; Anderson Valley Health Center)
Adaptive management	Infrastructure decisions should match changing conditions rather than fixed assumptions—including what to preserve, modify, or retire.	**Transportation:** Last Chance Grade ($2.1B reroute vs. $100M+ repeated repairs); seasonal closures in Mendocino and Trinity counties **Water:** Fort Bragg desalination (using ocean water as permanent supply); Klamath River dam removal (choosing retirement over perpetual maintenance) **Forestry:** Lake County tree mortality triage—hazard trees near evacuation routes prioritized over full removal
Integrated multi-benefit designs	Infrastructure should serve multiple functions simultaneously, which reduces per-function costs and unlocks funding streams that are unavailable to single-purpose projects.	**Water, habitat, and recreation:** McKinleyville CSD wetland (stormwater treatment, flood control, trails, groundwater recharge, habitat) **Fisheries, water quality, and cultural access:** Klamath River dam removal, combining PacifiCorp ratepayer and Prop. 1 funds across multiple benefit streams **Energy and emergency:** BLR microgrid serving as a Red Cross evacuation site, with medical device charging capabilities during grid failures

Note: Without action, infrastructure gaps produce real health and safety consequences: ventilator and oxygen equipment failures during outages, blocked medical access during floods and road closures, and heat-related illness in buildings without cooling. Each strategy above addresses these consequences through different but complementary pathways. For a direct comparison of nature-based and conventional approaches on cost, maintenance, and climate performance, see **Table 3.3**.

Tribal Nations throughout the North Coast hold Traditional Ecological Knowledge (TEK)—knowledge systems developed and passed down through generations of observation and practice that encompass fire regimes, water stewardship, and seasonal resource harvesting, as well as many other dimensions of ecological and cultural knowledge beyond the scope of this report. Co-stewardship approaches developed and led in partnership with Tribal Nations ensure that infrastructure planning works in concert with natural processes and upholds cultural responsibilities to place. Combined with regional coordination that pools resources across jurisdictions and ecosystems, these knowledge systems create frameworks for infrastructure components to "evolve together, not separately from one another" (Technical Advisory Board, 2024; International Institute for Sustainable Development, 2021; Schatz Energy Research Center, 2024).

This chapter examines infrastructure through the lens of community-identified vulnerabilities, evaluates locally appropriate solutions, and outlines pathways for transformation that align with the North Coast's ecological, cultural, and economic realities. It draws on a Community

Advisory Board made up of residents, Tribal members, and local officials; a Technical Advisory Board of engineers, planners, and resource managers; and input from the 2024 North Coast Climate Summit.

3.1.1 Transportation Infrastructure Impacts

LIFELINE VULNERABILITY

The North Coast's transportation network depends primarily on critical arterials—US Hwy 101, State Route (SR) 299, US Hwy 199, SR 20, and SR 29—with no meaningful alternatives when acute disruptions occur. As Logsdon (Lake County) notes, "grocery stores here start to empty within hours" when SR 20 floods near its junction with Interstate 5 at the town of Williams, as happened in 2017 (Kemp, 2017). When winter storms simultaneously trigger landslides on Hwy 101 and SR 299, and flooding on SR 20, the region loses its primary corridors—isolating entire communities and cutting off supply chains for days or weeks.

CHRONIC INFRASTRUCTURE DEGRADATION

Temperature increases both stress pavement and accelerate deterioration, as each degree of warming causes disproportionately more damage (Caltrans, 2021). Across thousands of miles of North Coast roads that are already suffering from decades of deferred maintenance, this accelerated degradation represents significant future costs. Facing massive maintenance backlogs, some counties now explicitly consider accepting a lower level of service for rural roads (Humboldt County, 2017; Implementation Measure C-IM18F1).

ATMOSPHERIC RIVER INTENSIFICATION

Atmospheric rivers—which provide 30–40% of the region's annual precipitation—are projected to increase in intensity by 25–40% by mid-century (Pierce et al., 2023; Chapter 1, **Figure 1.8**). The 2022–23 winter (December–January) sequence demonstrated these challenges: rivers including the Mad, Eel, and Navarro reached flood stage, while Honeydew in Humboldt County recorded 6.16 inches (15.65 cm) in early January 2023 alone. Intense rainfall produced mud and debris flows across hilly terrain, closing roads and isolating communities for extended periods (NOAA California Nevada River Forecast Center, 2023). Recovery from that sequence extended for years; as of early 2026, the US Forest Service was still clearing downed trees and repairing storm-damaged roads in the Shasta-Trinity National Forest, which spans much of Trinity County (US Forest Service, 2026).

Flood-driven stream migration presents additional access challenges for outlying communities. When channels shift during major storm events, they can destroy or undercut roads that provide sole access to rural residents. In Hyampom, Trinity County, the South Fork of the Trinity River consumed the end of Garrett Road—the only access route to four residences and a local animal clinic—after debris buildup from successive catastrophic winters redirected the channel (Trinity Journal, 2025). Restoring access is complicated by permitting requirements and costs that fall on individual landowners when counties decline responsibility; in the Hyampom case, the county declined to sponsor a Natural Resource Conservation Service (NRCS) Emergency Watershed

Protection project that would have covered 75% of restoration costs, leaving residents without recourse (Trinity Journal, 2025). These dynamics create extended isolation for the residents who can least afford the regulatory and financial burden.

Box 3.1: *Historic Watershed Alterations and Current Flood Risk to Infrastructure*

Authors: *Craig Benson and Christine Davis*

Historic logging and development have changed how rivers flow and alter the landscape, leading to severe flooding caused by moderate storms. In the Elk River watershed, decades of logging have deposited 4–6 ft (1.2–1.8 m) of sediment in the river channel, shrinking its storage capacity by 40–60%. This means a storm that should happen every five years now causes flooding equivalent to a 50–100-year event (a storm with a 1–2% chance of occurring in any given year, not one that happens every 50–100 years).

The problem extends beyond sediment. In Jacoby Creek (Humboldt County), so much material has accumulated that the creek bed now sits higher than the surrounding land. When high flows occur, the creek abandons its channel entirely and floods adjacent farms. Historically, these coastal streams spread across multiple channels and floodplains during storms. But past engineering forced them into single, straightened channels with no room to expand during high water. These changes mean the flood infrastructure was designed for rivers that no longer exist. What worked 50 years ago fails today because the underlying hydrology has been altered.

Similar infrastructure challenges occurred during the November 2024 flooding near Cannibal Island Road and the adjacent ranchlands at the mouth of the Eel River (Humboldt County, near Ferndale). The combination of an atmospheric river and high tides pushed the Eel River to 25.3 ft (7.7 m)—well above the 23-foot (7 m) major flood stage—overwhelming infrastructure throughout the delta (Lost Coast Outpost, 2024; Times-Standard, 2024). Fresh and salt water mixed across grazing lands as ranchers worked to evacuate cattle from flooded pastures. Cannibal Island Road was submerged in multiple locations, with forecasters warning of severe flooding along the western portion of the road (City of Ferndale, 2024).

Because saltwater inundation has caused reversion of land from grazable pasture back to historic brackish marsh, two property owners in the tidal zone have decided to sell portions of their land to the California Department of Fish and Wildlife (CDFW). These lands will become part of the Eel River Wildlife Area. This SLR retreat strategy with direct land acquisition by CDFW provides options for private landowners with land that is no longer supporting agricultural use, allowing them to receive fair market value for property while enabling restoration back to habitat-rich brackish marsh habitat. This example demonstrates how some agricultural communities are responding to coastal infrastructure and land use changes.

TREE MORTALITY AND SECONDARY IMPACTS

Chronic stressors like tree mortality create ongoing transportation hazards as temperature and precipitation changes drive insect population epidemics and pathogens that kill weakened trees along roadways. As Terre Logsdon, Lake County's Chief Climate Resilience Officer, explains: "Drought and wildfire leave trees susceptible to infestation years after the initial event. Atmospheric river storms with high winds tend to bring these trees down on houses and roads, endangering lives and properties." Lake County declared a local emergency for pervasive tree mortality in May 2022 (see also Chapter 2; Community Advisory Board, 2024).

COMPOUND DISASTER TRANSFORMATION

As Matt St. John of the North Coast Regional Water Quality Board observes, "atmospheric river rainfall events compounded on catastrophic wildfire events can have devastating impacts to watersheds and aquatic health" (Technical Advisory Board, 2024). Burned landscapes develop hydrophobic (water-repellent) soils that shed rainfall rather than absorbing it, while sediment yields increase 10–100 times normal levels, creating debris flows that behave like liquid concrete.

Traditional engineering often shows significant limitations at this scale in fire-prone watersheds (Furniss et al., 2025; see Chapter 1, **Figure 1.9**). Key knowledge gaps remain around how communities can prevent post-wildfire landslides, and how often the North Coast should expect back-to-back fire and heavy rain events. Similar gaps exist for energy systems: the resilience of distributed microgrids under back-to-back extreme events, the affordability of battery backup for low-income rural households, and regional variation in renewable resource viability across the six-county area remain insufficiently characterized for infrastructure planning purposes (Community Advisory Board, 2024; PSE Healthy Energy, 2021; Schatz Energy Research Center, 2024).

SEA LEVEL RISE AND COASTAL EROSION

Highway 101 through Humboldt Bay and near Crescent City already floods during king tides. With relative SLR of 0.18 in (4.6 mm) per year—double the global average due to tectonic subsidence—and projections of 1.3–1.5 ft (39–45 cm) by 2050, extensive sections of Highway 101 face regular inundation (NOAA, 2022; California Ocean Protection Council, 2024; Chapter 1, **Figure 1.11** and **Table 1.2**). Permanent loss of Highway 101 at Last Chance Grade (Del Norte County) could result in annual losses of $145 million in labor income and $456 million in business sales, affecting nearly 2,700 direct jobs and over 3,800 total jobs; a full closure would force a 320-mile (515 km) detour, adding over six hours of travel time (Caltrans, 2018).

Inland from coastal threats, the Klamath River corridor presents additional vulnerabilities where Hwy 169 and Tribal roads provide the only access to Yurok Reservation communities. Here, the threat comes from riverine flooding that is amplified by rain-on-snow events and debris flows from burned watersheds—impacts that can isolate communities for weeks rather than hours (Curtis et al., 2025).

Box 3.2: *Coastal Drainage Infrastructure Vulnerabilities*

When sea levels rise and storms coincide with high tides, coastal drainage systems stop working—and sometimes work in reverse. Storm drains designed to carry water away from cities and farms become submerged, causing flooding to back up into the very areas they are meant to protect. Around Humboldt Bay, 400 drainage pipes rely on one-way gates that open to release stormwater during low tide but close to keep the ocean out during high tide. As sea levels rise and high tides last longer, these gates stay closed when we need them open, trapping floodwater inland.

The region's sewage treatment plants face similar risks. Built behind earthen levees with minimal safety margins, these facilities weren't designed for projected SLR. Meanwhile, rising groundwater—pushed up by higher sea levels—is making it harder to maintain and repair underground utilities like sewer lines and power cables in low-lying areas. These are not future problems—they are happening now during king tides and will worsen as sea levels continue rising.

—Craig Benson, Department of Environmental Science, Cal Poly Humboldt (personal communication, September 15, 2025).

3.1.2 Energy Infrastructure Impacts

SYSTEM-WIDE VULNERABILITY

The region's electrical system has experienced reliability challenges and now faces climate stressors that may significantly impair network reliability (California Public Utilities Commission, 2024; PG&E, 2023). Both direct effects—physical damage to infrastructure—and subsequent indirect system failures deserve attention.

HEAT-RELATED DEGRADATION

Extreme heat directly degrades electrical infrastructure several ways. Transformers are at risk of accelerated aging when cooling systems that are designed for historically cooler temperatures cannot dissipate heat adequately—each 1.8°F (1°C) increase above design specifications reduces transformer lifetime by approximately 10% (Gao et al., 2017). Chapter 1 projections show inland cities facing summer maximum temperature increases of 5–7°F (2.8–3.9°C) by mid-century, with 20–30 additional days above 100°F (37.8°C) in the hottest areas (**Table 1.1**; **Appendix Figure 1.1.A**).

Distribution infrastructure across the North Coast's challenging terrain is particularly vulnerable. Wooden poles, many of which were installed decades ago and are already past design life, are at risk of accelerated decay as warming temperatures create optimal conditions for fungal growth. PG&E identified approximately 544,000 aging wooden poles at potential risk in a May 2021 safety notification to the California Public Utilities Commission, with more than 200,000 located in high fire-threat areas (PG&E Safety Issue Notification, 2021; CPUC, 2021).

Across the North Coast, energy systems built during the post-World War II resource extraction boom have aged without major upgrades for decades. Humboldt County's power infrastructure, constructed primarily between 1946–1966 to serve the timber industry, illustrates this regional pattern—investment has focused on maintaining rather than expanding the aging system since industrial decline began in the mid-1960s. The California Independent System Operator's 2024 approval of transmission infrastructure for offshore wind development could provide Humboldt County's first major upgrade in 60 years, offering the redundant capacity and reliability improvements needed to withstand climate impacts (Jacobson, 2025). Similar catalytic infrastructure investment remains scarce elsewhere across the region.

WILDFIRE RISK AND PROTECTIVE SHUTOFFS

Utilities maintain vegetation clearance requirements around power lines to prevent ignitions, while also addressing equipment failures that have caused many of California's deadliest wildfires—including the Camp Fire, which CAL FIRE investigators determined was caused by a failed C-hook on a PG&E transmission tower (CAL FIRE, 2019). When utilities cannot maintain adequate clearances across hundreds of miles of forested terrain, they implement Public Safety Power Shutoffs (PSPS)—planned, announced outages during high fire-risk weather—and Enhanced Powerline Safety Settings (EPSS), which automatically cut power when the system detects contact with a line, including falling trees or branches, without advance notice.

Lake County illustrates how tree mortality multiplies the triggers for these shutoffs: drought, Sudden Oak Death, and other stressors are killing tens of thousands of trees, virtually ensuring that falling branches will cause increasingly frequent EPSS activations (Community Advisory Board, 2024). Additionally, mid-century fire projections indicate significant increases in burn area likelihood across interior portions of the region (Chapter 1, **Figure 1.9**), suggesting PSPS frequency will continue to rise. While these shutoffs prevent fires, they leave rural communities without power for essential services—effectively trading one vulnerability for another.

RURAL INFRASTRUCTURE DISPARITIES

The October 2019 PSPS events exposed stark disparities in urban and rural infrastructure resilience. When PG&E cut power to prevent wildfire ignitions, approximately 2.5–3 million Californians lost electricity. Urban areas experienced inconvenience with power largely restored within 48 hours whereas rural communities endured outages extending up to two weeks, causing a complete loss of water pumping for wells and wastewater systems, failed communications including 911 access, and cascading failures that forced some businesses to close permanently (CPUC, 2020; PSE Healthy Energy, 2021).

The 2022–23 atmospheric rivers repeated this pattern: customers lost power while cellular networks failed and backup batteries died, despite state requirements for 72-hour reserves (CPUC, 2020; Cal OES, 2023). The Hoopa 1101 circuit, serving Tribal communities targeted by the Tribal Energy Resilience and Sovereignty (TERAS) microgrid project, currently averages 13 hours per outage compared to PG&E's typical 4–6-hour restoration times—extended periods that disable water pumping, medication refrigeration, and communication systems (Rural County Representatives of California, 2022).

Cascading failures can create life-threatening conditions for residents that are dependent on powered medical equipment, refrigerated medications, and electronic benefit systems. For residents dependent on electrically powered medical equipment—oxygen concentrators, insulin refrigeration, powered wheelchairs—these 13-hour outages create life-threatening gaps that no manual workaround can bridge (PSE Healthy Energy, 2021). Without backup power, these households face a double bind: keep the grid energized and risk catastrophic wildfire or shut it down through PSPS and disable the equipment they depend on to survive.

Resolving this double bind would need a change in how utilities classify infrastructure. Utilities pay for power lines and substations by spreading the cost across all ratepayers—because those are classified as essential infrastructure that everyone depends on. Microgrids are currently classified as backup supplements, which means they do not qualify for that shared financing. The full capital cost falls instead on the rural and Tribal communities that rely on them, communities that typically have the least access to conventional financing (NARUC/NASEO, 2021).

3.1.3 Water Infrastructure Impacts

SMALL SYSTEM VULNERABILITIES

In the North Coast region, small water systems (serving fewer than 3,000 connections) face particular vulnerabilities that larger systems might withstand. These systems reflect historical development patterns where communities formed around reliable springs, shallow wells, or creek diversions. Such sources served adequately for generations but now face unprecedented stress as drought frequency increases and evaporative demand rises (Chapter 1, **Figure 1.7**). Many operate with zero redundancy, so single-source failure equals system failure, according to Senate Bill 552's drought vulnerability assessments (SB 552, 2021; California Department of Water Resources, 2024). Monitoring gaps and inconsistent water-use reporting obscure the full extent of source decline across the region.

TEMPERATURE-DRIVEN WATER QUALITY CHALLENGES

In Lake County's Clear Lake—California's largest natural freshwater lake—rising temperatures fuel toxic algae blooms that conventional treatment cannot manage. Climate projections show Lakeport's mean annual temperature increasing 4.1°F (2.3°C) by mid-century, with summer maximums rising 4.8°F (2.7°C) (Chapter 1, **Table 1.1**), conditions likely to extend and intensify algae seasons. In September 2021, microcystin at Clearlake beach reached dangerous levels, with toxins detected in 22 of 31 homes drawing water directly from the lake (Solomon et al., 2022). In response to these conditions, the Big Valley Band of Pomo Indians leads monitoring efforts, collecting samples at more than 20 sites across the lake throughout the bloom season (Big Valley Band of Pomo Indians, n.d.). As warming trends intensify, this work will likely need to continue and expand, though monitoring alone cannot resolve the underlying water quality challenges.

POST-FIRE CONTAMINATION PERSISTENCE

Post-fire impacts to water infrastructure extend far beyond the burn period, creating water quality problems that can last decades. Fires alter water chemistry long after flames are extinguished, releasing heavy metals from soils and creating compounds that standard treatment plants cannot remove. Post-fire flows can contain 60% sediment by volume compared to normal flows of 5–10%, significantly changing infrastructure design requirements (Wilder, 2020; Furniss et al., 2025). These contaminated waters present system operators with difficult tradeoffs: use more chlorine and risk cancer-causing byproducts or reduce treatment and risk bacterial contamination (Writer et al., 2014).

The Klamath Basin shows a different trajectory. For decades, the reservoirs behind the lower Klamath dams produced chronic warm-season algae blooms, with microcystin concentrations that routinely exceeded public health thresholds and triggered recurring contact advisories on the mainstem (Klamath Basin Monitoring Program, 2024). Removal of the four lower dams, completed in 2024, generated a temporary and actively managed pulse of sediment and turbidity during reservoir drawdown (USGS, 2024; NOAA, 2024). Tribal monitoring since removal indicates marked improvement in water quality, including lower concentrations of algae toxins, heavy metals, nutrients, and suspended sediment, alongside a return toward a more natural temperature regime (Yurok Tribe Environmental Department, 2026). These are early results. Full ecosystem recovery is expected to unfold over years and unevenly, and because fall Chinook return on a roughly three-year cycle, assessing the effect on salmon populations will require sustained monitoring across multiple return cycles (Yurok Tribe Environmental Department, 2026).

SALTWATER INTRUSION

Coastal communities face saltwater intrusion into freshwater aquifers as groundwater pumping lowers inland water tables and sea levels rise—at rates of 3.1 in/decade (7.8 mm/yr) at North Spit and 1.4 in/decade (3.6 mm/yr) at Arena Cove (Chapter 1, **Figure 1.11; Table 1.2**). Unlike surface water contamination that improves when sources clean up, saltwater intrusion essentially creates permanent damage. Fort Bragg's water system includes three surface water sources with 10.5 million gallons of storage capacity, yet the City has operated a desalination plant since fall 2021 to treat brackish water during periods of low flows and high tides (WaterWorld, 2021). A Cascadia Subduction Zone earthquake would devastate water supplies through rapid coastal subsidence,

causing permanent saltwater intrusion affecting communities around Humboldt Bay (Eureka, Arcata, and surrounding areas; Dura et al., 2025; Chapters 1, 2, and 4).

3.1.4 Buildings and Built Environment Impacts

HEAT VULNERABILITY IN OLDER BUILDINGS

Most North Coast buildings reflect construction practices from earlier eras, leaving them ill-equipped for projected climate extremes. Most coastal structures were built without air conditioning, relying on predictable marine fog for cooling. As fog decreases and heat waves intensify, residents in these buildings—particularly those in mobile homes and older structures without adequate insulation—face increasing risks of heat stroke, cardiovascular stress, and respiratory complications. Only 38% of California's homes built before 1975 have air conditioning compared to the 59% statewide average, with coastal counties showing even lower rates (California Energy Commission, 2021; US Energy Information Administration, 2020).

Climate projections amplify these vulnerabilities: Lakeport and Ukiah face summer maximum temperature increases of 4.8°F (2.7°C) and 5.0°F (2.8°C), respectively, by mid-century (Chapter 1, **Table 1.1**). Lake County faces particular challenges: "51% of homes were constructed before 1973 and many of those are mobile homes or summer resort cabins that were never intended for year-round use and lack adequate, or any, insulation, exposing vulnerable populations to extreme heat and cold weather events" (Community Advisory Board, 2024). Older structures typically require substantial upgrades to electrical systems, ductwork, and structural components—retrofits whose costs fall disproportionately on those least able to afford them. Without systematic adaptation of the building stock, rising temperatures will increasingly stress both residents and the energy grid (Samuelson et al., 2020).

BUILDING FOUNDATIONS

Building foundations throughout the region face unprecedented stresses from changing moisture regimes. Along the coast, rising groundwater tables linked to SLR saturate soils that lose their bearing capacity, causing foundations to settle unevenly. In the Humboldt Bay area, some buildings already show structural distress despite being blocks from the Bay, with over 3 ft (0.9 m) of SLR expected to push groundwater to the surface ~160–425 ft (~50–130 m) from the shoreline (Befus et al., 2020; Chapter 1, **Figure 1.11**). Interior valleys face the opposite problem: drought causes expansive clay soils to shrink and crack, then swell when rains return, creating repeated cycles that stress foundations beyond their design limits (Olive et al., 1989).

WILDFIRE RISK TO BUILDINGS

As the wildland–urban interface expands and fire activity intensifies, building vulnerability has grown. Many North Coast communities were developed during eras when wildfire was seen as manageable, with buildings featuring wood siding, composition roofs that trap embers, and vegetation touching structures. Comprehensive wildfire retrofits can prevent total loss but require investment that many residents cannot afford (California Residential Mitigation Program, 2024). The insurance market compounds these vulnerabilities—the California Fare Access to Insurance

Requirements (FAIR) Plan's exposure grew from $112.75 billion to $724 billion between 2019 and December 2025 (California Assembly Insurance Committee, 2026). Whether insurers recognize fire-resistant retrofits or nature-based approaches as risk-reduction measures warranting premium reductions remains unresolved—a gap that weakens the economic case for both. Private insurers are also increasingly using proprietary flood risk models that identify high-risk properties beyond mapped flood zones designated by the Federal Emergency Management Agency (FEMA)—meaning property owners in riverine and coastal areas who have never been required to carry flood insurance may now face coverage loss or sharp premium increases, compounding the wildfire-driven insurance pressures documented above (Insurance Journal, 2024; Moody's RMS, 2025; see *Economic Consequences* in the next section).

Further, the North Coast has limited access to fire-resistant construction capacity compared to other parts of California. Contractors trained in fire-hardening techniques are scarce, as market forces concentrate experienced builders in higher-value communities. Local contractors in rural and far-north communities often lack familiarity with fire risk, and fire-resistant materials are specialty products that can be difficult to source in the right specifications (Christopher, 2025). The state's California Wildfire Mitigation Program has piloted in Lake, Shasta, and Siskiyou counties but has not yet reached Humboldt, Del Norte, Trinity, or most of Mendocino (Cal OES, 2025), leaving much of the North Coast without program infrastructure to support retrofit demand. Rural homeowners seeking to retrofit with fire-resistant siding, ember-resistant vents, or Class A roofing face limited contractor availability, higher material costs, and longer wait times—a workforce gap that compounds the insurance crisis. Chapter 4 addresses the workforce development pathways needed to expand fire-resistant construction capacity across the region.

Along the Klamath River, homes on the Yurok Reservation sit within the wildland–urban interface on steep, heavily vegetated terrain that limits defensible space options (Humboldt County Fire Safe Council, 2019). Where topographic constraints make standard setbacks infeasible, retrofit of the structures themselves becomes the primary risk-reduction strategy, and often an unaffordable one.

3.1.5 Cross-Cutting Impacts: Public Health and Emergency Response Failures

The infrastructure failures documented in this chapter propagate through interconnected systems, creating compounding impacts that exceed the sum of individual failures. **Table 3.2** maps these failure pathways across power, water, transportation, and emergency services.

Table 3.2 *How one infrastructure failure triggers system-wide consequences across power, water, transportation, and emergency services.*

Triggering Failure	Secondary Impact	System-Wide Consequence
Power outage	Water pump failure	Loss of drinking water and fire suppression capacity
Power outage	Medical equipment shutdown	Life-threatening gaps for medically vulnerable residents
Road blockage	Fuel delivery disruption	Backup generators fail, extending outage duration
Wildfire threat	PSPS activation	Water systems needed for firefighting go offline
Communication failure	Loss of 911 access	Emergency dispatch and coordination breaks down

HEALTH CONSEQUENCES

Infrastructure failure does not harm everyone equally. The resulting illness, injury, and premature death concentrate among older adults, children, people with chronic illness, and low-income households, through pathways shaped by both physiological sensitivity and unequal capacity to avoid or recover from harm. Wildfire smoke is the clearest case as it drives respiratory distress and cardiovascular events. A California study found a 10.3% increase in asthma-related hospital visits on high-smoke days, with the largest asthma effect among children under five and the cardiovascular burden concentrated in adults 65 and older (Heaney et al., 2022), and a Northern California study found smoke-related pediatric asthma risk was higher in communities already facing socioeconomic and environmental disadvantages (Sugrue et al., 2026). A statewide analysis attributed more than 50,000 premature deaths to wildfire PM2.5 between 2008–2018 (Connolly et al., 2024). Aside from wildfire smoke, post-fire water contamination can persist for decades (Writer et al., 2014; Furniss et al., 2025). Heat tracks the building stock: residents without home cooling face elevated heat-related health risks during extended heat events (Ostro et al., 2010). Communities experiencing repeated fires, floods, and evacuations document higher rates of Post-Traumatic Stress Disorder (PTSD), depression, and anxiety, with effects compounding across successive disasters (To et al., 2021).

Acute infrastructure failures intensify these health risks. The 2022–23 winter (December–January) atmospheric river sequence cut off North Coast communities for extended periods, with widespread power outages, road closures, and mandatory evacuations as the Mad, Eel, and Navarro rivers reached flood stage (NOAA California Nevada River Forecast Center, 2023). For people managing chronic illness, depending on refrigerated medication, or relying on powered medical equipment, that kind of simultaneous failure is a direct health threat. With extreme precipitation and other extreme events projected to increase in both frequency and intensity across the region by end-century (Chapter 1, **Figure 1.8**), the health burden of cascading failures is likely to grow.

ECONOMIC CONSEQUENCES

Simultaneous system failures prevent businesses from operating and impose high backup power costs on healthcare facilities. As private insurers have withdrawn from high-risk areas, property owners have been forced onto California's FAIR Plan, the state's insurer of last resort, which covers fire but not the comprehensive risks that conventional policies provide. Policies in force on the California FAIR Plan increased 139% between September 2021–March 2025 (California FAIR Plan, 2025), reflecting the scale of coverage loss across the region.

This trend may accelerate as private insurers bypass FEMA's outdated flood maps in favor of proprietary risk models that are capable of flagging North Coast properties as high-risk, even in communities never formally mapped for flood hazard (Insurance Journal, 2024; Moody's RMS, 2025). The consequences extend beyond insurance markets: without adequate coverage, businesses cannot secure reconstruction financing, properties lose marketability, and economic decline further erodes the municipal tax base needed for infrastructure investment.

These dynamics play out with particular force in communities where geography concentrates vulnerability. Highway 96 through Yurok territory functions as a single point of failure: road

closures prevent diesel fuel delivery to backup generators, disabling water systems and blocking medical evacuations—a pattern demonstrated during the 2023 atmospheric rivers that triggered FEMA disaster declaration DR-4683-CA (FEMA, 2023). The corridor's Hoopa 1101 electrical circuit experiences "some of the most frequent and longest duration outages in California," compounding vulnerabilities when storms simultaneously close roads and cut power (Cal Poly Humboldt, 2024).

Dunsmuir (Siskiyou County), with a population size of 1,700 (US Census Bureau, 2020), illustrates how these pressures compound over time. There, service degradation has coincided with declining property values and outmigration, narrowing the tax base that the town depends on for maintenance and recovery investment (Community Advisory Board, 2024). The community's adaptive capacity proved equally vulnerable to funding discontinuity: when the Resiliency Specialist position was eliminated following the loss of a subsequent state climate adaptation grant, the community lost not only financial resources but programmatic momentum, including funding for the childcare and food assistance that allow low-income and caregiving residents to participate in outreach events, costs that standard planning grants typically do not cover (Community Advisory Board, 2024).

EXTREME SCENARIO

The most severe cascade scenario involves a Cascadia Subduction Zone earthquake—simultaneous failure of every system with no warning interval. A magnitude 8.0+ event would rupture water mains, topple power lines, sever communications, and could trigger tsunamis within minutes. With an estimated 10–14% probability of occurrence in the next 50 years (based on average recurrence intervals of approximately 500 years and a last event in 1700), this hazard warrants serious planning attention (Goldfinger et al., 2012; Frankel et al., 2002).

TOWARD MORE FLEXIBLE SYSTEMS

Cascading failures share a common characteristic: rigid systems designed for historical conditions tend to fail when climate impacts push them beyond design thresholds. This points toward infrastructure strategies that build in flexibility and redundancy, design for higher tolerances, and incorporate nature-based approaches, including practices developed through generations of land stewardship in this region.



Figure 3.1: *Arcata Marsh treatment ponds and wetlands—processing wastewater naturally while supporting 300+ bird species and public trails. Source: Appropedia, Creative Commons*

3.2 Built Systems Adaptation Strategies

Across the region, communities are developing adaptation strategies that show early promise. Drawing on partner and community input and document review, this section focuses on four adaptation strategies that recur across the region: working with natural systems that provide infrastructure services through ecological processes; building distributed networks that eliminate single points of failure; applying adaptive management that matches infrastructure decisions to changing conditions; and developing integrated solutions that multiply benefits across sectors.

3.2.1 Strategy 1. Working with Natural Systems: Infrastructure as an Ecosystem

Natural systems approaches are gaining institutional recognition across the North Coast, with some emerging from contemporary environmental engineering and others drawing from practices Tribes have maintained continuously. Regional Tribal Nations bring complete knowledge systems to infrastructure planning—understandings of ecological processes increasingly recognized and uplifted alongside western engineering in regional infrastructure decisions.

WATER TREATMENT THROUGH WETLANDS

The Arcata Marsh and Wildlife Sanctuary has operated for four decades, applying natural systems principles to wastewater treatment. This 307-acre system processes 2.3 million gallons daily for 18,000 residents through a series of oxidation ponds and constructed wetlands. The facility operates with few mechanical systems, requires minimal maintenance, and continues functioning during power outages that would disable conventional plants. Beyond treating wastewater, the marsh supports over 300 bird species (**Figure 3.1**) and sequesters carbon—benefits no conventional treatment plant could provide (EcoTipping Points Project, n.d.; City of Arcata, 2023; Wolff, 2024).

BIOENGINEERED SLOPE STABILIZATION

Several North Coast road projects have used bioengineered stabilization, deep-rooted native vegetation that anchor slopes and reduce erosion-driven road failure, at roughly half the cost of conventional approaches; an additional benefit is that root networks continue to mature and strengthen over time (International Institute for Sustainable Development, 2021). The California Department of Transportation (Caltrans)'s Hwy 299 installations survived sustained atmospheric rivers while achieving near-complete vegetation coverage, indicating that nature-based solutions can withstand extreme weather through different mechanisms than conventional infrastructure (California Department of Transportation, 2003).

CULTURAL BURNING AND LANDSCAPE MANAGEMENT

The Karuk Tribe's cultural burning, practiced for generations before federal and state fire policy restricted its use in the 20th century, creates fire-resilient landscapes at scales needed to protect transportation infrastructure corridors, particularly in interior areas projected to experience the greatest increases in burn area by mid-century (Lake et al., 2021; **Appendix Case Study 2.1.C**; Chapter 1, **Figure 1.9**). California Senate Bill 310 (SB 310, 2024) removes state barriers to cultural burning on ancestral lands, acknowledging its key role in landscape management (California Wildfire & Forest Resilience Task Force, 2024).

ROAD AND WATERSHED MANAGEMENT

Strategic road and watershed management addresses a parallel threat from storm damage. The Six Rivers National Forest (Del Norte, Humboldt, Trinity, and Siskiyou counties) has decommissioned 462 miles (743 km) of roads and storm-proofed 197 miles (317 km) since the 1990s (US Forest Service, n.d.). Road decommissioning restores natural drainage patterns and prevents stream diversions when culverts fail during large storm events; storm-proofing complements this by upgrading culvert sizes on retained roads to reduce the likelihood of failure in the first place. Together, these efforts maintain transportation network integrity and improve watershed water quality.

LIVING SHORELINES

Along the coast, rising seas are prompting a shift in shoreline management strategies. Rather than relying on engineered barriers that require ongoing maintenance and replacement, practitioners are restoring salt marshes as living shorelines capable of attenuating wave energy while providing habitat (Times-Standard, 2022). Salt marshes grow vertically with rising seas through sediment capture and organic accumulation, providing protection that increases in effectiveness as vegetation establishes (Kirwan et al., 2016; Morris et al., 2002).

The Humboldt Bay spartina removal project illustrates this approach. By eliminating invasive cordgrass that had degraded habitat quality and altered sediment dynamics, the project enhanced the marsh's wave attenuation capacity, increased carbon sequestration, and improved wildlife habitat (City of Arcata, 2023).

NATURAL SURFACE DRAINAGE

Natural surface drainage works with topography rather than against it, moving water across roads before it accumulates erosive force. Rolling dips—gentle undulations that direct water laterally off-road surfaces—cost 50% less than culvert systems while eliminating the debris clogging that causes most road failures. Unlike culverts that plug during intense storms, rolling dips redirect surface water at the point of contact, a particularly effective method in a region with over 40 inches (1,000 mm) of annual rainfall (Furniss et al., 2025).

PASSIVE BUILDING DESIGN

Passive building design harnesses solar, wind, and water resources to cool, heat, and light buildings with fewer mechanical systems and less external energy input. Cal Poly Humboldt's Behavioral and Social Sciences Building, the first LEED (Leadership in Energy and Environmental Design) Gold building in the California State University (CSU) system (2007), uses rainwater catchment for toilets, increased natural lighting, and smart controls (Cal Poly Humboldt, n.d.). The Anderson Valley Health Center in Mendocino County achieved LEED Gold (2009) through maximizing natural daylighting and strategic solar orientation (Anderson Valley Health Center, n.d.).

The examples above operate primarily at agency or community scale, but nature-based approaches are also available to private landowners managing forests, rangelands, and farms. Gully stuffing—filling eroding channels with woody debris and slash to slow water and rebuild soil—is a low-cost technique practiced by timber and cannabis landowners across Humboldt and Trinity counties to reduce sediment delivery to streams and stabilize access roads. Ranchers in the Eel River delta and elsewhere have used riparian fencing, off-stream water sources, and vegetation buffers to reduce bank erosion while maintaining grazing operations (Technical Advisory Board, 2024). These private-landowner-scale practices do not typically appear in program databases the way agency projects do, but they represent a significant and largely undocumented component of the region's nature-based infrastructure portfolio.

As documented throughout the North Coast's implementation experience, nature-based solutions tend to have lower costs and improved performance characteristics than conventional engineering, while delivering co-benefits that engineered systems cannot match (**Table 3.3**).

Table 3.3 *Comparing Nature-Based and Conventional Infrastructure: North Coast Implementation Examples.*

Solution Type	Relative Cost	Maintenance	Climate Performance	Co-Benefits
Conventional Wastewater	Higher	High/ongoing	Fails without power	None
Arcata Marsh System	~50% less	Minimal	Works without power	Recreation, habitat, carbon storage
Concrete Slope	Standard	Degrades over time	Vulnerable to extremes	None
Bioengineered Slope	Lower	Self-maintaining	Grows stronger	Habitat, water filtration
Culvert System	Standard	Frequent clogging	High failure rate	Single function
Rolling Dips	~50% less	Minimal	Self-maintaining	Watershed benefits

Note: Cost comparisons are illustrative based on a small number of North Coast projects; site-specific conditions will produce different results. Sources: Arcata Marsh (2006–2023 operations), Highway 299 bioengineering project (2003), and McKinleyville CSD wetland (2004).

3.2.2 Strategy 2. Distributed Networks: Eliminating Single Points of Failure

Geographic and economic constraints make traditional infrastructure redundancy impractical in rural communities; the North Coast realistically cannot build parallel highways or duplicate treatment plants. Without backup, the failure of a single component can cut off an entire community. To strengthen resilience, communities are instead creating distributed systems: multiple components that function independently, so the failure of any one component degrades rather than disables the system.

TRANSPORTATION NETWORKS

Transportation resilience depends in part on network redundancy. Mendocino County's two major evacuation projects demonstrate this approach: the Brooktrails Second Access Route at $12 million and Redemeyer Road Extension at $52 million create alternative routes serving daily needs while providing life-saving redundancy during emergencies (Caltrans, 2025; Mendocino County, 2025). The Great Redwood Trail (under construction) will transform 307 miles (494 km) of abandoned railroad into a multi-use corridor while also providing evacuation alternatives (Great Redwood Trail Agency, 2024).

ENERGY SYSTEMS

Distributed energy infrastructure has emerged across varying scales in response to chronic grid failures that have left communities without power for days or weeks. At the residential level, efficient designs and upgrades and technologies like rooftop solar with battery backup reduce household vulnerability to outages while lowering energy costs—a foundation that community-scale systems can build on.

At the community and Tribal scale, microgrids combine solar, battery storage, and backup generation to maintain power independently during outages. Blue Lake Rancheria's microgrid, operational since 2017, demonstrates what this model can achieve. During the December 2022 earthquake, when transmission lines fell and substations failed, the system kept the Tribe operational as an "island of electrical activity" and designated Red Cross emergency evacuation site, opening facilities for medical device charging when the larger grid failed for days, with reports of life-saving interventions (Microgrid Knowledge, 2024; California Energy Commission, 2019). A similar microgrid was installed at the Redwood Coast Airport in 2022.

Across the region, counties have matched renewable energy technologies to local conditions. Trinity County balances low-cost hydroelectric power with resilience needs through Hoopa Valley Tribe's solar and battery installation at their Community Center (Solar Power World, 2017). Lake and Mendocino counties address wildfire-driven shutoffs through battery storage deployed via Self-Generation Incentive Program (SGIP) incentives and California's first iron-air battery installation, respectively (Lake County, 2024a; California Energy Commission, 2023). Del Norte County overcomes geographic isolation with Crescent City Harbor's 576 kW solar installation, while Siskiyou County prioritizes elder safety through Karuk Tribe solar installations at their casino and elder homes (Wild Rivers Outpost, 2021; Schatz Energy Research Center, 2024).

The most ambitious regional effort was the Tribal Energy Resilience and Sovereignty (TERAS) initiative, designed to create three nested microgrids along the 142-mile Hoopa 1101 circuit, serving Hoopa Valley, Yurok, and Karuk Tribes with locally owned renewable energy capable of operating independently during outages. A $87.6 million conditional federal award was announced in January 2025; the DOE GRIP grant for TERAS was cancelled in October 2025; the microgrid projects are moving forward with state and utility funding, with prospective federal support through tax credits and potential DOE programs (Schatz Energy Research Center, 2024; US Department of Energy, 2024; Lost Coast Outpost, 2025).

These distributed energy systems perform best when sized to local load and outage patterns rather than to standardized design templates, which is what grant and procurement structures typically favor. The Scotts Valley Band of Pomo Indians' bioenergy system, which converts local woody biomass into power at neighborhood scale, illustrates the point: appropriately sized infrastructure can work where a larger facility would not, because the economics of hauling biomass to a utility-scale plant rarely pencil out in rural areas. Yet the same funding and procurement structures continue to push developers toward scale. As one community advisor put it, "big ideas are hard to fit into small, rural communities" (Community Advisory Board, 2024). These institutional pressures are taken up in *Section 3.3 Key Considerations for Policy* below.

The small system vulnerabilities described earlier—single-source dependence, aging creek and spring diversions, and limited operator capacity—have driven a regional shift toward strategic partnerships that maintain local infrastructure while pooling expertise. One reason for this shift toward partnering is fiscal: California's Proposition 218 limits what water utilities can charge customers, and rates must reflect current, documented costs of service rather than anticipated future needs, which makes it difficult for agencies to set money aside for climate adaptation work without risking a legal challenge. The January 2025 merger creating Ukiah Valley Water Authority illustrates the practical consequence: the Redwood Valley and Ukiah systems retain separate treatment plants and distribution networks for backup capacity, while sharing operational

expertise and management costs to access Safe and Affordable Funding for Equity and Resilience (SAFER) program funding that neither could secure alone, precisely because neither had the upfront capital that reimbursement-based programs require (MendoFever, 2025).

Similarly, the Round Valley Indian Tribes' Tribal Council serves as the Utility Board for four interconnected Public Water Systems, balancing local control with shared technical capacity (Round Valley Indian Tribes, n.d.). Regional support programs like Rural Community Assistance Corporation's circuit rider model complement these partnerships by rotating certified operators between small systems to ensure compliance with the Safe Drinking Water Act at lower costs than individual operators (RCAC, 2024).

3.2.3 Strategy 3. Adaptive Management: Right-Sizing Infrastructure for New Realities

A third strategy involves accepting that not all infrastructure can be maintained at historical standards. Rather than exhausting resources on perpetual repairs, communities are making strategic decisions about what to preserve, what to modify, and what to abandon.

TRANSPORTATION INFRASTRUCTURE

The Last Chance Grade tunnel represents one adaptive approach: choosing a permanent solution over repeated fixes. The site's active landslide has required over $100 million in repairs since 1997. With maximum daily precipitation projected to increase 20–40% by end-century (see Chapter 1, **Figure 1.8**), the slope conditions driving that instability are expected to worsen, making continued incremental repair increasingly untenable. Caltrans determined that routing a 6,000-foot (1.8 km) tunnel through stable bedrock, at $2.1 billion upfront, provides a better long-term outcome than endless stabilization of a corridor already at its limits. Once complete, it will be California's longest tunnel, and it will permanently reroute US-101, the only continuous highway along the North Coast, away from the active landslide zone (Last Chance Grade Project, 2024; Caltrans, 2024).

Where major capital investment is not feasible, counties are recalibrating maintenance standards to match climate realities rather than engineering against them. These decisions reflect an approach that might be termed "pragmatic adaptation"—the recognition that maintaining year-round access to every road at every standard is neither fiscally sustainable nor climatically realistic in a region where seasonal conditions increasingly define what infrastructure can bear. For example, Mendocino County implements seasonal closures on Fort Bragg/Sherwood Road (22 miles/35 km) and Usal Road during winter months rather than attempting year-round maintenance of storm-damaged surfaces (Mendocino County Department of Transportation, 2025). Humboldt County has explicitly considered "accepting a lower level of service" for rural roads (Humboldt County, 2017; Implementation Measure C-IM18F1), while Trinity County established processed gravel as an acceptable standard for low-density areas (Trinity County Department of Transportation, 2024).

WATER SYSTEMS

Fort Bragg's (Mendocino County) approach to water security illustrates adaptive management: accepting ocean water as a permanent supply source rather than a temporary emergency

measure. The city's emergency desalination plant, operational since September 2021, provides 144,000 gallons (545,000 liters) per day of backup capacity for treating brackish Noyo River water—a $691,796 system fully funded by the State Water Resources Control Board (WaterWorld, 2021). Rather than treating this as temporary, Fort Bragg expanded its commitment with a $1.49 million wave-powered desalination pilot in 2023, testing renewable ocean-based water production independent of grid power (Mendocino Voice, 2025).

The Klamath River dam removal (Siskiyou County) demonstrates infrastructure retirement as climate adaptation. Four aging dams had blocked fish migration and degraded water quality for over a century, damaging salmon runs central to the cultures, diets, and economies of the Klamath Basin Tribes. Decades of Tribal-led advocacy, litigation, and a negotiated settlement among Tribes, states, the dams' owner, and federal agencies reshaped the relicensing path, adding fish-passage and water-quality requirements that made retrofitting the aging dams costlier than removal; the owner pursued removal on that basis (Federal Energy Regulatory Commission, 2022). Removal addressed the underlying barrier rather than engineering around it, beginning to restore the salmon runs that anchor Klamath Basin Tribes' food systems and cultural practices while eliminating the dams' recurring compliance and maintenance obligations. Early post-removal monitoring indicates the retirement is performing as intended, with water quality and fish passage improving rather than requiring the indefinite intervention the dams demanded (Yurok Tribe Environmental Department, 2026).

COMMUNITY-SCALE ADAPTIVE MANAGEMENT

Lake County's tree mortality emergency declaration in May 2022 illustrates community-wide adaptive management at scale. After extreme drought, groundwater depletion, and multi-species bark beetle infestation drove county-wide tree mortality from an estimated 3,000 dead trees in 2019 to nearly 590,000 by 2022, the Board of Supervisors proclaimed a local emergency (reissued in 2023) and shifted from attempting full removal to prioritizing removal of hazard trees near roadways and evacuation routes (Lake County Board of Supervisors, 2022; Lake County News, 2022).

Some communities face similar decisions about service levels: rather than rebuilding to previous scales, they reduce service areas, consolidate resources, and plan for smaller populations. Adaptive management is sometimes the right answer. But planning frameworks that ask who should receive new investment tend to give less attention to who will absorb the cost when service levels fall, a gap documented in climate adaptation planning research more broadly (Shi et al., 2016). On the North Coast, the answer to that question tends to follow patterns of existing disadvantage.

3.2.4 Strategy 4. Integrated Multi-Benefit Solutions

North Coast communities have learned to design infrastructure that serves multiple functions simultaneously, accessing multiple funding streams and serving diverse constituencies from a single investment.

COMMUNITY-SCALE INTEGRATION

McKinleyville Community Services District's (Humboldt County) wetland system demonstrates integrated infrastructure benefits. Built in 2004 to meet water quality regulations, the 8-acre constructed wetland treats stormwater from central McKinleyville before it reaches the Mad River Estuary, while also providing walking trails for recreation, flood control during storms, groundwater recharge, and habitat creation, extending a regional pattern of multi-benefit water infrastructure demonstrated earlier at the Arcata Marsh (McKinleyville CSD, 2004).

REGIONAL-SCALE INTEGRATION

The Klamath River dam removal illustrates how aligning multiple constituencies behind a single outcome can make a large project financeable. The roughly $450 million removal was funded not by one source but by two: a PacifiCorp customer surcharge across Oregon and California, about $184 million from Oregon customers and $16 million from California customers, and $250 million appropriated from California's Proposition 1 water bond (Congressional Research Service, 2024). Neither funder acted alone; both were unlocked by a decade-long settlement among Tribes, the states of California and Oregon, the dam owner, irrigators, and conservation and fishing groups, a coalition assembled around shared interests in fisheries recovery, water quality, Tribal cultural restoration, and river function. The project was financeable in large part because that settlement aligned constituencies that no single funding mechanism, and no single party, could have served on its own.

MULTI-BENEFIT INTEGRATION AND FUNDING

Achieving integrated infrastructure benefits requires coordinating multiple funding sources—each with different application processes, reporting schedules, and compliance standards that can overwhelm rural communities. The North Coast Resource Partnership emerged specifically to address this challenge, pooling technical expertise across seven counties and Tribal governments. Operating through consensus-based decision-making drawn from Tribal governance traditions, the partnership ensures smaller communities have equal voice with larger counties. Since 2004, this shared capacity has invested over $120 million while leveraging over $160 million in matching funds, with 85% of projects benefiting disadvantaged communities (North Coast Resource Partnership, 2024).

North Coast Resource Partnership (NCRP)'s technical assistance investments of approximately $350,000 have leveraged an estimated $50 million in funded projects, demonstrating how shared regional capacity multiplies returns on coordination investment (North Coast Resource Partnership, 2024). By sharing grant writing, fiscal management, and compliance costs, jurisdictions transform projects from administrative hardships to more achievable initiatives. The NCRP's 20-year record shows what regional coordination can accomplish. However, NCRP is a voluntary partnership with no formal legal authority, no dedicated funding stream, and no binding power over its members. As the need for regional coordination grows, the state could consider whether this kind of voluntary model needs a stronger institutional foundation to provide services at the scale needed.

The structure of adaptation funding, not just its quantity, determines who can use it. North Coast funding comes mainly from competitive federal programs (FEMA, US EPA), state programs (California Climate Investments, SAFER, Strategic Growth Council), and occasional philanthropy. Reliance on competitive federal awards is itself a vulnerability, as the 2025 termination of the conditionally awarded DOE GRIP grant for the regional TERAS microgrid project illustrates (Lost Coast Outpost, 2025). For small and Tribal communities, the barriers are structural: local match requirements that fall hardest on places with small tax bases (Headwaters Economics, 2023), limited staff capacity to navigate competitive applications, and requirements to cover costs upfront before reimbursement (US Government Accountability Office, 2024). Delivery mechanisms that route advance payments or block grants through regional coordinators like NCRP ease these barriers; smaller grants that are more accessible for individual landowners and community groups would extend adaptation funding to communities too small to compete for large federal awards.

SYNTHESIS

The four adaptation strategies—working with natural systems, distributed networks, adaptive management, and integrated multi-benefit solutions—reinforce each other in practice: nature-based solutions reduce maintenance costs, freeing resources for distributed systems; adaptive management releases funds from perpetual repairs for innovative approaches; and integration multiplies limited investments across multiple benefits. Infrastructure transformation often emerges through combining these approaches rather than pursuing single solutions. The resulting systems perform differently than conventional infrastructure—self-maintaining rather than degrading, flexible rather than rigid, multi-functional rather than single-purpose.

3.2.5 Pathways for Infrastructure Transformation

The infrastructure failures documented in this chapter—cascading power outages, highway closures, water system contamination—threaten to destabilize North Coast communities as climate impacts intensify. The chapter also documents working solutions: Tribal microgrids maintaining power during regional outages, wetland systems treating wastewater effectively for decades, regional partnerships pooling resources across jurisdictions, and nature-based approaches outperforming conventional engineering, often at lower costs. Experience across the region suggests as much; the question this section examines is what constrains their wider adoption.

PLANNING UNDER UNCERTAINTY

Part of what constrains the wider adoption of these proven working solutions is the nature of the planning problem itself. Infrastructure planning under conditions of high stakes, significant uncertainty, and long-time horizons requires robust decision-making that performs adequately across multiple climate scenarios rather than optimizing for any single predicted future (e.g., Lempert et al., 2006; Walker et al., 2013). **Appendix 3** provides economic frameworks for evaluating infrastructure investments under these conditions, including methods for valuing co-benefits, flexibility, and distributional equity. This means avoiding investments that lock in vulnerability while preserving flexibility to adjust course. Communities must proceed despite incomplete knowledge, build capacity to detect when assumptions fail, and accept that some decisions will prove wrong. Infrastructure planning becomes an iterative process of implementation, monitoring, and adjustment rather than a linear progression toward fixed goals.

3.3 Key Considerations for Policy

The infrastructure failures and adaptation successes documented throughout the North Coast reveal a persistent mismatch between regulatory frameworks designed for urban contexts and rural climate adaptation needs. Despite four decades of proven local solutions, communities must navigate policies that treat nature-based infrastructure, distributed systems, integrated multi-benefit approaches, and regional partnerships as exceptions rather than legitimate approaches. The result is substantial resources consumed by administrative process, adaptation delayed, and locally successful models that cannot expand to the scale the region needs. While multiple opportunities for policy innovation exist, North Coast experience points to five areas where current frameworks constrain documented adaptation strategies (**Appendix 3** details economic methods supporting these directions).

First, the state's Proposition 218, passed in 1996, restricts property-related fees to the cost of the service provided to the ratepayer paying them. Climate adaptation is in tension with that constraint: future upgrades by water agencies such as backup water supplies, larger flood infrastructure, and system redundancy are challenging without built-out financial reserves, but costs for these future improvements are hard to tie to the service and individual ratepayer receives today. This makes it difficult for water agencies to build the financial reserves that long-term resilience planning requires (Hanak et al., 2014; Bardeen, 2025). More clear state guidance would help agencies move forward, but only so far. The harder question—whether climate preparation should be treated as a shared public obligation rather than a service people pay for only when they directly benefit—is ultimately political and current frameworks largely leave it unanswered.

Second, state funding eligibility rules were designed primarily for conventional single-purpose infrastructure and often exclude effective alternatives. Tribal cultural burning, for example, is ineligible for cost-share under the California Forest Improvement Program. As a result, resources are directed toward approaches that qualify rather than approaches that work (Community Advisory Board, 2024; California Wildfire & Forest Resilience Task Force, 2024; Clark, Miller & Hankins, 2022).

Third, infrastructure transformation requires sustained multi-year investment for governance structures, community acceptance, and system integration to develop. When experienced staff and organizational knowledge disperse between funding periods—as documented in Dunsmuir when grant cycles ended—communities bear the cost of rebuilding capacity rather than applying it (Community Advisory Board, 2024). The North Coast Resource Partnership's 20-year record of sustained regional coordination represents the exception that illustrates the rule (NCRP, 2024).

Fourth, distributed energy systems and alternative water supplies have demonstrated they can maintain critical services during outages, but they are still classified as backup supplements rather than essential infrastructure. That classification has direct financial consequences: essential infrastructure is financed through shared public investment, yet backup supplements are not. The Hoopa 1101 corridor—one of California's least reliable electrical circuits—experiences frequent, extended outages due to aging transmission infrastructure serving a dispersed population across 142 miles (228 km). Distributed alternatives capable of addressing this exposure have not been financed at the scale the problem warrants (Schatz Energy Research Center, 2024).

Fifth, the insurance market's withdrawal from high-risk areas compounds every other barrier. When insurers do not lower premiums for fire-resistant retrofits or nature-based risk reduction, communities have no financial incentive to invest in the approaches this chapter documents. The FAIR Plan's total insured exposure, the property value it would owe in a total loss, grew from $112.75 billion in 2019 to $724 billion by December 2025, driven by private insurers leaving the market rather than expanded protection for homeowners (California Assembly Insurance Committee, 2026). This reflects a market that prices risk but does not credit risk reduction.

Appendix 3 (Economic Framework for Climate-Resilient Infrastructure Investment) develops the financing dimensions of these policy directions. For each barrier identified above, the appendix pairs a financing mechanism with a documented North Coast project; it also introduces emerging tools, including state-aggregated parametric insurance and ecosystem service markets. Sources are organized by topic for practitioners working on implementation.

3.3.1 Assessment Limitations

This analysis draws from a limited sample of North Coast projects, many operating less than two decades, which constrains long-term performance assessment. The focus on four infrastructure sectors excludes telecommunications, solid waste, and other systems. Community consultation was broad but cannot capture all perspectives. Insurance market dynamics affecting infrastructure investment are addressed in Appendix 3 but warrant deeper analysis than this assessment provides, and regional health data for cascading infrastructure failures remain limited. Solutions shown to work in rural, low-density, isolated conditions may not transfer directly to other contexts.

3.4 Looking Ahead

Climate impacts will continue to push North Coast infrastructure beyond design capacity. This chapter documents that effective adaptation is already underway—often led by communities and Tribes with limited resources—and that documented barriers often prevent these approaches from scaling to match the pace of intensifying impacts. Without adjustment, these structural barriers will continue to favor approaches that qualify over approaches with the strongest evidence of effectiveness—even as climate impacts accelerate.

The region's two decades of operational experience with nature-based infrastructure, distributed networks, adaptive management, and integrated multi-benefit approaches provide an unusually strong empirical basis for policy innovation, as well as transferable lessons for other rural and coastal regions facing similar conditions. Aligning financing and regulatory frameworks with the strategies the evidence supports is the central implementation challenge.

Chapter 4.

Social Systems and Cultural Resources

Authors: *Jen Marlow, Daniel Lipe, Ana Alanis, Catriona Barr, Kayla Begay, Alec Brown, Mark Cederborg, Christine Davis, Jennifer Kalt, Erin Kelly, Kristina Kunkel, Lulu Mickelson, Evan Mills, Keith Parker, Brandon Quintana, Kaitlin Reed, Laurie Richmond, Eric Riggs, Wendy Ring, Cutcha Risling Baldy, Selena Rowan, Julie Sorfleet, Grace Woodmansee, Sylvia van Royen*



Key Message

The North Coast is a place people love for its unique landscapes, communities, and way of life. Planning for the region's future requires place-based climate adaptation approaches tailored to the landscapes, communities, and economies of the North Coast. Legacies of colonialism and the genocide of California Native Americans, extractive capitalism, high unemployment and poverty rates, housing unaffordability, health disparities, and pollution compound regional climate impacts. Despite the urgent need to address these issues systematically, the North Coast is under-resourced. The North Coast Resource Partnership, a collaboration of local and Tribal governments, estimates over $3 billion in unmet funding needs for climate and ecosystem resilience projects (North Coast Resource Partnership, personal communication, August 20, 2025).

Despite the region's relative isolation and longstanding lack of public investment, North Coast communities have a strong history of organizing to meet local needs. Residents also hold deep, place-based knowledge of their communities, understand which resilience and adaptation approaches are most likely to work locally, and maintain trusted community networks that are often not accessible to outside planners and consultants. Building on these strengths and millennia of Traditional Ecological Knowledge, Tribes in the region are leading pragmatic and transformative future-focused adaptation projects for the rest of the state. Regional initiatives, such as Indigenous land return, workforce development programs, landscape-scale restoration, regenerative farming and ranching, and regional governance collaboratives, have demonstrated effective adaptation approaches, whose successful outcomes make a compelling case for sustained investment. For example, the North Coast Resource Partnership is co-led by appointees from North Coast Tribes and counties who ensure that the collaborative's funding strategies are shaped by those closest to the region.

Policy frameworks developed for urban contexts may not fully address the distinct conditions of rural and Tribal communities in the North Coast. As exemplified below, regional planning frameworks developed with local input align more meaningfully with North Coast livelihoods and conditions. The chapter begins by foregrounding Indigenous Knowledges and Tribal leadership and by acknowledging how colonization has shaped present-day climate risks and responses. It then examines the diverse ways climate change affects many of the social and cultural systems across the region's six counties. The chapter concludes by identifying five cross-cutting challenges and opportunities for North Coast climate adaptation.

4.1 Indigenous Knowledges

Authors: *Daniel Lipe, Jen Marlow, Keith Parker*

> ***"We are in a crisis, a full-blown emergency, here on the Klamath River. We are losing our salmon. They are everything to us. Our children's future depends on it…The Klamath River is who we are. It is our lifeline. It is our livelihood." —Yurok Tribe Chairman, Joseph L. James (Weinreb, 2021)***

Potawatomi scholar Kyle Whyte identifies colonialism—not climate change alone—as the root cause of Indigenous vulnerability, emphasizing how settler systems systematically undermine Indigenous adaptive capacity (Whyte, 2017; Whyte et al., 2019). In California, these conditions

are rooted in a history of state-sponsored genocide, land theft, enslavement, the trafficking of Indigenous women and children, boarding schools and missions, the criminalization of Indigenous land practices, and exploitative settler land use that dismantled Indigenous social, political, and economic systems (Madley, 2016). These settler-colonial policies and practices have constrained the recognition and exercise of Tribes' inherent sovereign authority, displaced deep relational governance system (Temin, 2023), and degraded ecological systems (Reed, 2023).

Kaitlin Reed's concept of the "rush pattern," described in the excerpt below from her 2023 book *Settler Cannabis: From Gold Rush to Green Rush in Indigenous Northern California*, illustrates how extractive economic regimes (including gold mining, commercial fishing, and cannabis cultivation) have relied on and reinforced policies of dispossession of Indigenous peoples and lands and systematically reduced regional climate resilience. Climate adaptation strategies that reproduce these extractive logics risk further entrenching colonial power relations (Gilio-Whitaker, 2019) and perpetuating unsustainable extraction from ecosystems essential to collective survival (Akins & Bauer, 2021; see also **Appendix Case Study 2.3.A**). In response, Reed shares her vision for climate resilience for the North Coast region in **Box 4.1**.

Box 4.1: *Land Return as a Strategy for Climate Resilience*

©University of Washington Press. Excerpted with permission from Settler Cannabis: From Gold Rush to Green Rush in Indigenous Northern California by Kaitlin Reed.

We have entered an ecological crisis. As fires engulf the western United States and water shortages impair habitats, we will be forced to reckon with the unsustainable nature of settler-colonial orientations to land. The ecological crisis wrought by climate change will, whether by force or choice, change the way settler society engages with the environment. And while the damages of climate change become more visible every day through uncontrollable wildfires to fish die-offs, a "business as usual" approach to economic growth via resource extraction rages on. The return to Indigenous stewardship is necessary to rectify historical injustices of settler-colonial dispossession and extraction, but it also is fast becoming an ecological necessity.

Decolonization means land return, and we are at an incredibly important moment regarding decolonial land returns. Powerful examples of healing are occurring throughout Indian Country.... On October 21, 2019, the city of Eureka returned Tuluwat Island—a site of both World Renewal Ceremonies and genocidal violence—to the Wiyot Tribe in northwestern California. This is "the first time in the history of our nation that a local municipality has voluntarily given back Native land absent an accompanying sale, lawsuit, or court order" (Greenson, 2019). Tuluwat is just one example of many. Across the nation, more land is being returned—by universities, missions, governments, nonprofits, and even individuals (Risling Baldy & Tully, 2019). The return of stolen land is possible. Healing is possible.

....To begin healing from the genocide that tried to destroy us—our lands and our peoples—we must engage in community environmental restoration. We must begin to pick up the pieces that over a century of resource rushing has scattered about. Here in Northern California, Indigenous tribes have been at the forefront of all critical environmental movements, including dam removal (Orona, 2013), salmon habitat protection (Middleton Manning & Reed, 2019; Sims, 2018), and returning fire to the landscape (Marks-Block & Tripp, 2021; Tripp, 2020).

My sustainable vision for California is land return. Decolonization. Ecologically speaking, I argue this is the only path forward. We need to operate within a framework of radical relationality that rejects the commodification and control of nature for wealth accumulation....[W]e have to imagine beyond settler-colonial orientations to land; we must think outside the prescribed "rush" pattern of the gold rush, the timber rush, the fish rush, and now the green rush. For Native people, social and environmental justice is impossible without land return. Climate justice requires decolonization.

4.2 Education

Authors: *Cutcha Risling Baldy, Kaitlin Reed, and Kayla Begay*

As Reed identified in **Box 4.1**, anthropogenic climate change has intensified the changes imposed on Indigenous Peoples by colonialism and capitalism (Reed, 2023) (see the Fifth Assessment's "Tribal and Indigenous Communities Statewide Topical Report"). Addressing colonialism as a driver of Tribal climate vulnerability requires a return to TEK and Indigenous science, and the implementation of an indigenized curriculum (CAIFS, 2021).

4.2.1 Traditional Ecological Knowledge & Indigenous Science

Indigenous sciences are increasingly recognized as essential to understanding and responding to climate change. TEK or Indigenous Environmental Science (IES) is broadly defined as encompassing millennia of environmental knowledge passed down intergenerationally through observation, spiritual practices, and interactions with the environment (Anderson, 2005). TEK is modern, adaptive, and may have various meanings specific to different Indigenous groups. Despite TEK and IES's inclusion of interventions and methodologies of ecology, biology, chemistry, astronomy, zoology, and other western fields, it is rare to see TEK valued or centered as part of these western scientific disciplines. Robin Wall Kimmerer reflects on how climate change raises "more complex questions" than science and technology alone can answer, including "what should we do?" and "how is it that we should live?" (Cal Poly Humboldt, 2021).

4.2.2 Toward a PolyTEK for All

As a "PolyTEK" university that ethically incorporates Indigenous sciences into the polytechnic institution, Cal Poly Humboldt is becoming a national leader in implementing Indigenous perspectives across curricula and programming (Reed, 2022). With the continued revitalization of IES and TEK, students in the natural sciences are increasingly seeking opportunities to engage with curricula developed through ethical partnerships with Tribal Nations. Principles from Cal Poly Humboldt's PolyTEK initiative that could inform climate education at other institutions include:

- Partnering with Tribes to support Tribe-directed knowledge sharing while upholding Tribal sovereignty, self-determination, cultural protocols, intellectual property, and the right to refuse participation; Partnering with Tribes as equal partners on projects that are being developed on their lands or in their Tribal communities. Consultation is not collaboration; and
- Co-developing curricula with Tribal knowledge holders that truly embraces Indigenous Knowledges as part of all majors across campuses or all subjects of study.

4.3 Governance

This next section on *Governance* treats Tribal and state and regional governance separately, as Tribes are inherently sovereign governments that predated state and regional governments. Distinguishing the two also highlights the significant challenges climate change poses to modern governance. Climate governance requires coordination across multiple levels of government and continuous government interaction with Tribes, private entities, and residents (Termeer et

al., 2010). These challenges are compounded by settler colonialism, which has systematically undermined Indigenous governance systems and constrained Indigenous authority within state-led decision-making processes (Gilio-Whitaker, 2019). Additional governance barriers arise from the need to coordinate across overlapping policy and regulatory frameworks, increasing administrative costs and generating conflicts and compromises that can weaken or delay time-sensitive decisions (Freeman & Rossi, 2012; Jordan et al., 2018).

Despite consensus that climate change governance should be multi-level, consensus is lacking on how it should be organized (Jordan et al., 2015). Models relevant to the North Coast include Senate Bill 1260 (SB 1260, 2018), which recognizes cultural burning as a climate strategy; the Lake County Community Risk Reduction Authority, formed via a joint powers agreement to work across jurisdictions on equitable climate change adaptation; and the North Coast Resource Partnership (NCRP) (see **Appendix 3.2**).

4.3.1 Tribal Governance

Authors: *Daniel Lipe, Jen Marlow, and Keith Parker*

Colonization severely disrupted Tribal governance along the North Coast. Unlike most federally recognized Tribes, California Tribes lack ratified treaties, leaving many California Tribes landless with limited jurisdiction over their traditional homelands. The lack of treaty protections to Tribes' ancestral territories creates a unique tension in their relationship with the state and federal governments (see the Fifth Assessment's "Tribal and Indigenous Communities Statewide Topical Report").

However, North Coast Tribes have maintained their place-based identity and cared for their traditional homelands through practices such as cultural burning since time immemorial (Lake, 2022; Anderson, 2005). To Tribes, cultural burning is not a symbolic act but a responsibility. According to a Karuk fire practitioner and ceremonial leader, "Fire is the oldest teacher on Earth." Yet, for over 100 years, fire suppression policies have threatened Tribal sovereignty and altered the land, leading to overgrown forests, degraded habitats, and water scarcity (see Chapter 1, *Section 1.4.1 Observed Fire*; Chapter 2, *Section 2.2 Terrestrial Systems*). Fir-dominated woodlands have encroached upon and replaced oak savannahs, increasing competition for water. Higher temperatures and disrupted precipitation patterns mean streams and rivers run dangerously low, creating conditions for toxic algal blooms and fish die-offs—especially among salmon, a culturally and ecologically vital species (see Chapter 2).

Moving climate governance forward will require models that place Indigenous Peoples as leaders. California has recently taken important steps toward supporting Indigenous fire practices (e.g., **Appendix Case Study 2.1C**). SB 1260 (2018) recognizes cultural burning as a climate strategy and SB 310 (2024) created a streamlined permitting process for federally recognized Tribes entering agreements with the state to lead cultural burns on ancestral lands. Despite the number of Tribes in the region, only the Karuk Tribe has secured such an agreement. Expanding current cultural burn legislation to Tribes without federal recognition could potentially enhance resilience benefits. The Prescribed Fire Claims Funds offers another encouraging development. It provides up to $2 million in liability coverage in case of fire escapement for qualified burn bosses and Tribal fire practitioners. Programs like the Prescribed Fire Claims Fund that reduce financial risk are critical to enabling more cultural fire projects, especially in high-risk regions.

Moving forward, cultural fire programs demonstrate a pathway toward resilience that treats Tribes not as interested parties or worse—labels Tribes as stakeholders, which fails to recognize their sovereign status—but as sovereign nations with inherent jurisdiction and expertise. Continued efforts to strengthen and build upon policies that recognize and support Tribal sovereignty and leadership could also lead to more inclusive efforts and collaborative relationships to future land restoration efforts. The Karuk Tribe's Good Fire II report outlines current barriers to the expansion of cultural burning and prescribed fire along with recommendations and possible solutions for the future (Clark et al., 2024).

4.3.2 State and Regional Governance

Author: *Lulu Mickelson*

In addition to being home to the largest population of Tribes in California, the North Coast is home to rural, under-resourced communities, all finding creative ways to build resilience in the face of climate change. State and regional governance challenges tend to reflect rural realities, including the region's remoteness and distance from power centers like Sacramento. Del Norte County Supervisor, Chris Howard, summarized the sentiment: "We're always at the bottom of the wave and getting buried every time there's a policy change in the State of California" (C-Span, 2017).

However, there are several opportunities to expand state climate policy frameworks to better address rural community realities and enable community and Tribally-led solutions (Clark, Miller & Hankins, 2022). For example, small organizations, budget-limited local governments, and Tribal Nations have more access to funding and resources when reimbursement-based grant structures and match requirements are waived (Headwaters Economics, 2023; US Government Accountability Office, 2024). Advance payments and greater budget flexibility are associated with broader access to resources and more timely project delivery (Community Advisory Board, 2024). Additionally, rural communities typically drive longer distances and have fewer alternatives to zero-emission transportation (Becker, 2024; Deryugina & Rees, 2024). Opportunities to potentially offset the resulting outsized impacts of climate policies on these communities could include direct household dividends, refundable tax credits, utility-bill credits, targeted community investments, clean-vehicle rebates for lower-income drivers, expanded public transit, or EV-charging infrastructure along remote corridors.

As California adapts, the North Coast offers several compelling examples modeling innovative approaches to multilevel governance for the rest of the state. One is the North Coast Resource Partnership (NCRP), a coalition of thousands of partners (Tribes, counties, NGOs, RCDs, and private sector groups) focused on enhancing the communities and ecosystems of California's 19,000-square-mile North Coast region. The partnership is governed by a Leadership Council of appointees from the region's Tribes and counties, a nationally unique model of sovereign Tribal Nations and local governments working collaboratively on climate (see **Appendix 3.2**). Other organizations like the Rural Community Assistance Corporation and California Trout North Coast provide additional technical support to help rural communities access and implement these collaborative approaches (see **Appendix 4.2**).

Other examples of multi-level regional partnerships successful at fostering long-term, multi-benefit outcomes include the Northern California Tribal Fisheries Collaborative, working to improve the climate resilience of culturally and economically important Tribal marine and

estuarine fisheries in far Northern California; the Cal Poly Humboldt Sea Level Rise Institute, working with academia, government, and Tribes to advance equitable and transformational responses to sea level rise; the Tribal Marine Stewards Network, an alliance of Tribal Nations working to steward the coast and oceans; and the Schatz Energy Research Center, working to support clean energy, climate-resilience, equity, and justice. Other documented successes serving as regional guides for future initiatives include:

1. State support for Indigenous land return, including restoration of the Klamath Blue Creek Salmon Sanctuary and the Yurok Tribal Community Forest.
2. Strategic Growth Council's Regional Climate Collaborative projects, such as the Siskiyou Climate Collaborative.
3. SB 1339 (2018), which created a $200 million statewide grant program for community microgrids, along with regional projects such as the Tribal Energy Resilience and Sovereignty (TERAS) and the Blue Lake Rancheria (BLR) microgrid (see Chapter 3).

4.4 Labor and Workforce Development

Author: *Jen Marlow*

The growing restoration economy is "a bright spot in a moment that often feels pretty bleak." — Casey O'Neill, Happy Day Farms (see* Appendix Case Study 4.3.A*)

The following four sections shift the focus from the role of the public sector to the role of the private sector in growing a climate-resilient economy. Regional planning documents identify gaps in North Coast training and apprenticeship pathways to build and sustain the workforce needed for climate resilience (NCRP, n.d.). Unemployment rates in all counties except Humboldt County are higher than the rest of California (see **Appendix Table 4.1.A**). The region reflects a legacy of economic disinvestment according to California Jobs First criteria, which consider median household income, poverty rates, and unemployment levels (CCRP, 2025). Workers face limited access to clear career pathways, while employers struggle to recruit and retain qualified personnel (Community Advisory Board, 2024). The absence of structured progression from entry-level fieldwork to stable, living-wage careers constrains regional capacity to implement climate adaptation and land stewardship strategies (see Chapter 3).

At the same time, the region faces significant growth potential. Climate resilience is estimated to become a $39 billion industry, adding 177,000 jobs to California's workforce (Frisch & Sanford, 2022). Training a local workforce, rather than outsourcing work to external contractors and consultants that shift investment outside the region, presents both a challenge and an opportunity for the North Coast. Hundreds of millions of dollars in ecological restoration projects are currently planned for the North Coast, representing an under-recognized source of regional economic activity that can be leveraged for climate resilience. According to Mark Cederborg, the Director of Policy and Advocacy at the nonprofit Ecological Workforce Initiative, as much as 20%, and likely much more, of reported civil construction spending and job creation in North Coast counties, is actually ecological uplift work.

Cederborg defines ecological uplift as the construction, stewardship, and land-management activities that result in measurable improvements in ecosystem and economy health, function, and diversity—elements essential to climate resilience. Cederborg prefers the term ecological uplift over ecological restoration, which, he argues, "perpetuates the notion that restoration is optional. In fact, restoration is integral to the economy." Ecological uplift jobs include equipment operators, erosion control technicians, revegetation crews, and landscape stewards—family-sustaining positions that strengthen local economies. Approximately 30–40% of construction costs go directly to workers' wages and benefits. Growing the workforce aligns with the need for nature-based solutions (see Chapter 3). With further investment, such growth could fill needed gaps, including the region's lag in fire-resistant construction training relative to other parts of California (Jolley & Blackmer, 2025).

The North Coast could also prioritize training for projected shortages in fire managers, conservation scientists and foresters, sustainable loggers, utility line clearance technicians, and renewable energy technicians and operators—occupations which support well-paying jobs with benefits (Frisch & Sanford, 2022). Targeted workforce development in these fields would require education and skills-building for long-term career pathways focused on retention, not just recruitment, helping ensure ecological uplift investments remain in the region and build long-term regional capacity (Conway & Giloth, 2014). Support for wraparound services, such as transportation, childcare, and housing would remove barriers for participants (CCRP, 2025). Workforce development pathways are also needed to recruit and retain architects, electricians, planners, designers, attorneys, engineers, entrepreneurs, and policy analysts to develop, build, and manage climate-resilient housing, buildings, and critical public health and transportation infrastructure (Klein, 2025; Kirsch, 2023; CCRP, 2025; see also Chapter 3).

Several North Coast initiatives already demonstrate how targeted workforce investments can operationalize this strategy. Successful examples include Redwood Region RISE (Resilient Inclusive Sustainable Economy), a coalition of 150+ member organizations engaging over one thousand residents across Tribal lands, Del Norte, Humboldt, Lake, and Mendocino counties to implement a 10-year Regional Roadmap to bring sustainable, quality jobs to our region while advancing environmental stewardship and inclusivity through the statewide California Jobs First initiative. Redwood Region RISE's Career Pathways: Fire, Forests, Fish & Facilities (4F) Project Workplan implements a $1.1 million catalyst grant, 60% of which is directed at priority communities. Other model programs include: the Lake Workforce Program; the Yurok Coast Workforce Initiative; and the California Conservation Corps. These models demonstrate that ecological uplift requires diversifying economic activities across different modes of financing and scale.

The state has options to build on these successes. If the North American Industry Classification System (NAICS) codes were updated to categorize ecological uplift activity as a distinct employment category, as Cederborg suggests, the state could more accurately report the economic activity generated by ecological uplift. Better accounting may attract additional public and private investments. Furthermore, delays in permitting and fragmented interagency coordination have been identified as implementation barriers to ecological uplift work, suggesting that institutional streamlining presents an opportunity to build a regional workforce while accelerating progress toward state climate goals.

4.5 Finance

Author: *Selena Rowan*

Disasters like the 2020 August Complex Fire and 2022–23 winter storms illustrate the high cost of climate inaction in our region. Suppression for the August Complex Fire alone cost $1.4 billion (National Interagency Fire Center, 2020), while statewide infrastructure recovery from the storms climbed into the billions (National Weather Service, 2023; see also the Fifth Assessment's "Climate Impacts to the Economy Statewide Topical Report"). Climate adaptation will be expensive but can be cost-effective if implemented in time. On the North Coast, climate finance supports wildfire mitigation, water systems, regenerative agriculture, fisheries, workforce training, and Tribally-led ecological programs. But access is uneven, with funding often going to a few entities that control who participates and what gets done.

The need to evolve funding mechanisms to better match community needs in the North Coast is a known challenge. From the collapse of legacy cannabis markets to climate impacts (see Chapter 1), North Coast communities need consistent, equitable funding to build durable economic alternatives. Happy Day Farms, for example, is a diversified family farm in the hills of Northern Mendocino County that has built a patchwork of funding sources to support the farm's adaptation to climate change. The farm has greatly benefited from the facilitation of local organizations in applying for and managing state funds. The Mendocino County Resources Conservation District obtained funding from CDFW Cannabis Restoration Grant Program, Point Blue Conservation Science regranted Wildlife Conservation Board funding, and the Mendocino County Equity Program distributed funds from California cannabis equity funds. The farm also received key funding from the CDFA Farm to School program and the Good Farm Fund, a local foundation. CDFW's Cannabis Restoration Grant Program is entirely funded by the cannabis excise tax collected at point of sale and represents direct financial investment by the cannabis industry into climate resilience.

Other proven strategies for meeting North Coast financing needs encompass federal programs, public and philanthropic funds, corporate investments, and locally generated revenue (see the Fifth Assessment's "Adaptation Finance" report prepared by the California Department of Insurance). Corporate mechanisms, such as community benefit agreements, supplement traditional grants and support communities directly affected by large-scale energy, infrastructure, and resource development projects to negotiate more equitable outcomes (Gunton et al., 2021). Developers of offshore wind projects in the Humboldt Wind Energy Area have committed over $12 million in community benefit agreements for Tribal engagement, workforce training, and environmental monitoring (Hoff & Segal, 2023; Ciara et al., 2020). Additionally, green microfinance models, which link finance practices to ecological uplift goals, demonstrate opportunities for financial instruments to support small-scale, climate-resilient livelihoods, such as sustainable agriculture, renewable energy adoption, and land stewardship (Huybrechs et al., 2019) (see also **Appendix 4.3.A**). Outcomes, however, depend heavily on institutional reform and safeguards against reinforcing structural inequities (Milana & Ashta, 2012).

Financing models for climate resilience are most effective when structured around equity, flexibility, and durability. The Karuk Tribe offers a compelling model reliant upon TEK and western science. With $10 million secured from California's Early Action Determination for the Proposition

4 Climate Bond, the Karuk Climate Resiliency Center is implementing large-scale fire resiliency, salmon habitat restoration, and regenerative economic development. But this funding is only one-third of what will ultimately be needed.

To ensure continuity, the Karuk Tribe and Humboldt Area Foundation are developing an Eco-Cultural Revitalization Fund—a long-term operating reserve fund with the goal of securing at least $50 million, which would be capable of generating $2.2 million in operating funds annually. Currently at $1.4 million, the fund is growing through contributions from philanthropy and flexible grants. The Karuk Tribe is also seeking funding through two bold new sources that would redirect: 1) land-grant university endowment revenue to support what Dr. Bill Tripp, the Tribe's Director of Natural Resources and Environmental Policy, calls the "climate resiliency workforce of the future"—long-term Tribal workforce development, tuition, cooperative extension, and climate resilience on Indigenous terms; and 2) utility settlement funds toward long-term operating reserve funds for Tribes and fire safe councils to implement forest resiliency efforts statewide. Conservation finance literature identifies endowment-style funds as providing predictable, durable revenue streams over multi-decade time horizons while functioning as core components of institutional and governance infrastructure (Meyers et al., 2020).

4.6 Insurance

Author: *Alec Brown*

California's insurance system was not designed to cover today's climate-driven extremes. On the North Coast, escalating wildfire and flood risks are pushing parts of the region toward uninsurability. A Senate report flags Lake, Trinity, and Siskiyou counties among those most affected by non-renewals and premium spikes, with Trinity County's average premiums rising ~109% since 2020 (US Senate Committee on the Budget, 2024).

Lake County illustrates these pressures. Since 2015, every Lake County resident has faced at least one mandatory evacuation (Community Advisory Board, 2024). Nearly 70% of the county has burned, insurers are pulling coverage from high-risk areas, and premiums have surged (LCEDC, 2024). The county also experiences repeated drought and flood exposure including "exceptional" drought conditions from 2013–2023 (LCEDC, 2024) and leads the state in flood insurance claims linked to atmospheric rivers (Larson, 2023).

Insurance costs are now feeding directly into the housing affordability crisis. At the same time as the number of new homeowners' insurance policies decreases across the region (**Figure 4.1**), and private homeowners' insurance premiums increase (**Figure 4.2**), state FAIR Plan enrollments and reliance on costly difference-in-conditions (DIC) private policies have surged (see **Appendix Figures 4.3.B.1** and **4.3.B.2**).

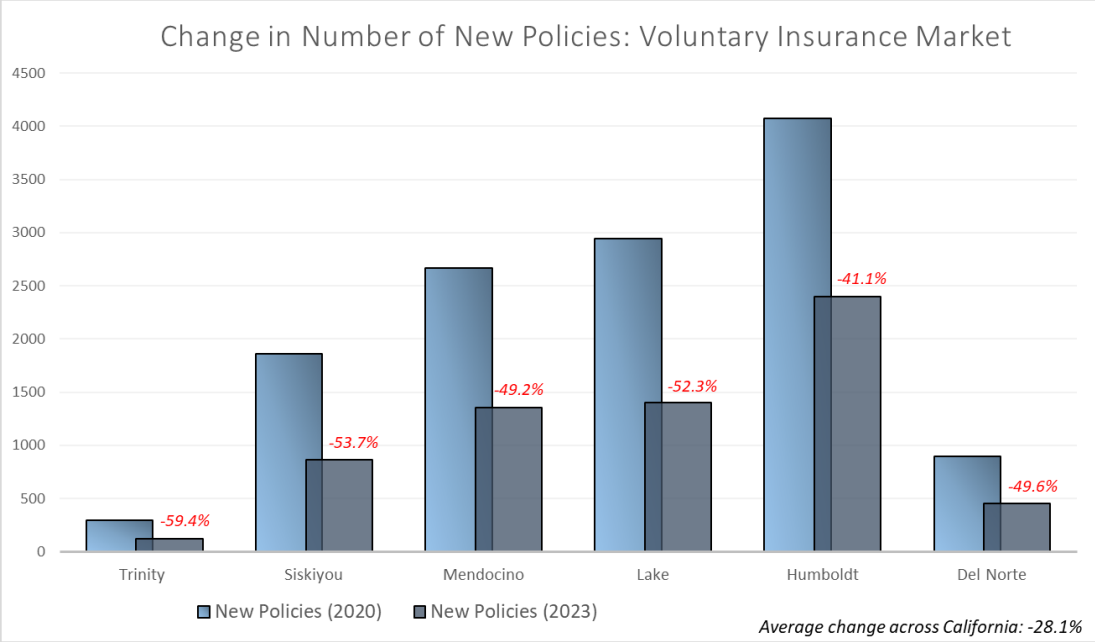


Figure 4.1: *Year-over-year homeowners insurance policy counts by county for the North Coast region (2020–2023). From Residential insurance policy analysis by county, 2020–2023, by California Department of Insurance, 2024. County-level data were used to calculate percentage changes; statewide mean change shown for comparison.*

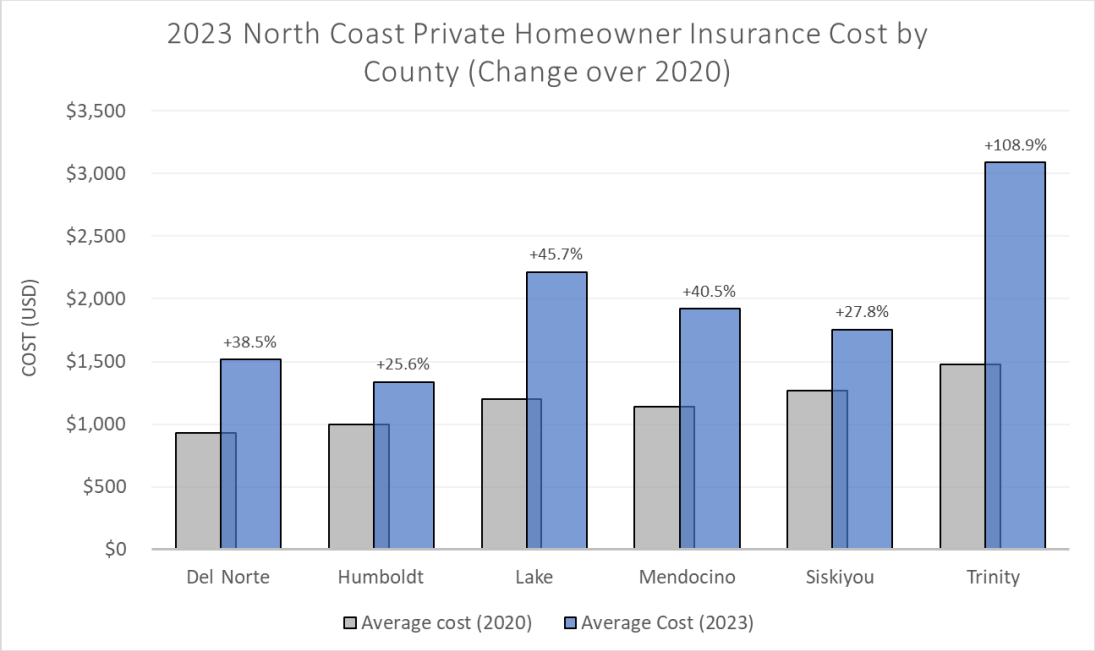


Figure 4.2: *Year-over-year change in private homeowners' insurance premiums for six North Coast counties. Source: Rojanasakul and Flavelle (2024), drawing on Keys and Mulder's CoreLogic-based escrow methodology. County averages represent the median insurance premium within counties with at least 10 observations.*

Purely risk-based insurance pricing, which raises premiums in hazard-prone areas (Keys & Mulder, 2024), exacerbates wealth inequality across race, education, and homeownership status and drives unequal outcomes in recovery and long-term economic stability (Howell & Elliott, 2019). Rather than address affordability through discounted premiums, which distort risk, scholars have proposed income-based vouchers paired with low-interest hazard mitigation loans (Kousky & Kunreuther, 2014). Mechanisms reducing procedural barriers, such as advance payments, flexible funding structures, and community-based delivery, have been associated with improved accessibility and more equitable outcomes (Wilson et al., 2021).

However, without concurrent risk reduction, affordability reforms may perpetuate the "safe development paradox," may increase long-term exposure by encouraging development in hazard-prone areas (Sanchez et al., 2024; Breen et al., 2022). Example programs that tie risk reduction to affordability incentives include the Insurance Institute for Business & Home Safety's Wildfire Prepared Home and FEMA'S Community Rating System (CRS) (IBHS, 2024). However, these programs require scaled funding and on-the-ground help to reach rural homeowners. While Lake and Trinity counties currently earn CRS discounts—15% and 5%, respectively—other North Coast counties, although enrolled, do not currently qualify.

Nature-based solutions—approaches that restore or enhance ecosystems to reduce climate risks and strengthen resilience, such as salt-marsh restoration, floodplain reconnection, fire-adapted forest stewardship (see Chapter 3)—can further reduce losses and be incorporated into parametric and indemnity insurance models when policy frameworks recognize their risk-reduction value (Reguero et al., 2020; see also Chapter 3). Programs like the CRS or FAIR Plan could similarly channel savings into "upstream investments" in wildfire and flood resilience, yielding far greater cost-effectiveness and long-term security (US Chamber of Commerce, 2024; National Institute of Building Sciences, 2020). The $20 million in earmarked Proposition 4 funding for Clear Lake watershed resilience offers a rural roadmap for continued upstream investments that increase resilience.

Several other insurance modernization efforts may accelerate these shifts. The California Department of Insurance's Sustainable Insurance Strategy incorporates forward-looking catastrophe models that incorporate climate data into pricing (California Department of Insurance, 2024), and FEMA's Risk Rating 2.0 introduces more property-specific flood pricing. Regional efforts to develop public-facing catastrophic wildfire risk assessment models aim to improve transparency and risk-assessment accuracy—both key to pricing insurance coverage for large-scale hazards (see **Appendix Case Study 4.3.C**). Insurers can also drive research and innovation for climate resilience by investing in renewable technologies, green building, and even de-insuring carbon-polluting industries to manage and mitigate risk (Mills, 2012; Trivedi & Srivastava, 2023).

4.7 Economics

The Economics section documents the social and cultural impacts of climate change on ranching (see Chapter 2 for climate impacts), and cannabis in detail (see also **Box 2.2** for impacts on Native fishing and **Box 4.2** for impacts on viticulture). While ranchers are adapting in place to climate challenges, climate-related disruption from wildfires, flooding and road washouts, and drought has begun to shift cannabis production indoors and/or outside the region.

Box 4.2: *Reimagining Winemaking in a Climate-Changed World by Jen Marlow*

California wineries—including in Mendocino and Lake counties—are facing climate impacts on productivity, with earlier growing seasons, heat and drought stress, water constraints, new pests and diseases, and wildfire smoke affecting yield, composition, and quality (Parker et al., 2024). Current evidence points more toward gradual adaptation than widespread relocation out of the region. California wine growers and the wine industry are prioritizing "climate-smart" adaptation options tailored to site and variety (Parker et al., 2024), such as improving soil structure, irrigation management using cover cropping and no-till management (see Lake County's Shannon Family of Wines), and managing vineyards for heat exposure and wildfire smoke risk (Zakowski et al., 2023). However, some studies suggest shifting cultivation over time to cooler, coastal climate refugia as a longer-term strategy for economic viability (van Leeuwen et al., 2024).

4.7.1 Impacts on Ranching

Author: *Grace Woodmansee*

Ranchers in Siskiyou County face compounding climate-related threats amid a shifting policy and market landscape. Challenges associated with an aging rancher demographic, generational succession planning, and increasing market value of ranch properties are intensified by climate-related impacts and the rising cost of production (Munden-Dixon, 2018; Brunson, 2008). Privately-owned ranches play an important role in the conservation of working landscapes (see Chapter 2). Previous research suggests that California ranchers view climate change as an important component of their business and are changing their management to adapt (Petersen-Rockney, 2022; Woodmansee, 2021). Programs that center the values and lived experiences of ranchers, rather than narrowly focused technical environmental understanding, are more likely to result in engagement (Petersen-Rockney, 2022; Woodmansee, 2025). The place-based knowledge of land managers, including ranchers, positions them as important partners in co-developing and implementing management strategies that preserve natural resources while mitigating and adapting to the effects of climate change.

DROUGHT

Drought and decreasing water availability are critical concerns for Siskiyou County ranchers (Ikendi et al., 2025). In 2021, during the most recent severe drought, the State Water Resources Control Board adopted an emergency curtailment of surface water and groundwater use across the Scott River (30% reduction) and Shasta River (15% reduction) watersheds, which impacts forage availability, livestock drinking water, and the survival of perennial grasses. In 2022, approximately 24,000 total acres in Siskiyou County were fallowed due to lack of water availability (Siskiyou County Department of Agriculture, 2023). Fallow land is prone to erosion, invasive weeds, and reduced soil health, whereas established perennial grasses contribute to key ecological benefits and require less inputs to maintain (Joyce, 2013; Wilson, 2006). Although curtailment orders were originally implemented in response to extreme, multi-year drought conditions, they have remained in place despite consecutive years with limited to no drought impacts (US Drought Monitor). AB 263—signed into law in September 2025—allows curtailments to remain in place until January 1, 2031, or until permanent rules are adopted (whichever comes first), underscoring the urgency for ranchers to adapt to lasting regulatory changes.

COST OF PRODUCTION

Climate change impacts create economic pressures that are increasingly untenable for Siskiyou's ranchers. Agricultural input costs increased substantially between 2020–2025, eroding already-thin profit margins (USDA National Ag Statistics Service, 2025). The market value of ranches continues to rise, far exceeding revenue from livestock production. This disparity drives land use change, often leading to increased absentee landowners, development, fragmentation of working landscapes, and a decline in available grazing land (Brunson, 2008; Briske, 2023; Ikendi, 2025). The increasing frequency and intensity of climate-related events, particularly wildfire, has made access to affordable and reliable insurance one of the most critical gaps in economic resilience for Siskiyou's agricultural producers. These trends highlight how climate-related threats amplify existing economic vulnerabilities, leaving Siskiyou ranchers with fewer tools to sustain viable operations. First-generation ranchers and small- to mid-sized operators often have fewer resources to buffer the effects of these threats, leaving the next generation of land stewards particularly vulnerable (Woodmansee, 2025; Munden-Dixon, 2018; Roche, 2016).

POLICY MISMATCH AND ACCESS BARRIERS

Regulations can limit adaptation and become counterproductive when applied through a one-size-fits-all approach, developed without input from on-the-ground managers, or lacking the flexibility to accommodate local conditions (Woodmansee, 2021; Ikendi, 2025; Roche, 2016). For example, ranchers who proactively implemented irrigation efficiency projects were disproportionately impacted by curtailment orders, as their reduced "baseline" water use resulted in greater relative cutbacks. Groundwater recharge projects, widely recognized as win-win opportunities across Siskiyou, have been substantially delayed due to lack of coordination among agencies, inconsistent policy interpretations, and tedious reporting requirements.

The cost of regulatory compliance must also be considered. Ranchers are required to monitor inputs and impacts (e.g., applied water, soil moisture), largely at the expense of the individual operator. The cost of these efforts is twofold: 1) infrastructure, and 2) time in the form of labor associated with monitoring or reporting. In a 2023 focus group, one Siskiyou County rancher commented "the amount of time that we spent tracking our 30% water curtailment… getting that third-party certified… is unrealistic." (Ikendi et al., 2025).

RANCHING AS CLIMATE INFRASTRUCTURE

To enhance the resilience of forage systems, Siskiyou County ranchers are becoming increasingly interested in the potential benefits of alternative crops and resurgent and novel land management strategies (e.g., cover crops, compost application). Although these strategies have been extensively researched in other regions of California, science-based best management practices for Siskiyou are urgently needed. Broad, priority research topics for ranchers include: 1) building economic and ecological resilience to drought and reduced irrigation water availability, and 2) adaptive management strategies for dryland and irrigated pasture (e.g., timing of planting, variety/cultivar selection, tolerance to deficit irrigation, etc.).

Flexible, stable funding is critical for researchers and technical assistance providers to lead region-specific research and outreach efforts. Funding sources and cost-share programs with flexible inputs (e.g., management strategies, plant species, monitoring plans) that can be tailored to fit region-specific needs are most beneficial. For example, many state and federally funded programs specify which plants (e.g., native vs. non-native classification) must be seeded as part of a pasture enhancement or restoration project. When these requirements are prescriptive, the likelihood of project success is reduced. Projects can effectively center local knowledge and expertise by:

1. **Prioritizing land manager knowledge in shaping climate-related policy decisions.** Programs centering rancher values and lived experience achieve higher engagement, while a "one-size-fits-all" approach limits adaptive capacity and risks leaving critical land resources unprotected (Petersen-Rockney, 2022; Woodmansee, 2025; Roche, 2016).
2. **Expanding cost-share opportunities** for projects that enhance the climate resilience of working lands. Successful models advance current best management practices (e.g., Roche, 2016; Woodmansee, 2025).
3. **Updating regulatory frameworks to enable agile adaptation.** Scaling up climate adaptation at a meaningful pace requires flexible, region-specific strategies focused on achieving clear outcomes rather than adhering to prescriptive management approaches (Petersen-Rockney, 2022; Roche, 2016).

4.7.2 Cannabis

Author: *Evan Mills*

Despite significant post-legalization market disruption due to collapsing prices, inflation, and regulatory compliance hurdles, California cannabis production continues to rise (DCC, 2026) (see **Appendix 4.4** for climate and energy footprint of cannabis cultivation). Total licensed production increased 82% between 2020–2025 while falling 2% in the North Coast (**Figure 4.3**), resulting in the region's share of statewide production declining from 28% to 15%, accompanied by falling gross revenues, farm closures, consolidation, relocation of farms out of the area, and reversion to unlicensed operations. While highly energy-dependent indoor cultivation is uncommon in the North Coast, volumes doubled over this period (DCC, 2026b), while more than tripling statewide.

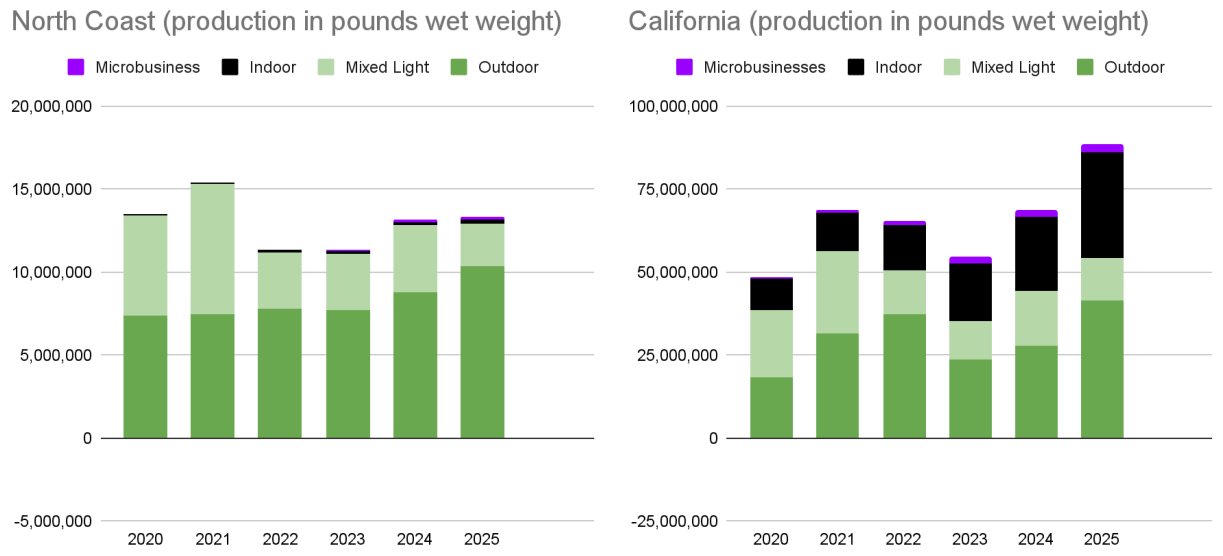


Figure 4.3: *Trends in Licensed Cannabis Production (wet weight), North Coast (left) and California (right). North Coast includes Lake, Mendocino, Humboldt, Trinity, and Siskiyou counties (Del Norte grouped as "Other" by DCC, so not included in the chart on the left). Indoor cultivation occurs in permanent structures using exclusively artificial light, or within any type of structure using artificial light, at a rate >25 W/ft²; mixed-light combines natural and supplemental lighting (Tier 1 ≤6 W/ft²; Tier 2 >6–25 W/ft²). Microbusinesses cultivate <10,000 ft² using any of the three methods and may also distribute, manufacture (Level 1), and retail. Data exclude nurseries and home cultivation.*

CLIMATE RISKS TO THE CANNABIS INDUSTRY

Multiple climate risks to cannabis production are recognized by the industry (Silverberg, 2025). Outdoor cultivation is vulnerable to extreme weather, drought, and pests, particularly when occurring during seasonal peak production in the fall (see **Appendix Figure 4.4.B**, top panel) as to gradual climate shifts that impact growing conditions. Mixed-light facilities typically obtain two harvests and are thus more temporally diversified, while indoor facilities exhibit the most diversification (see **Appendix Figure 4.4.B**, lower panel). Wildfire is a hazard to all forms of cultivation—production losses estimated at 9–43% in northern counties in recent years (Dillis et al., 2023)—with recovery more costly for indoor cultivators and few perceiving indoor cultivation as an attractive adaptation strategy (Martin et al., 2025) due to expense and remaining smoke-damage risk combined with vulnerabilities to energy costs and power disruptions. For indoor facilities, power outages—projected to increase under climate change due to many reasons (see Chapter 3)—can disrupt critical illumination, irrigation, and dehumidification, and the latter can trigger destructive fungal outbreaks resulting in crop losses. Further compounding risk, cannabis operations' loads on the grid have contributed to documented power outages (Mills, 2025a).

Indoor agriculture offers protection against weather extremes but creates other maladaptations in that energy requirements to maintain artificial climates and illumination are orders of magnitude higher than for outdoor-grown crops, and entail higher water use when figuring in electricity production and non-utilization of rainfall (Mills, 2025a and b). Water availability will decline in some areas due to climate change (see Chapter 1). Statewide, about 20% of cultivators report

rainfall as their primary source of irrigation water (Schimelpfenig et al., 2021), presumably more in wetter coastal regions. These factors may result in coastal areas becoming more optimal for outdoor cultivation. Adaptation via relocation is challenging, particularly with respect to capital-intensive indoor facilities and relicensing challenges.

Poor cultivation practices can also erode resilience in other spheres. Examples include land use change, pollution of air and water, water table depletion, solid waste production, wildlife disturbance, and trespass cultivation, each amplifying vulnerability of human and natural systems to climate impacts (Bustic et al., 2018; Dillis et al., 2020; Parker-Shames et al., 2022; Wartenberg et al., 2021). Moreover, indoor cultivation environments can compromise health and safety of workers who tend to disproportionately represent marginalized populations (Mills, 2025a; Warren, 2023), while high capital and operating costs raise insolvency risk (Pinstrup-Andersen, 2018; Bomford, 2023) and associated local economic impacts.

CLIMATE RESILIENT CANNABIS

Many considerations outlined here suggest that the climate vulnerability of indoor cultivation has lower probability but higher consequences. Rural, coastal cultivation could provide superior climate resilience and related socio-economic and public health benefits. North Coast licensed operators currently have negligible existing exposure to indoor cultivation risks and associated environmental burdens compared to the rest of the state, although indoor operations may be more common among unlicensed operators, some of which are powered by diesel generators (Humboldt County Sheriff's Office, 2023).

Adaptation strategies for indoor operations are particularly costly, including on-site generation or battery storage. Land use required for powering these facilities with solar PV arrays exceeds the use needed for open-field cultivation by many-fold (Mills, 2025b). Some of these strategies are thus maladaptative. Constructive pathways for outdoor cultivation include seasonal water storage together with restorative farming techniques using less land and water (Beeby et al., 2020; Moore, 2010; Mills, 2022), while eliminating synthetic inputs and respecting land ownership (see *Section 4.1 Indigenous Knowledges;* see also Reed, 2023), environmental regulations, and worker rights. A hybrid approach, utilizing lightweight hoop-house structures, employs a translucent weather-protection membrane but does not require space-conditioning or artificial lighting, consequently using ~1% as much energy as industrialized facilities while offering multiple resilience benefits (Mills, 2025b). Sustainable cultivation methods improve resilience while commanding higher product prices. Importantly, federal crop insurance—a financial tool for resilience—is unavailable to cannabis producers.

Market distortions—such as bans on outdoor cultivation across large portions of California, regulatory incentives, and differential subsidies such as utility rebates—favor indoor cultivation. These market structures warrant further evaluation, particularly the extent to which market design, consumer information about sustainability, and branding of outdoor appellations (which are particularly distinctive in the North Coast region) could realign incentives toward climate-resilient production (Mills, 2025a; CDFA, 2026). Given the proprietary nature of the licensed market and secrecy in the unlicensed market, public-goods research and development could support improved practices (Mills, 2025c). Promising focus areas include resilient siting based

on microclimate data, cropping methods for reduced water and land use, cultivar selection and genetic-level resilience enhancements, crop-protection strategies that do not require significant energy use, and market-focused research such as evaluating evidence that outdoor-grown cannabis can be of equal or higher quality (Mills, 2025a).

4.8 Public Health

Authors: *Wendy Ring and Ana Alanis*

The final four sections address climate change as a risk multiplier, exacerbating pre-existing social vulnerabilities that can hinder community adaptive capacity. With respect to public health, the North Coast faces climate impacts similar to those affecting the rest of California (see the Fifth Assessment's "Public Health" report prepared by the California Department of Public Health for statewide context). However, higher proportions of residents who are physiologically sensitive and/or socioeconomically vulnerable, along with the resource limitations characteristic of rural counties, disproportionately increase health harm in our region.

4.8.1 Physical Health: Extreme Heat

The Office of Environmental Health Hazard Assessment (OEHHA) and Cal-Adapt define extreme heat as temperatures above the 95th or 98th percentile of the historic temperatures for a specific location. This definition recognizes that daytime temperatures in the high 70s (°F) and nighttime temperatures in the high 50s (°F) on the coast can confer the same risk as much higher temperatures inland (see **Table 1.1** and **Appendix 1.1**). As climate change proceeds, not only might average temperatures increase, but variability (especially in summer) may also increase (see **Appendix 1.1**). Extreme heat increases emergency room visits, hospital admissions, cardiorespiratory deaths, kidney disease, and adverse birth outcomes (Bell, 2024; Le, 2025; Lakhoo, 2025). Children under 5, adults over 65, people with chronic disease, residents of disadvantaged communities, people with disabilities, people living alone, and outdoor workers are disproportionately affected (Bell, 2024).

The Heat and Health Index, developed by the U.S. Centers for Disease Control and Prevention (CDC), identifies many zip codes in the North Coast region as being at unusually high risk due to higher-than-average percentages of these vulnerable groups, with some zip codes ranking in the top 10% nationally (CDC, 2025; **Figure 4.4**). Residing in a mobile home also confers significant risk, with mortality rates 6–8 times higher for those living in a mobile home compared to those living in a building (Varfalameyeva et al., 2021). Mobile homes comprise 10–20% of housing units in Mendocino, Lake, Trinity and Siskiyou counties and over 20% of homes in Del Norte County. Disability is one indicator in the Heat and Health Index that deserves particular attention, as the North Coast has a high prevalence of disability compared with the state average (**Figure 4.5**). In Lake and Del Norte counties, which rank in the top five, one in five residents is disabled.

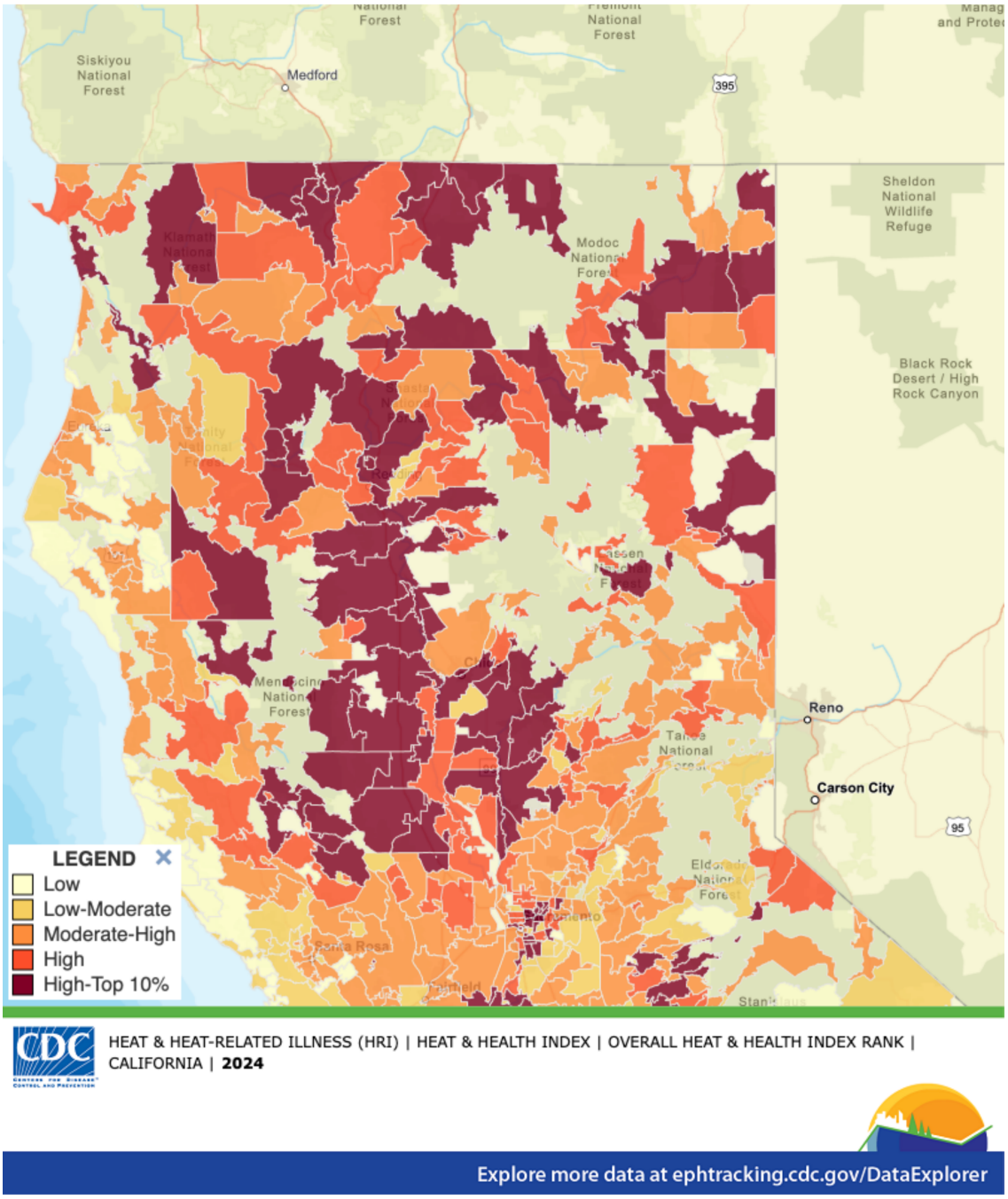


Figure 4.4: *Heat Health Index (HHI) for California ZIP Code Tabulation Areas (ZCTAs). The US Centers for Disease Control and Prevention (CDC) HHI map depicts relative heat-health vulnerability at the zip code level, categorized from Low (light yellow) to High–Top 10% (dark red).*

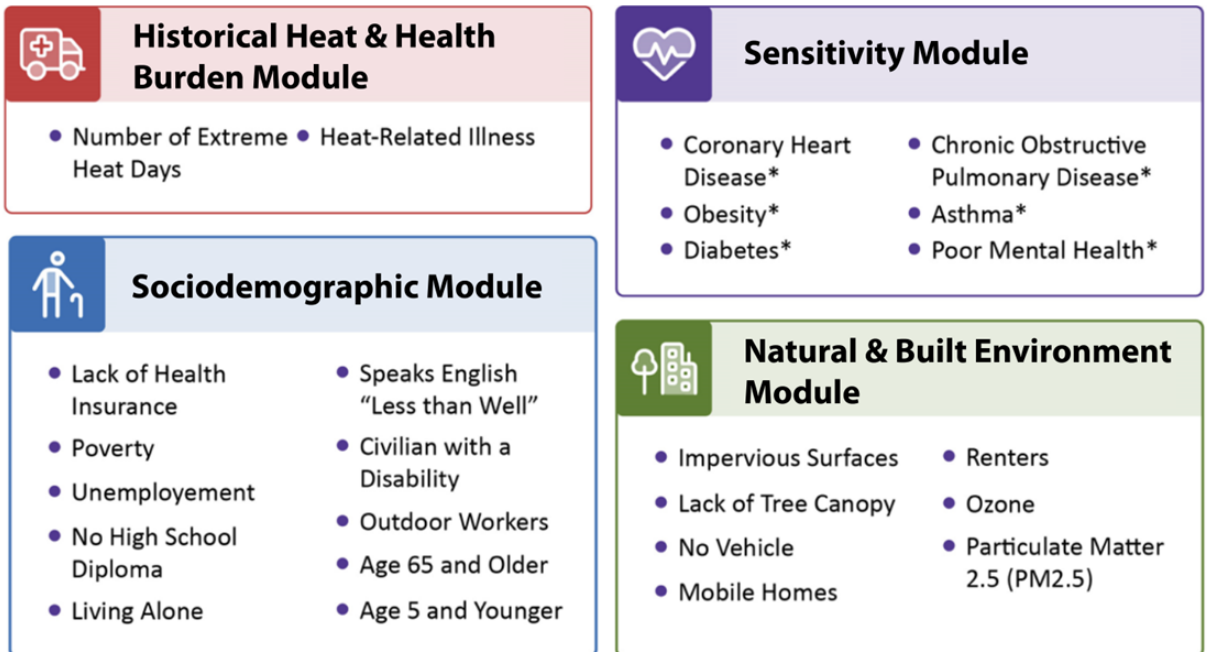


Figure 4.5: *Heat Health Index (HHI) for California ZIP Code Tabulation Areas (ZCTAs).*

4.8.2 Physical Health: Wildfire

The North Coast has had more exposure to wildfire smoke over the past two decades than other parts of the state. Between 2006–2020, counties in the region experienced some of the highest numbers of "smoke waves" in the state and highest long-term exposures to Particulate Matter 2.5 (PM2.5) (OEHHA, 2022; Casey, 2024; Koman, 2019). Wildfire smoke contains harmful air pollutants: polycyclic aromatic hydrocarbons, which have irritant, carcinogenic, teratogenic, and endocrine disrupting properties; nitrogen oxides and volatile organic compounds, which are ozone precursors; and fine particulates (PM2.5), which pose the greatest hazard to health. Inhaled fine particulates penetrate deep into the body, damaging respiratory, cardiovascular, neurologic, immune, and reproductive systems. Wildfire PM2.5 increases premature deaths, hospitalizations, emergency room visits, and adverse reproductive outcomes (Liu et al., 2022). Low-income and Native residents were disproportionately affected and are among the groups most vulnerable to poor air quality, along with children, elders, and people with heart and lung disease (OEHHA, 2022).

Recent research has shown wildfire PM2.5 to be more toxic than PM2.5 from fossil fuel, causing nearly double the mortality rates and an increase in adult and pediatric respiratory hospitalizations by nearly 10 times (Aguilera, 2021; Yu, 2023; Alari, 2025). Serpentine soils unique to our region add additional toxicity as wildfires convert chromium to its highly toxic and carcinogenic hexavalent form and incorporate it into airborne fine particles (Lopez, 2023). Heat and wildfire smoke are synergistic in their health impacts, with co-exposures causing more premature births and hospital admissions than would be expected from their individual effects

(Ha, 2024; Chen et al., 2024). North Coast residents have less protection from both due to a low prevalence of air conditioning.

Policymakers sometimes find false assurance in the fact that North Coast counties are among the few in attainment for state and federal air quality standards (CARB, 2024; see also **Appendix 4.5** for climate impacts on drinking water). This status is misleading because air pollution from wildfire and prescribed burns is exempt from attainment considerations (EPA, 2019). Since wildfire PM2.5 now constitutes 50% of California's PM2.5 pollution, this exemption increasingly divorces air quality standards from wildfire's actual public health impacts (Krupnik, 2021). Another common misconception is that lower background levels of PM2.5 provide protection from wildfire smoke, when they may actually increase susceptibility. Studies suggest that older adults in historically low-pollution areas may experience larger relative increases in hospitalization risk per incremental rise in PM2.5 compared to those in chronically polluted regions (Di et al., 2017; Wang et al., 2020).

4.8.3 Mental Health

Climate change adds stress to a population already overburdened with mental health challenges. The six North Coast counties consistently rank among the highest in the state for mortality rates due to drug overdose, suicide, and accidental injury (California Department of Public Health, 2024). Adverse Childhood Experiences (ACEs), such as losing a family member to one of the above causes, have lifelong consequences. Four or more ACEs triple the risk of mental illness, increase the risk of drug abuse eleven-fold, and raise the risk of suicide attempts by 3,000% (Felitti et al., 1998). Quadruple ACEs also increase rates of heart, lung, and liver disease; cancer; and dementia (Hughes et al., 2017; Schickedanz et al., 2022). Forty of the North Coast's population is enrolled in Medi-Cal. Likewise, 33–61% of screened Medi-Cal adults in the region report having four or more ACEs, a burden two-to-three times the state average (ACEs Aware, 2025). Experiencing a climate-related disaster is not an ACE, but it increases other ACEs. Domestic violence service providers in California have reported 200–300% increases in demand for shelter and restraining orders several months after wildfires. Wildfire survivors have increased rates of anxiety, depression, and substance abuse (Weisberg, 2025; To, 2021). Domestic violence, suicides, and drug overdoses increase with extreme heat (Dennett, 2025; Le, 2025). Developing emotional resilience skills and social connections decreases the adverse effects of ACEs and should be part of building multi-generational resilience to climate impacts.

Climate change further harms mental health by threatening culturally significant foods, places, and practices. For Native residents, climate-related loss of salmon has been associated with declines in physical and mental health. Save California Salmon is a nonprofit whose advisory board includes leaders from Tolowa, Hoopa Valley, Winnemem Wintu, Yurok, and Sherwood Valley Tribes. On their website, they reported apparent increases in Yurok suicide rates linked to low salmon runs and poor river health and noted that: "since salmon numbers have declined, it is estimated the Karuk Tribe's diabetes rate soared to nearly four times the US average" (Save California Salmon, n.d.; see also Norgaard, 2005). Scholars have further described how ecological losses of culturally significant kin can manifest as ecological anxiety, grief, and trauma, particularly to Indigenous and frontline communities (Ray, 2020; Reyes, 2025) and children (Hickman et al., 2021).

4.8.4 Limited Access to Care

Access to healthcare on the North Coast is limited by critical shortages of mental health, primary care, and specialty providers. All six of the region's counties are designated Health Professional Shortage Areas (Arledge & Flynn, 2023). Recent federal health cuts are already shrinking public health departments and are about to swell the ranks of the uninsured, posing a severe threat to the solvency of rural hospitals. Accessing health facilities and clean air and cooling centers may require long drives on roads in poor condition that can be blocked by wildfires, slides, and floods (see **Table 3.2**). While these respite centers and microgrid-powered community hubs are important resources for resilience (see *Section 3.2.5 Pathways for Infrastructure Transformation*), many rural residents won't be able to reach them.

Home retrofits would resolve many of these barriers while reducing energy bills and greenhouse gas emissions. But incentive programs designed to serve other parts of the state either have eligibility criteria that exclude everything except Tribal lands, or impose application and documentation requirements that give large urban companies unfair advantage over the region's small solar and HVAC businesses in the competition for limited funds.

4.8.5 Regional Strengths

The foregoing picture of a population highly vulnerable to large and escalating climate forces is frightening but not the full picture. Conditions like heart disease, reactive airways, and lack of air conditioning or gas money to escape heat and smoke are physical factors that should not be conflated with weakness and inability to participate in and contribute to planning for resilience. The key to limiting the health impacts of climate change in the North Coast region is planning for and with the population segments most vulnerable to harm as well as addressing housing, workforce development, and other infrastructure critical for public health (see Chapter 3).

4.9 Racial and Social Equity & Climate Justice

Author: *Jen Marlow*

As evidenced in *Section 4.8 Public Health* above, regional social and demographic characteristics increase exposure or sensitivity to climate impacts (see also Chapter 1 and **Box 4.3**), thus lessening the ability of the region's vulnerable communities and Tribes to cope with these impacts. The North Coast's population is predominantly white (72%) compared to the rest of the state (44%) (see **Appendix Table 4.1.B**). The North Coast has a higher proportion (4%) than the state (1%) of the population identifying as American Indian or Alaska Native. A growing percentage of the population identify as Hispanic or Latino (19%) and multi-racial (13%) (see **Appendix Table 4.1.B**).

Analysis by the California Center for Rural Policy (CCRP) suggests that vulnerable populations experience many of the same impacts from climate hazards (see **Appendix Figure 4.6.A** and **Figure 4.6**). However, Tribal populations throughout the region face disproportionate threats (see **Appendix Case Study 2.3.A**), including declining access to fresh drinking water sources, fisheries, and cultural activities (CCRP, 2025).

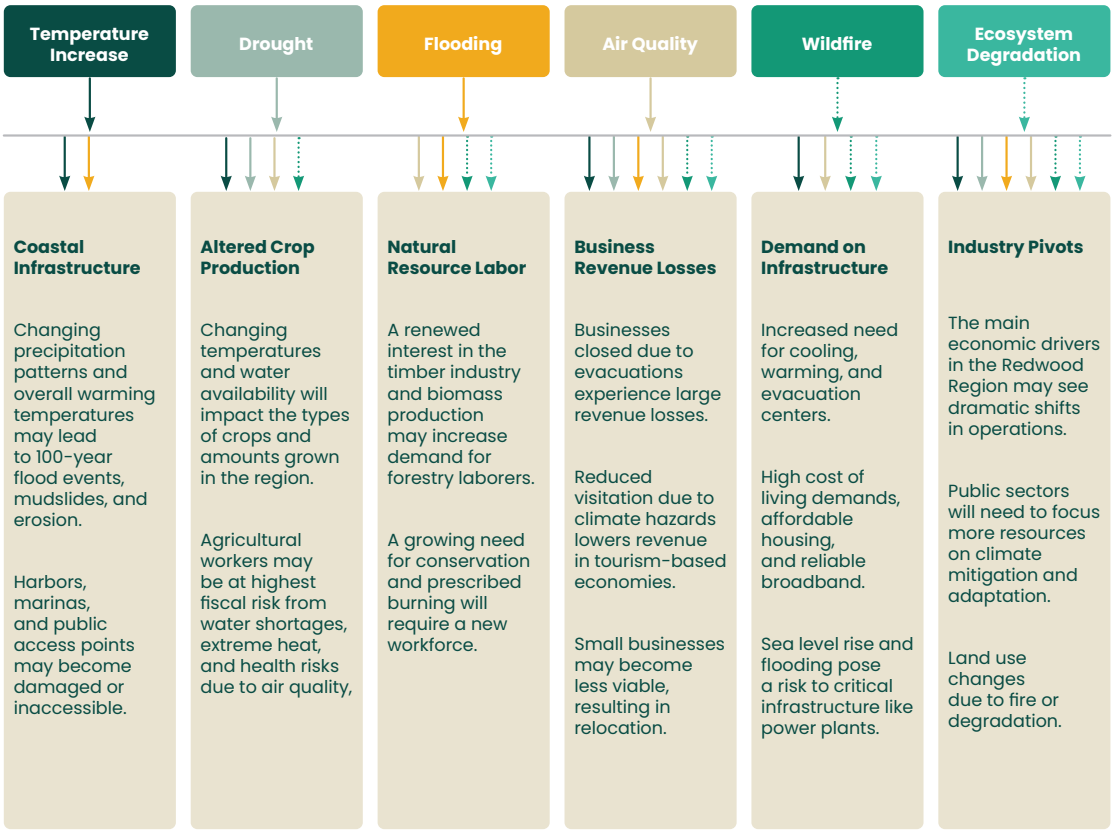


Figure 4.6: *Climate impacts on vulnerable populations in the Redwood Coast Region. Sourced from The California CCRP. (2025). Redwood Region Regional Plan Part 1, California Center for Rural Policy at Cal Poly Humboldt. Reprinted with permission.*

One outstanding challenge is that despite the high levels of poverty in the region, the North Coast ranks low on environmental justice screening tools such as CalEnviroScreen, which uses 21 statewide indicators to characterize pollution burden and sensitive populations and guide priority climate investments (see **Appendix 4.6.C**). Due to conflicting nomenclature, metrics, and criteria used by state and federal agencies to define which geographic areas are disadvantaged, distorted rankings may result in the unjustified disqualification of deserving areas in this region for urgently needed funding. For these reasons, there is value in thinking about equity more broadly by taking a more nuanced and regional approach (Community Advisory Board, 2024). One possible way to increase the region's eligibility to receive billions of dollars in needed climate and ecosystem resilience funding may be to allow the North Coast to convene a process that designates which environmental justice criteria are most meaningful to the region and demonstrate how such criteria apply to various funding proposals.

Ensuring that such a process is fair and inclusive is critical. Research shows that perceptions of fairness in decision-making processes can be as important as the fairness of the outcomes themselves (Thibaut & Walker, 1975). In **Box 4.3**, Brandon Quintana demonstrates how substantive and procedural justice considerations are equally essential to coastal communities impacted by sea level rise in Mendocino County.

Box 4.3: Sea Level Rise, Environmental Justice, and Equitable Coastal Adaptation

Author: *Brandon Quintana*

On California's North coast, the impacts of sea level rise—more extensive storm and tidal flooding, rising groundwater, and increasing rates of erosion rates (Griggs et al., 2017; see also Chapters 1 and 2)—are not distributed equitably among populations. Taken together, the impacts of sea level rise on coastal beaches, wetlands, habitats, and public accessways, often available to the public for little or no cost, will disproportionately affect environmental justice communities whose members cannot afford to live near the coast and/or were forcibly restricted from living in coastal areas (California Coastal Commission, 2024). Environmental justice communities often experience heightened risk and increased sensitivity to climate change and have less capacity and fewer resources to cope with, adapt to, or recover from climate impacts (Cutter et al., 2009; Cutter et al., 2003). This is particularly true for communities dependent on at-risk industries that are reliant on being adjacent to the coastline, those already facing economic hardship, and populations with limited capacity to adapt, including lower-income, linguistically isolated, elderly, and other vulnerable populations.

Tribal communities face distinct climate risks (see **Appendix 4.6.B**; see also the Fifth Assessment's "Tribal and Indigenous Communities Statewide Topical Report"). Sea level rise threatens coastal access, subsistence resources, and sacred cultural sites, local water quality, traditional food systems, and harvesting practices (see Chapter 2). Many Tribes were forcibly relocated to coastal lands now at high risk of flooding and erosion, with limited options for retreat. Infrastructure and ancestral sites face growing vulnerability (**Appendix Case Study 4.3.A**). The Yurok Tribe, for example, has highlighted surface water and aquatic resource degradation as key threats (Black et al., 2015). These risks affect food systems and food sovereignty (the right of communities to define their own food systems, including access to traditional and subsistence foods), health, and cultural survival. Adaptation planning must account for the interconnections among shared values.

At the statewide level, the California Coastal Commission's Environmental Justice Policy (2019) marked a shift in integrating equity into regulatory guidance. The Commission used Coastal Zone Management Act Section 309 funding to update the 2018 Sea Level Rise Policy Guidance. Staff convened eight paid environmental justice and Tribal advisors who helped shape the public engagement plan and draft outline. Their feedback led to major updates: earlier and deeper engagement requirements, strategies for identifying vulnerable communities, and clearer integration of health and environmental burdens in the Local Coastal Plan and the Coastal Development Permit review process. Several advisors stated this process was the first time they felt heard by a government agency. The updated policy guidance illustrates how environmental justice can be embedded in adaptation frameworks—from public meetings to funding streams, to agency guidance, and regulatory mandates. Meaningful inclusion of environmental justice communities and Tribal leadership is essential to equitable planning (see **Appendix 4.6.D** for a Mendocino County case study). Ensuring these voices are heard and considered in the planning process is essential to developing equitable and meaningful responses to coastal climate change in California. As climate impacts escalate, the effectiveness and legitimacy of coastal planning will depend on how well it reflects the knowledge, priorities, and rights of those most affected.

4.10 Human Displacement

Authors: *Laurie Richmond and Kristina Kunkel*

Climate-induced displacement—a growing phenomenon statewide—is particularly salient for the North Coast (see the Fifth Assessment's "Climate-Induced Human Displacement and Migration Statewide Topical Report"). King Salmon, a small, unincorporated community on the North Coast, faces some of the highest projected sea level rise (SLR) risk in the state (Laird, 2019). King Salmon is located in Wigi, or Humboldt Bay, a region experiencing the highest recorded rate of relative SLR in California if not the US west coast (NHE, 2014; Patton et al., 2017, 2023; see also Chapter 1, *Section 1.5 North Coast Sea Level Rise*). Wigi is the Wiyot name for Humboldt Bay; Wigi is a part of the ancestral territory of the Wiyot people.

Interviews with 17 residents, property owners, and business operators in King Salmon revealed a community deeply tied to place but unsure of its future. King Salmon already experiences periodic flooding during extreme high tides. Projections indicate that even 1 foot (0.3 m) of SLR would

cause monthly flooding in many areas. At 3.2 feet (1 m) of SLR, King Salmon would experience daily inundation, with transportation routes overtopped monthly (**Figure 4.7**).



Figure 4.7: *King Salmon, California, projected mean monthly maximum water with 1 foot or 0.3 m of SLR, showing (in blue) daily tidal inundation in nearly all residential areas on a monthly basis. Right: Projected mean monthly maximum water with 3.2 feet or 1 m of SLR, showing near total inundation of residential areas, assets, and transportation routes on a monthly basis. Laird 2018; SLR projections from California Sea Level Rise Guidance (2024).*

Several residents expressed a desire to adapt in place by raising homes or fortifying infrastructure. Others acknowledged they might one day have to relocate but felt uncertain about when, how, or whether help would be available. One resident explained, "I might have to move and I'm just keeping my fingers crossed…I'm assuming at some point, everybody's gonna have to move out of here." During a Humboldt County "Communities at Risk" workshop in 2018, a few residents suggested relocating the community or showed an interest in relocating on their own. One person asked, "Can't the school and homes and structures be moved? What's the point of building a barrier if groundwater will flood the area anyway?" Some expressed concern that King Salmon and similar communities might be "written off" as unworthy of protection due to their lower property values and socioeconomic status.

These findings offer important insights relevant statewide across different contexts, including inland locations. Planning for climate displacement can fail to address equity risks deepening patterns of privilege and dispossession. Community-driven planning processes in King Salmon, for example, have demonstrated that approaches that center equity are more likely to avoid risking retreat becoming a vehicle for coastal gentrification. If lower-income communities are relocated and wealthier areas protected, the result will be a more exclusive and inequitable coast. Encouragingly, Humboldt County has secured funding from the California State Coastal Conservancy to co-create community-driven vulnerability and adaptation plans for King Salmon and nearby Fields Landing based on sustained outreach, support for locally appropriate strategies, and a commitment to equitable outcomes. Such projects may serve as a model for inland communities displaced by wildfire, although further research is needed to assess how to adapt them to different contexts (Bardeen, 2024).

4.11 Emergency Capacity and Rural Recovery

Authors: *Catriona Barr and Erin Kelly*

> *"The experience of climate-related disasters changes you. Devastation can bring people together." —Terre Logsdon, Chief Climate Resiliency Officer, Tribal Liaison, Lake County*

Turning next to inland disaster contexts, this final section demonstrates how rural regions remain a blind spot in mainstream disaster planning. The 2020 wildfire season burned over 4.2 million acres in California, testing emergency response systems and revealing stark differences in recovery capacity between communities. The towns of Ruth (Trinity County) and Happy Camp (Siskiyou County) exemplify how varying levels of formal and informal infrastructure shaped both immediate relief and long-term rebuilding and guide recommendations to policymakers (see **Table 4.1**).

Table 4.1 *Select fire-impacted communities and their attributes.*

Fire-impacted communities	Happy Camp, CA	Ruth, CA
Population size	1,000	300
Population distribution	Identifiable town and town center	Dispersed population, no town center
2020 fire	Slater Fire (157,270 acres)	August Complex (1,032,648 acres)
2020 fire impacts	212 homes destroyed, 2 people killed	228 homes destroyed (across Trinity County), 1 person killed

Both towns were economically vulnerable before the fires, facing declining timber revenues and a collapsing cannabis market. Post-fire, survivors in both communities navigated a patchwork of fragmented recovery resources administered by FEMA, state agencies, nonprofits, and private businesses. Most residents lacked insurance, and renters were largely excluded from assistance. According to one person involved in Happy Camp's recovery, "80% of the people who lost their homes [in the Slater Fire] didn't have insurance, and some of them had lost it that year because the insurance companies just don't write in our area anymore." Furthermore, complex eligibility rules and siloed programs often delayed aid.

In the face of systemic gaps and barriers, these communities turned to local resources and their social networks to meet recovery needs, advocate for more assistance, and directly support one another. In Happy Camp, the Karuk Tribe and the Happy Camp Community Center led the recovery. The Karuk Tribe swiftly delivered food and supplies and repurposed COVID-19 relief funds to provide approximately 100 travel trailers as temporary housing. This enabled Tribal staff and other residents to return to Happy Camp and to their jobs, stabilizing the community. In the words of one resident: "[The trailers] really did keep people here…With the advent of receiving those RVs, people could come back. They could work. They could keep things going." The Happy Camp Community Center worked with other regional partners including the Ford Family Foundation, the McConnell Foundation, and United Way to launch a relief fund for fire survivors and provide case management, childcare, and trailer repair. The Slater Fire Long-Term Recovery Group, a FEMA-endorsed model, brought together the Community Center, the Karuk Tribe, and statewide nonprofits to coordinate housing recovery and, ultimately, fire mitigation planning.

In contrast, Ruth and nearby Zenia, lacked such formal structures. Residents organized evacuation shelters and volunteer kitchens, while key individuals leveraged personal networks to bring in

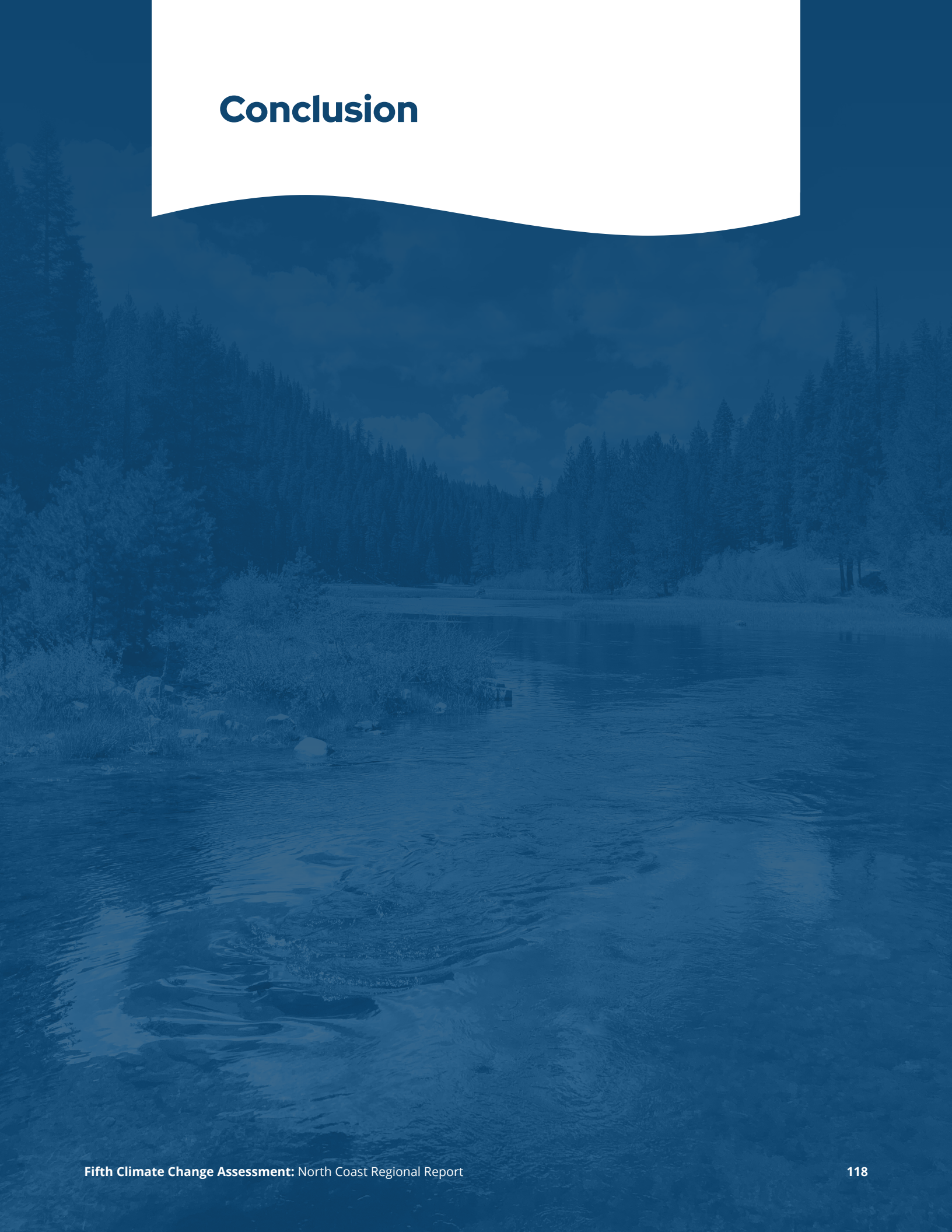
resources. Regional nonprofits and Humboldt County businesses sent supplies, and local churches and stores became informal distribution centers. Fire survivors used donated supplies and volunteer labor to repair infrastructure—especially water systems.

Yet, formal support for rebuilding was nearly non-existent. There was no FEMA trailer program, no county-level Long-Term Recovery Group, and only one household received a grant for rebuilding. A single disaster case manager served as the only link to the external recovery system. Of the 65 households that lost homes, only eight are rebuilding. Case management data suggests 90% of those impacted by the fire have left the area following the August Complex, with most leaving the state of California entirely (see the Fifth Assessment's "Climate-Induced Human Displacement and Migration Statewide Topical Report"), with implications for population size (DeWaard et al., 2024), workforce, and local tax revenue (DeWaard et al., 2024; Paci et al., 2023).

Lessons learned from Ruth and Happy Camp that demonstrate the importance of post-fire recovery to climate resilience include:

1. **Creative and flexible funding models strengthen recovery.** In the unincorporated community of Happy Camp, the Karuk Tribe led recovery efforts by leveraging the Tribe's sovereign status to secure federal recovery assistance after FEMA initially denied a Major Disaster Declaration for the Slater Fire.
2. **Community-based organizations play a significant role in emergency response.** Grassroots institutions—like churches, food banks, and general stores—often serve as effective distribution centers in rural communities. Programs such as FireSafe Council's Trinity County Local Area Advisors Program that recognize or compensate informal community leaders as liaisons and recovery coordinators build local capacity to respond to wildfire swiftly and effectively.
3. **Prioritize multi-hazard mitigation plans.** Accounting for demographics, population size, and access to resources can empower communities in advance of wildfire. Strategic communications messaging that reflects local contexts, like the Blue Lake Rancheria's Tribal Multi-Hazard Mitigation Plan, and relies on accessible messaging, creates preparedness plans that are language, age, and culturally appropriate (see also **Appendix Case Study 4.2**).

Conclusion



The North Coast region stands at a critical juncture as accelerating climate impacts intensify existing vulnerabilities, while also creating new opportunities for adaptation and investment. The success of climate adaptation in the North Coast may ultimately depend on whether state policies can evolve to support and scale the Tribally-led, locally driven, and nature-based solutions already proving effective at increasing resilience across the region. Five cross-cutting themes emerged from this report that can help guide state climate adaptation policy:

1. **Tribal sovereignty.** Projects centering Tribal sovereignty in multilevel government approaches to climate adaptation have restored land, rights, and relationships—all pathways to building climate resilience (see *Section 4.1 Indigenous Knowledges*). Examples include land return, such as the return of Tuluwat Island to the Wiyot Tribe and Blue Creek to the Yurok Tribe. Existing legislation, such as SB 310 on cultural burning, which streamlines permitting for federally recognized Tribes, could be extended to non-federally recognized Tribes. Curriculum development in partnership with Tribal knowledge holders, such as Caring for Clear Lake for K–12, and Cal Poly Humboldt's Native American Studies Department PolyTEK programming, could serve as models to promote reciprocal knowledge exchange (see *Section 4.1 Indigenous Knowledges, Section 4.3.1 Tribal Governance*, and *Section 4.2 Education*). Projects that recognize Tribal sovereignty could contribute to addressing historical harms, reducing climate risk, and restoring ecological and governance relationships in California.

2. **Reformed finance, grant making, and insurance.** Finance, insurance, and grant reform are central to strengthening regional resilience in the North Coast. Programs that optimize co-benefits—such as regenerative agriculture, upstream ecological restoration (ecological uplift), and workforce development initiatives like Redwood Region RISE (Resilient Inclusive Sustainable Economy)—have generated well-paying jobs while advancing long-term adaptation. Notably, ecological uplift work already represents an estimated 20% of civil construction spending in the region but could be formally recognized in existing job classification systems (see *Section 4.4 Labor & Workforce Development*). Where market structures incentivize practices that increase climate risk, realigning incentives could strengthen regional resilience (see *Section 4.6 Insurance* and *Section 4.7 Economics*). Grant reform is equally critical: reducing match requirements, providing advance payments, expanding cost-share models, and incorporating green microfinance mechanisms could provide more equitable access to funding (see *Section 4.3 Governance* and *Section 4.5 Finance*). Finally, wildfire events such as the Slater and August Complex Fires—where many residents lacked insurance and renters were largely excluded from assistance—highlight the necessity of exploring alternative insurance models along with more transparent risk modeling to support post-disaster recovery (see *Section 4.6 Insurance* and *Section 4.11 Emergency Capacity and Rural Recovery*).

3. **Tailored climate vulnerability metrics.** Environmental justice screening tools do not always capture North Coast realities. Standards that exclude wildfire pollution, for example, may underestimate health impacts in our region, which otherwise has clean air (see *Section 4.8 Public Health*). Relatedly, in places that appear off the map, "no data" does not always mean "no risk"; holes in the data require further investigation via community-engaged research methods (see *Section 4.10 Human Displacement*). Finally, redirecting disaster resources to invest in smaller, ad hoc, community-focused networks in rural and unincorporated communities could build local capacity and speed up recovery (see *Section 4.11 Emergency Capacity and Rural Recovery*).

4. **Regional collaborations.** Regional collaboratives have emphasized prioritizing multi-objective projects that address convergent crises, including ecosystem health, extreme heat, human mobility, affordability, and inequitable access to healthcare. The concentration of mobile homes in Mendocino, Lake, Trinity, Siskiyou, and Del Norte counties—representing 10–20% of housing—presents an opportunity to test whether targeted renewable energy programs could simultaneously address housing quality, public health, workforce development, and energy resilience goals (see *Section 4.3 Governance* and *Section 4.8 Public Health*). Organizations such as the North Coast Regional Partnership showcase how regional governance models have been uniquely successful at aligning state programs and resources with regional priorities.

5. **Local knowledge and expertise.** Adaptation strategies based on local and Traditional Ecological Knowledge have achieved higher engagement and reflected lived experiences, while standardized "one-size-fits-all" approaches have limited adaptive capacity (see *Section 4.7.1 Impacts on Ranching*), perpetuated historic injustices (see *Section 4.9 Racial and Social Equity & Climate Justice*), and risked leaving critical needs unaddressed (see *Section 4.3 Governance*). Agile adaptation policies that enable and scale regionally specific strategies are more likely to produce desired outcomes than prescriptive approaches designed for outside the region (see *Section 4.7 Economics*).

Glossary of Terms

This glossary defines key terms used throughout the Fifth Assessment's North Coast Regional Report (Chapters 1–4 and Appendices). It is intended for general readers who may be unfamiliar with scientific, policy, or cultural terminology used in the report. Definitions are written in plain language and, where relevant, include context specific to the North Coast region. Terms appear in alphabetical order. Terms already defined within the body of the chapters are included here for consolidated reference.

Adaptation tipping points: Points at which current infrastructure will no longer meet performance standards under changing climate conditions, triggering the need for fundamental redesign rather than incremental upgrades.

Adverse Childhood Experiences (ACEs): Traumatic events or conditions experienced during childhood — such as abuse, neglect, household dysfunction, or loss—that have measurable lifelong effects on health and well-being. The Public Health section notes that four or more ACEs dramatically increase risks of mental illness, substance abuse, and chronic disease. Climate-related disasters can trigger or compound ACEs in affected communities.

Anadromous: Describing fish species born in freshwater that migrate to the ocean to grow and return to freshwater to reproduce. Salmon, Pacific lamprey, and green sturgeon found on the North Coast are anadromous species.

Anoxia: The total depletion of dissolved oxygen in a body of water, which can cause fish kills and other ecological damage. Anoxia can develop in stratified lakes when oxygen-depleted deep water cannot mix with oxygenated surface water.

Anthropogenic climate change: Changes in the Earth's climate patterns caused by human activities, primarily the burning of fossil fuels and deforestation, which increase atmospheric concentrations of greenhouse gases and trap heat.

Arterials: Major transportation corridors—such as US-101, SR-299, US-199, SR-20, and SR-29—that serve as lifeline routes for regional connectivity and are subject to climate-related disruptions from landslides, flooding, and sea level rise.

Atmospheric river events: Long, narrow corridors of concentrated water vapor that form over the Pacific Ocean and transport large amounts of moisture from tropical regions toward the coast. When atmospheric rivers make landfall, they release this moisture as intense rainfall or snow, accounting for 30–50% of the region's annual precipitation and contributing to most flooding and landslide events.

Bioenergy system: A system that converts local organic material—typically woody biomass from forest thinning or waste—into electricity or heat at neighborhood or community scale, as demonstrated by the Scotts Valley Band of Pomo Indians' installation.

Bioengineered slope stabilization: The use of deep-rooted native vegetation, sometimes combined with structural elements, to anchor hillside soils and prevent erosion-driven road and slope failures. Unlike concrete approaches, bioengineered slopes become more effective over

time as root networks mature and also provide wildlife habitat and water filtration benefits. North Coast installations on Highway 299 were completed at approximately half the cost of conventional methods.

Biotic homogenization: The reduction of species diversity across a landscape as a limited number of generalist or invasive species come to dominate, displacing native species and simplifying ecosystems. Climate-driven habitat changes and disturbances can accelerate biotic homogenization, with cascading effects on pollinators, culturally important plants, and overall ecosystem function.

Brackish marsh: A marsh environment created where freshwater and saltwater mix, typically at river mouths and estuary edges, resulting in conditions less saline than the open ocean but more saline than freshwater systems. Brackish marshes provide important habitat and are expanding in some North Coast areas as sea level rise pushes tidal waters further inland.

CalEnviroScreen: A statewide screening tool developed by the California Office of Environmental Health Hazard Assessment (OEHHA) that uses 21 indicators of pollution burden and sensitive populations to identify California's most disadvantaged communities and guide climate investment priorities. The report documents that CalEnviroScreen systematically under ranks North Coast communities because it excludes wildfire smoke pollution, does not account for rural residential patterns, and fails to capture energy poverty and heat burden facing rural populations.

California Current System: A large-scale ocean circulation system in which cold, nutrient-rich water flows southward along the Pacific Coast from British Columbia to Baja California. The California Current drives coastal upwelling that supports some of the most productive marine ecosystems and fisheries in the world, including the salmon, rockfish, and crab fisheries of the North Coast.

Carbon sequestration: The capture and long-term storage of carbon dioxide from the atmosphere through biological processes—such as tree growth, wetland peat accumulation, or soil organic matter formation—or engineered systems. Forests, rangelands, and coastal wetlands of the North Coast represent significant carbon sequestration capacity that climate change and wildfire place at increasing risk.

Cascadia Subduction Zone: A major fault system running offshore from Northern California through Oregon and Washington, where the Juan de Fuca tectonic plate slides beneath the North American plate. A large Cascadia earthquake—the most recent occurred in 1700—would produce simultaneous ground shaking, tsunami, and land subsidence across the North Coast region and represents the most severe single infrastructure failure scenario discussed in this report, with an estimated 10–14% probability of occurrence in the next 50 years.

Climate/fire refugia zones: Areas of the landscape buffered from the most severe climate and fire impacts due to topography, moisture, or other local conditions, allowing species and habitats to persist and potentially recolonize surrounding areas as conditions shift. Riparian corridors, north-facing slopes, and mesic zones often serve as climate refugia.

Climatic water deficit (CWD): The difference between the amount of water that plants and soils could evaporate and transpire given prevailing temperatures and the amount of water actually

available through precipitation. As temperatures rise, CWD increases even when precipitation stays the same, reducing plant productivity, shortening growing seasons, and increasing drought stress and fire risk.

Climatic whiplash: The pattern of large swings between extreme wet and extreme dry conditions, when drought years alternate with high-precipitation years. Climatic whiplash is projected to intensify in the North Coast, creating compound challenges for water storage, flood management, and ecosystem recovery.

Coastal squeeze: The compression of coastal habitats—particularly salt marshes and intertidal zones—between rising sea levels on the ocean side and fixed barriers such as levees, roads, or developed land on the landward side. As water levels rise, habitats that would normally migrate inland are blocked and gradually disappear.

Colonialism-induced climate change: A framework developed by Indigenous scholar Kyle Whyte that attributes Indigenous vulnerability to climate change to the ongoing and historical processes of colonization—including displacement from ancestral lands, suppression of traditional land management, disruption of food systems, and the imposition of extractive economic systems—rather than treating climate change as a politically neutral phenomenon.

Community benefit agreements (CBAs): Legally binding contracts negotiated between developers of large-scale projects—such as offshore wind facilities—and local communities, establishing commitments for local hiring, workforce training, environmental monitoring, and other community investments. Offshore wind developers in the Humboldt Wind Energy Area have committed over $12 million in CBAs.

Community Rating System (CRS): A voluntary FEMA program that rewards communities for implementing flood risk reduction activities beyond minimum National Flood Insurance Program requirements, with participating communities earning credits that translate into discounted flood insurance premiums for residents. Lake and Trinity counties currently earn CRS discounts, while other North Coast counties are enrolled but do not yet qualify.

Community-based catastrophe insurance: An insurance model that covers entire communities for a particular hazard, guaranteeing that all residents have some degree of coverage rather than leaving coverage to individual purchase decisions.

Conservation easements: Legal agreements in which a landowner voluntarily restricts certain types of development or land use on their property to protect its natural, agricultural, or cultural values. The landowner retains ownership, but the restrictions are permanent and transfer with the land when it is sold.

Cooler nodes: Solar-powered cold storage units that maintain food safety and reduce post-harvest losses for local agricultural producers, funded through programs such as the United States Department of Agriculture (USDA) Resilient Food Systems Infrastructure grants.

Crown level wildfires: Fires that burn through and across the top level of the forest canopy, typically moving faster and at higher intensity than ground fires and causing greater tree mortality. Coastal forests that have historically experienced little fire may be at increasing risk of crown fires as conditions warm and dry.

Cultural fire: The purposeful, knowledge-based use of fire by Indigenous Peoples to shape forests, grasslands, and other habitats, supporting biological diversity, healthy watersheds, culturally important species, and resilience to wildfire. Cultural fire practices reflect longstanding relationships between Indigenous Peoples and their homelands and are distinct from conventional prescribed burning in their goals, timing, and governance.

Decarbonizing: The process of reducing or eliminating carbon dioxide and other greenhouse gas emissions from an energy system, economy, or sector, typically by transitioning from fossil fuels to renewable energy sources and improving energy efficiency.

Decolonization: In the context of this report, the process of dismantling the ongoing political, economic, and cultural structures of colonialism—including returning land and resources to Indigenous Peoples, restoring Indigenous governance and sovereignty, and rejecting extractive economic models that subordinate Indigenous lifeways to settler land uses. The report frames decolonization as both a matter of justice and an ecological necessity for genuine climate resilience.

Demersal species: Fish and other aquatic animals that live and feed near the bottom of a body of water, including rockfish and other groundfish species important to North Coast fisheries.

Dentalia: Small, tubular mollusk shells harvested by Yurok and Tolowa Peoples used for ceremony and cultural regalia, that were also historically used as currency and traded widely among Northern California Tribes.

Difference-in-conditions (DIC) insurance: A supplemental insurance policy that covers risks not included in standard homeowners' insurance, such as flood and earthquake damage. As private insurers have withdrawn from high-risk North Coast areas and the California Fair Access to Insurance Requirements (FAIR) Plan covers only fire, many residents have been forced to purchase costly DIC policies to maintain basic coverage.

Dike-breaching: The intentional removal or opening of earthen levees or dikes to allow tidal water to re-enter formerly diked agricultural land, restoring coastal wetland habitat and allowing natural sediment deposition that can help marshes keep pace with rising sea levels.

Disadvantaged Community (DAC)/Severely Disadvantaged Community (SDAC): Designations used by California state agencies to direct climate funding and environmental justice resources to communities experiencing the greatest economic hardship and environmental burden, typically determined by comparing a community's median household income to the statewide median. The report highlights that conflicting definitions and screening tools across agencies produce inconsistent rankings, causing some genuinely underserved North Coast communities to be disqualified from priority funding.

Disjunct: Describes a population or habitat that is geographically fragmented and separated from other populations of the same species or community type. Disjunct populations are often more vulnerable to local extinction and less able to recover from disturbance.

Drought: A water deficit that accumulates over time as evaporative demand from warming temperatures outpaces available precipitation. Extreme drought is defined here as water year precipitation below the 10th percentile of the historical distribution (1951–2000). Even without

changes in total annual precipitation, rising temperatures increase drought frequency and severity by increasing evaporative water demand.

Dynamic Adaptive Policy Pathways (DAPP): A planning approach that develops multiple infrastructure or policy pathways in advance and identifies specific observable conditions—such as sea level reaching a particular threshold—that would trigger a shift from one pathway to another. Rather than committing to a fixed long-term plan, DAPP formalizes adaptive decision-making so that responses to changing conditions are planned rather than reactive.

Ecological grief/ecological anxiety: The emotional distress, grief, and trauma arising from the loss of or threats to ecologically and culturally significant species, places, and relationships. Climate-related losses—particularly of culturally significant species such as salmon—can manifest as ecological grief and anxiety, with disproportionate impacts on Indigenous and frontline communities and children.

Ecological uplift: Construction, stewardship, and land management activities that result in measurable improvements in ecosystem and economic health, function, and diversity. The term encompasses erosion control, revegetation, cultural burning, watershed restoration, and other activities that serve both community and ecological needs simultaneously and is estimated to represent approximately 20% of civil construction spending in the North Coast region.

Eelgrass: A submerged flowering plant that forms underwater meadows in shallow coastal bays and estuaries, providing critical habitat for juvenile fish, invertebrates, and waterfowl, while also stabilizing sediment and sequestering carbon. Eelgrass beds in Humboldt Bay declined dramatically during the 2013–2016 marine heat wave and drought but have partially recovered since.

El Niño-Southern Oscillation (ENSO): A recurring pattern of climate variability driven by fluctuations in sea surface temperatures and atmospheric pressure in the tropical Pacific Ocean. During El Niño phases, warming of the central and eastern Pacific shifts weather patterns and can raise sea levels along the California coast; during La Niña phases, cooler conditions typically prevail. ENSO cycles can temporarily mask or amplify the underlying long-term trend of sea level rise.

Endemic: A species or ecological community that is unique to and found only within a specific geographic location. The North Coast region hosts an unusually high concentration of endemic species, particularly in the Klamath Mountains.

Enteric methane production: Methane gas produced as a byproduct of digestion in ruminant animals such as cattle and sheep, representing a significant source of agricultural greenhouse gas emissions. Research into seaweed feed amendments shows potential to reduce enteric methane production in North Coast livestock operations.

Environmental Impact Bond (EIB): A financing tool that structures repayment around independently verified environmental outcomes—such as reduced stormwater runoff or improved water quality—over a multi-year period, rather than disbursing funds on a fixed schedule. EIBs align financial incentives with project performance and keep funders engaged until outcomes are demonstrated.

Eutrophication: The excessive enrichment of a body of water with nutrients—typically nitrogen and phosphorus from agricultural or urban runoff—triggering rapid algae growth that depletes oxygen levels and can cause fish kills and loss of aquatic biodiversity.

Extirpated: Locally or regionally eliminated from an area while still surviving elsewhere. A species that is extirpated from the North Coast has been lost from this region but has not gone globally extinct. The report references species such as the California Condor that have been successfully reintroduced after extirpation.

Fire weather conditions: Atmospheric conditions that significantly increase the likelihood and spread of wildfire, including high temperatures, low humidity, and dry offshore (east or "Diablo") winds. Fire weather conditions in the fall are projected to become more extreme across the North Coast under climate change.

Food calendar: The traditional seasonal schedule of food availability used by Indigenous Peoples, organizing fishing, hunting, and gathering activities around the natural cycles of plants, animals, and marine species. Climate-driven disruptions to these seasonal cycles—such as earlier salmon returns or altered shellfish availability—directly affect both food security and cultural practice.

Food sovereignty: The right of communities to define their own food systems, including access to traditional and subsistence foods. For Tribal communities on the North Coast, food sovereignty encompasses rights to salmon, shellfish, lamprey, acorns, and other traditional foods, and is inseparable from cultural identity, spiritual practice, and physical health.

Forage palatability: A measure of how readily livestock and wildlife prefer to eat a particular plant species or vegetation type. Drought and heat stress can cause plants to invest more in drought-adaptive compounds that reduce palatability, decreasing the nutritional and grazing value of rangelands.

Forb species: Non-woody flowering plants that are neither grasses nor grass-like, including wildflowers and many culturally important plant species. Forb diversity is particularly important in North Coast grasslands and rangelands as a food source for pollinators, and as traditional plant resources for Tribal communities.

Forest Resilience Bond (FRB): A multi-beneficiary financing structure in which private investors fund forest restoration and fuel reduction work upfront, with repayment provided over time by federal and state agencies that benefit from reduced wildfire risk and improved watershed health. The model is designed to address the funding gap between the immediate cost of restoration work and the long-term, diffuse benefits it provides.

Green bank: A publicly capitalized financial institution designed to accelerate private investment in clean energy, climate resilience, and related projects by absorbing a portion of the financial risk that private lenders would otherwise face. Green banks can provide bridge financing, low-interest loans, and loan guarantees that allow rural and Tribal communities to access capital that conventional financing markets do not typically offer.

Green microfinance: Financial products and services such as small loans and savings accounts structured to support low-income borrowers in adopting climate-resilient or ecologically beneficial practices (sustainable agriculture, renewable energy, or land stewardship). Unlike conventional

microfinance, green microfinance explicitly links financial terms and criteria to ecological and sustainability goals.

Habitat compression: The compression of cold, productive upwelling conditions into narrow bands along the coast, particularly during periods of reduced upwelling when warmer offshore waters intrude into the coastal zone and reduce the extent of productive, cold-water marine habitats. Habitat compression can force marine mammals and fish into shoreward areas, increasing interactions with coastal fisheries.

Harmful algal bloom (HAB): A rapid overgrowth of algae or cyanobacteria that can produce toxins dangerous to marine life, wildlife, and humans. HABs are driven by warm water temperatures, excess nutrients, and stratified conditions—all projected to intensify with climate change. On the North Coast, HABs have affected Dungeness crab fisheries, contributed to public health advisories at Clear Lake, and produced toxic conditions in the Klamath River prior to dam removal.

Hydrodynamic energy: Energy derived from the motion of water—including wave, tidal, and current energy, as distinct from hydroelectric power, which relies on dammed water and changes in elevation.

Hydrological restoration: The process of returning a degraded watershed, stream, wetland, or other water system to a more natural condition, restoring natural flow patterns, water quality, and the biological communities that depend on healthy hydrology.

Hydrophobic: Describes soils that repel water rather than absorbing it, often caused by wildfire heating organic compounds at the soil surface. Hydrophobic soils dramatically increase surface runoff after rainfall, contributing to flooding and erosion in post-fire landscapes.

Indigenous stewardship: The enhancement, management, and care of ecosystems by Indigenous Peoples, grounded in long-term, generational relationships between Indigenous Peoples and their lands. Indigenous stewardship encompasses cultural burning, seasonal harvesting practices, Traditional Ecological Knowledge, and relational responsibilities to non-human kin.

Kelp forest: Underwater ecosystems dominated by large brown algae (kelp) that grow in dense canopies in cold, nutrient-rich coastal waters and provide critical habitat and food for fish, invertebrates, and marine mammals. A 217-mile (350-kilometer) stretch of North Coast kelp forest collapsed during the 2013 marine heat wave, resulting in the closure of the $44 million commercial abalone fishery.

King tides: The highest tidal events of the year, occurring when the gravitational alignment of the Earth, sun, and moon produces stronger-than-usual tidal forces. King tides offer a preview of future regular tidal conditions as sea level rises and already cause flooding of Highway 101 along Humboldt Bay and near Crescent City.

Land back project: An effort to return stolen homelands to Indigenous Peoples, restoring Indigenous stewardship, sovereignty, and ownership of their lands. Examples in the North Coast include the return of Tuluwat Island to the Wiyot Tribe and the 47,000-acre Blue Creek watershed to the Yurok Tribe—the largest land back conservation deal in California history.

Landward transgression: The inland migration of the shoreline as sea levels rise, allowing coastal and estuarine habitats to expand into previously upland areas. Where landward transgression is blocked by development or infrastructure, coastal squeeze results.

Living shorelines: Coastal protection approaches that use natural elements—such as restored salt marshes, oyster reefs, or native vegetation—to absorb wave energy and reduce erosion, rather than relying solely on hard structures like seawalls or rock revetments. Unlike hard barriers, living shorelines can adapt with rising sea levels, becoming more protective over time while also supporting wildlife habitat and carbon storage.

LOCA2-Hybrid: A statistical method used in California's Fifth Climate Change Assessment to translate coarse global climate model projections to local geographic scales. It combines two downscaling approaches—LOCA2 (Localized Constructed Analogs, version 2) and a hybrid statistical method—to produce high-resolution climate projections for specific locations across the state, enabling infrastructure planning and vulnerability assessment at the community level.

Maladaptation: An adaptation action that reduces vulnerability in the short-term but increases risk, vulnerability, or greenhouse gas emissions over the longer term, or that shifts burdens unfairly to other communities or systems. The report cites indoor cannabis cultivation as an example—while it protects crops from weather extremes, it dramatically increases energy use and associated climate impacts.

Managed retreat: A planned, voluntary relocation of people, structures, or infrastructure away from areas subject to chronic flooding, erosion, or sea level rise, rather than attempting indefinite defense with engineered barriers. The report references managed retreat in the context of Eel River farmland that has reverted to brackish marsh, with landowners selling property to the California Department of Fish and Wildlife.

Marine heatwave: A prolonged period of anomalously warm ocean surface temperatures, typically lasting weeks to months, that can have severe ecological impacts. The 2013–2016 marine heatwave off the North Coast caused the collapse of 217 miles (350 kilometers) of kelp forest and contributed to the closure of the commercial abalone fishery.

Marine Protected Areas: Designated areas of the ocean that receive special protections for conservation purposes, restricting certain types of fishing, development, or other activities to allow marine ecosystems to recover and maintain resilience.

Maritime climate buffering: The moderating effect of the ocean on coastal temperatures, which prevents the extreme temperature swings experienced in interior areas. The thermal mass of the ocean absorbs heat in summer and releases it in winter, keeping coastal zones cooler in summer and warmer in winter—an advantage for coastal North Coast communities and ecosystems that may diminish as ocean temperatures rise.

Mean longest heat wave per year: A climate metric defined as the duration of consecutive days per year when temperatures exceed the 98th percentile of the historical temperature distribution for a given location. This measure accounts for the fact that dangerous heat thresholds differ across the region—what constitutes an extreme heat event on the coast differs significantly from inland areas.

Mesic zones: Areas of the landscape that maintain relatively consistent moisture levels even during dry seasons, including springs, seeps, shaded canyons, north-facing slopes, and beaver-modified valleys. Mesic zones function as climate refugia by buffering temperature extremes and providing continuous water availability for sensitive species.

Microcystin: A liver toxin produced by cyanobacteria (blue-green algae) during harmful algal blooms, which can cause illness through skin contact or ingestion. Microcystin poses particular challenges in Clear Lake and the Klamath River, where rising water temperatures intensify and extend bloom seasons.

Microgrids: Localized electricity systems that combine generation sources—typically solar, battery storage, and backup generators—and can operate independently from the main power grid during outages. Blue Lake Rancheria's operational microgrid and the Tribal Energy Resilience and Sovereignty (TERAS) project serving Hoopa Valley, Yurok, and Karuk communities demonstrate how microgrids can maintain essential services when the regional grid fails.

Ocean acidification: The ongoing decrease in ocean pH resulting from the absorption of excess atmospheric carbon dioxide. Carbon dioxide absorbed by the ocean reacts with seawater to form carbonic acid, making conditions increasingly hostile to shell-forming organisms such as oysters, mussels, sea urchins, and certain plankton that form the base of the marine food web.

Onshore advection: The transport of temperature and water mass characteristics from offshore to onshore areas by winds and ocean currents. During marine heatwaves, onshore advection can bring abnormally warm offshore waters into the coastal zone, reducing the extent of productive cold-water habitats.

Organisms' life histories (phenology): The timing of seasonal biological events in an organism's life—such as flowering, spawning, migration, or emergence—and how these are linked to environmental cues like temperature and day length. Climate change is shifting these seasonal cues, creating mismatches between organisms and the habitat conditions or food sources they depend on.

Orographic: Relating to or caused by mountains. Orographic effects occur when moist air is forced upward by mountain terrain, cooling as it rises and releasing precipitation. The North Coast's steep coastal mountains produce strong orographic effects, resulting in much higher precipitation on west-facing slopes than in inland valleys.

Oxidation ponds: Large, shallow wastewater treatment basins that use sunlight, algae, and natural biological processes to break down organic matter and pathogens without the need for mechanical equipment. The Arcata Marsh system uses oxidation ponds as the first stage of treatment, continuing to function during power outages that would disable conventional treatment plants.

Pacific Decadal Oscillation (PDO): A long-term pattern of climate variability in the North Pacific Ocean, cycling between warm and cool phases over periods of roughly 20–30 years. During warm (positive) PDO phases, sea surface temperatures along the Pacific Coast tend to be warmer and sea levels can be elevated; cool phases have the opposite effect. PDO cycles can temporarily mask or amplify longer-term sea level rise trends along the California coast.

Parametric insurance: A type of insurance that issues payouts automatically when objective, predefined conditions are met—such as wind speed exceeding a threshold or groundshaking reaching a certain level—without requiring a damage assessment. Parametric insurance can provide faster, more predictable financial recovery after disasters than traditional indemnity insurance.

Particulate Matter 2.5 (PM2.5): Fine airborne particles smaller than 2.5 micrometers in diameter, small enough to penetrate deep into the lungs and bloodstream. PM2.5 from wildfire smoke is documented in the report as more toxic than PM2.5 from fossil fuel combustion, and is responsible for increased premature deaths, hospitalizations, and adverse reproductive outcomes in the North Coast region.

Passive building design: An approach to construction that uses a building's orientation, insulation, natural ventilation, and daylighting to maintain comfortable conditions with minimal mechanical heating, cooling, or electrical systems. Passive design reduces energy use and maintains habitability during power outages, serving as both an energy efficiency strategy and a climate resilience measure.

Patterns of change in fire severity: The amount and type of vegetation change that follows a wildfire, used as a proxy for fire intensity. High-severity fires kill most of the vegetation, while low- and mixed-severity fires create a mosaic of burned and unburned patches. Increasing proportions of high-severity fire in historically low- or mixed-severity landscapes is a key concern for the North Coast.

Pelagic species: Fish and other organisms that inhabit the open water column rather than the ocean floor or coastal zones. Pelagic species' distributions are projected to shift northward as ocean temperatures rise, affecting fisheries access for North Coast communities.

Phenological shifts: Changes in the timing of seasonal biological events—such as plant flowering, insect emergence, fish spawning, or bird migration—driven by shifts in temperature and precipitation patterns. When the timing of interdependent events becomes mismatched, ecosystem function and species survival can be compromised.

“Pirish fire” (Karuk term): The Karuk Tribe's term for good fire—the intentional, culturally grounded use of fire to steward grasslands, manage invasive species, promote native wildflowers, and maintain the ecological and cultural health of the land. The Karuk Tribe is actively employing Pirish fire as a climate adaptation and land stewardship strategy.

Public Safety Power Shutoff (PSPS): A planned, announced utility outage during which electricity is preemptively cut to prevent power infrastructure from igniting wildfires during extreme fire weather—such as high winds, low humidity, and high temperatures. While PSPS events prevent fires, they can leave rural and Tribal communities without power for days at a time, disabling water systems, medical equipment, and communications.

Quadratic model: A mathematical curve used to describe relationships where the rate of change is not constant—for instance, where sea level rise is accelerating rather than increasing at a steady rate. A quadratic fit to tide gauge data reveals the acceleration in sea level rise that a simple linear trend would underestimate.

Rare fen habitats: Peat-forming wetlands fed by groundwater seeps or springs, supporting highly specialized plant communities adapted to permanently waterlogged, nutrient-poor conditions. Fens are among the most climate-vulnerable wetland types because they depend on consistently cold, stable water sources that can be disrupted by drought and warming temperatures.

Regenerative agriculture: Farming practices that actively restore soil health, increase biodiversity, sequester carbon, and improve watershed function—through cover cropping, composting, rotational grazing, and elimination of synthetic inputs—going beyond sustainability to improving conditions over time. The report highlights regenerative approaches as both a climate adaptation strategy and a source of economic resilience for North Coast farmers.

Riparian corridors: Strips of vegetation along rivers, streams, and lakes that provide habitat, moderate water temperatures, filter runoff, reduce erosion, and connect fragmented landscapes. Riparian corridors are critical climate refugia for temperature-sensitive species and are particularly important for maintaining cold-water fish habitat on the North Coast.

Robust Decision Making (RDM): A planning methodology that evaluates infrastructure and policy investments across a wide range of possible future conditions—rather than optimizing for a single predicted scenario—to identify strategies that perform adequately across the most plausible futures. RDM is especially useful for climate adaptation planning, where deep uncertainty about future conditions makes single-scenario optimization unreliable.

Rolling dips: Gentle undulations in road surfaces designed to direct water laterally off the road before it accumulates erosive force, rather than channeling it along the road toward culverts. Rolling dips cost approximately 50% less than culvert systems and eliminate the debris clogging that causes most rural road failures during intense storms.

Safe development paradox: The phenomenon in which subsidized or artificially affordable insurance in hazard-prone areas encourages continued development there, ultimately increasing the total population and value at risk over time. The report references this as a concern with purely affordability-focused insurance reforms not paired with meaningful risk reduction.

Saltwater intrusion: The movement of saline ocean or brackish water into freshwater aquifers or surface water supplies, typically caused by sea level rise, reduced freshwater recharge from drought, or excessive groundwater pumping. Unlike surface water contamination, saltwater intrusion can permanently damage freshwater supplies.

SB 310 prescribed fire: California Senate Bill 310 (SB 310, 2024), which streamlines the permitting process for federally recognized Tribes to enter agreements with the state to conduct cultural burns on ancestral lands. The bill also removes liability from qualified burn bosses and cultural fire practitioners in cases of escaped prescribed fires when certain requirements are met, and explicitly includes cultural practitioners identified by federally recognized Tribal groups.

Seasonal sharpness: The concentration of precipitation into a shorter wet season, with less rainfall occurring in the shoulder seasons of fall and spring. Increased seasonal sharpness means longer dry seasons, earlier onset of fire weather conditions, and greater stress on trees and vegetation at the end of the dry period.

Sediment remediation: The process of cleaning up contaminated sediment—typically found in rivers, bays, and other water bodies—to reduce toxic exposure and restore ecological function.

Settler-colonial erasure: A concept recognizing the elimination of Native peoples as foundational to settler society and as an ongoing process perpetuated through colonial structures such as private property law, forced assimilation policies, and environmental injustice that systematically undermine Indigenous sovereignty and cultural continuity.

Shared Socioeconomic Pathway (SSP): One of a set of global scenarios used by climate scientists to project future greenhouse gas emissions based on different assumptions about population growth, technological development, energy policy, and economic integration. This report primarily uses SSP 3–7.0 (a *high* emissions pathway) to project mid- and late-century climate conditions for the North Coast, alongside the *medium* SSP 2–4.5 and *very-high* SSP 5–8.5 scenarios.

Shoreline revetment: A sloped hard barrier, such as a seawall or riprap structure, that protects land from wave erosion. While revetments protect what is immediately behind them, they can block the landward migration of coastal habitats, contributing to coastal squeeze.

Silvicultural science: A science-based approach to managing forests through control of species composition, stand density, health, and growth, in order to meet defined ecological, cultural, or economic goals. Silvicultural practices are used in the North Coast to restore old-growth characteristics, reduce wildfire fuel loads, and support watershed health.

SLR adaptation and resiliency: Sea level rise (SLR) adaptation refers to actions designed to keep communities and ecosystems safe by adjusting to changing coastal conditions—such as building setbacks, restored marshes, or elevated infrastructure. SLR resiliency refers to the capacity of individuals and communities to recover quickly from harm or disruption caused by rising water levels.

Sterodynamic: Referring to sea level changes driven by changes in the ocean's circulation patterns, temperature, and salinity, as distinct from changes caused by the addition of water from melting ice. Sterodynamic changes can cause regional sea levels to rise or fall differently from the global average.

Stochastically modeled: Modeled using methods that incorporate random variables and probability distributions to simulate a range of possible outcomes rather than a single predicted result. Stochastic fire modeling, for example, generates thousands of simulated fire years to assess the likelihood of burning across a landscape under different conditions.

Stratification (ocean): The formation of distinct, poorly mixing layers in the water column that are separated by differences in temperature, salinity, or density. Increased ocean stratification driven by warming surface waters limits the mixing of oxygen and nutrients between layers, reducing marine productivity and the availability of cold, nutrient-rich water in coastal habitats.

Substantial fire deficit: The condition in which much less fire occurs on a landscape than was present historically before EuroAmerican settlement and the suppression of Indigenous burning practices. A fire deficit results in the accumulation of fuels and the loss of fire-adapted ecosystem structures that depended on frequent, low-intensity fire.

Tectonic subsidence: The sinking of land due to geological processes, particularly movement along fault systems or within the Earth's crust. Tectonic subsidence in the Humboldt Bay area amplifies the local rate of sea level rise well above the global average, making the North Spit tide gauge the highest recorded rate on the US West Coast.

Temperature inversions: Atmospheric conditions in which a layer of warmer air sits above cooler air near the ground, trapping smoke, pollutants, and moisture below. In the North Coast, temperature inversions are not uncommon during warm seasons due to the interaction of cool marine air with warm inland air, particularly in mountainous terrain.

Thermal stratification: The separation of a lake or reservoir into distinct temperature layers, with warm water near the surface and cold water at depth. Extended periods of thermal stratification reduce oxygen in deep waters, forcing heat-intolerant fish to occupy warmer, less suitable habitat, and can trigger nutrient release from sediments that worsens water quality.

Tidal prism: The total volume of water that moves in and out of an estuary or bay with each tidal cycle. As sea levels rise, the tidal prism expands, increasing the volume and velocity of tidal flows that can accelerate erosion of marsh edges and tidal channel banks.

Tide gates: One-way valves or gates installed in drainage pipes or channels that open to release stormwater during low tide but close automatically when tidal water levels rise, preventing saltwater from backing up into low-lying areas. As sea levels rise and high tides last longer, tide gates remain closed when communities need drainage, trapping floodwater inland.

Tidelands: Low-lying coastal and estuarine areas periodically flooded by tidal action. Many North Coast tidelands were historically diked and drained for agriculture; as sea levels rise, some are being restored to tidal function through dike-breaching and managed retreat.

Traditional Ecological Knowledge (TEK): A cumulative body of knowledge, practices, and worldviews developed by Indigenous Peoples over generations of direct observation, ceremony, and stewardship, encompassing relationships between people, land, water, plants, and animals. TEK includes knowledge of fire regimes, seasonal resource use, species ecology, and place-based environmental processes, and is recognized throughout this report as an essential complement to western scientific approaches in climate adaptation.

Type conversion: A permanent or long-term shift in the dominant vegetation of a landscape from one type to another—for example, from conifer forest to shrubland, or from native grassland to annual grasses—typically triggered by repeated high-severity wildfire, prolonged drought, or invasive species establishment. Type conversion is a significant ecological loss because the original vegetation community may not return without active restoration.

Upwelling: The process by which deep, cold, nutrient-rich water is brought to the ocean surface through interactions between seasonal winds and ocean currents. Coastal upwelling along the North Coast drives exceptionally high marine productivity, supporting fisheries for salmon, rockfish, and Dungeness crab.

Vernal: Relating to spring or describing ecosystems that are seasonally active in spring. Vernal pools are temporary bodies of water that fill with winter rains and dry out by summer, supporting specialized plant and animal communities adapted to this ephemeral cycle.

Vertical land motion (VLM): The upward or downward movement of land due to geological processes, including tectonic activity, sediment compaction, or groundwater extraction. VLM significantly affects the local rate of sea level rise: land that is sinking experiences faster effective sea level rise, while land that is rising experiences slower rise. At Humboldt Bay's North Spit, downward VLM contributes to the highest recorded rate of relative sea level rise on the US West Coast.

Wildfire retrofits: Structural modifications to existing buildings that reduce vulnerability to wildfire, including installation of ember-resistant vents, fire-resistant roofing and siding, and creation of defensible space through vegetation management around structures.

Wildland–urban interface (WUI): The zone where developed land—homes, businesses, and infrastructure—meets or intermingles with undeveloped wildland vegetation. Properties in the WUI face the highest risk from wildfire, particularly where vegetation fuels are in direct contact with structures. Much of the North Coast's rural development sits within the WUI.

Appendices



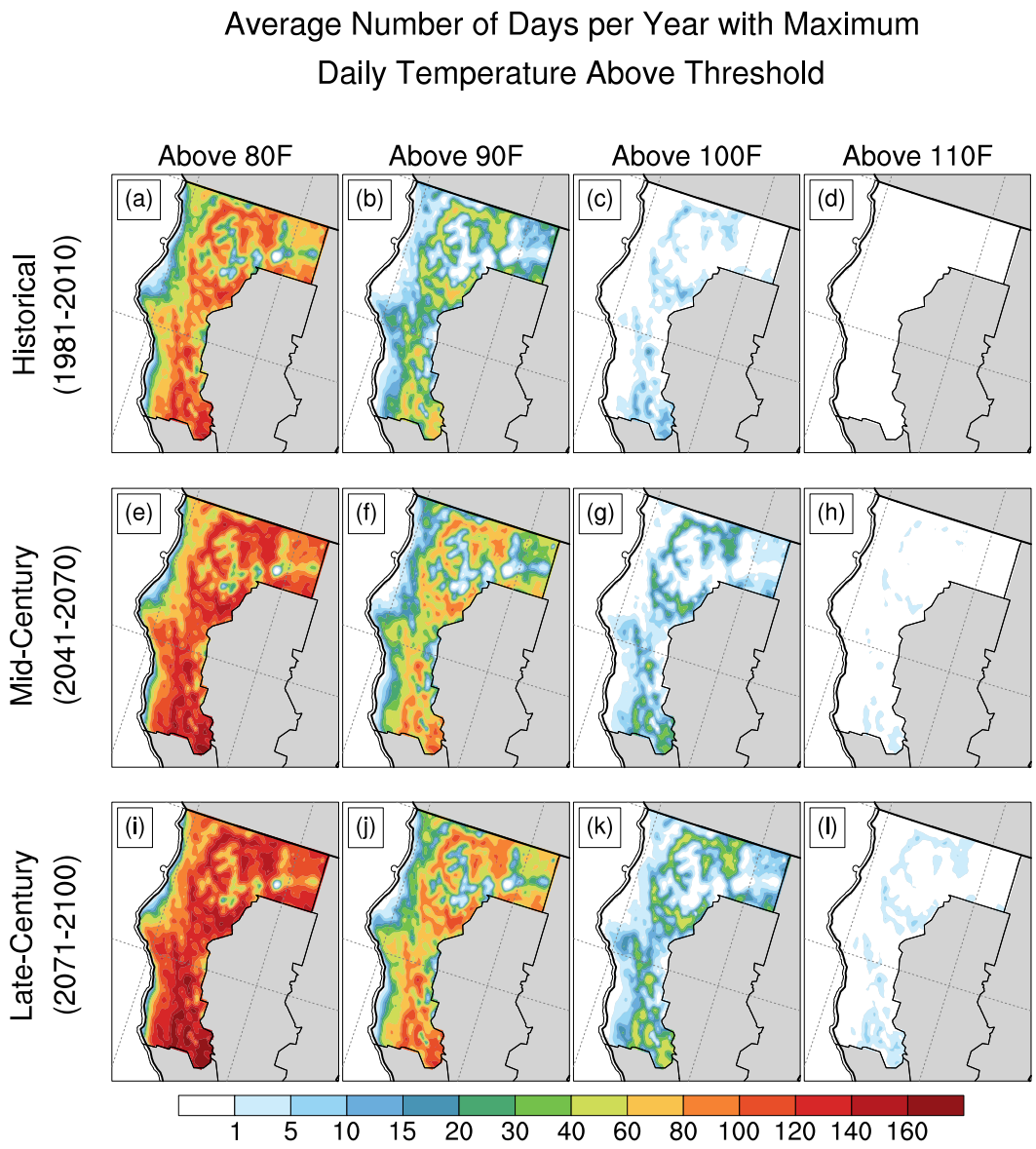
Appendix 1. Climate Science

Appendix Table 1.A. Recent Climatology of Key Cities in the North Coast Region.

All measures reflect annual averages for the period 1991-2020 using a multi-model averaging approach with SSP3-7.0 LOCA2 Hybrid data. Measures were calculated as the average value of an approximately 15x15 km area centered around each city.

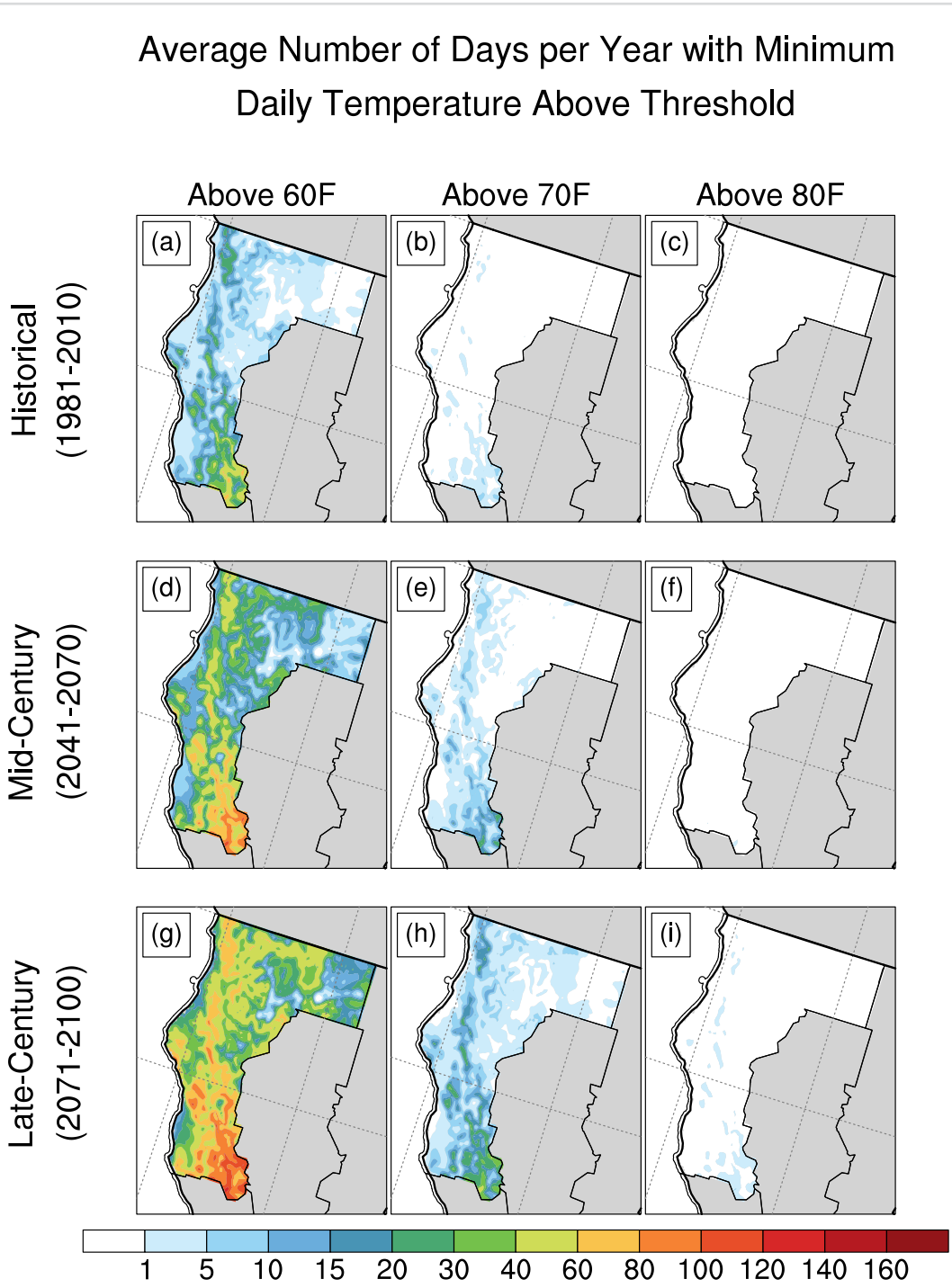
Climate Measures	Crescent City	Eureka	Hoopa	Weaverville	Happy Camp	Yreka	Ukiah	Lakeport	Fort Bragg
Mean annual temp °F (°C)	52.7 (11.5)	52.0 (11.1)	53.2 (11.7)	51.7 (10.9)	53.1 (11.7)	50.4 (10.2)	57.7 (14.2)	57.5 (14.1)	52.2 (11.2)
Average winter max daily temp °F (°C)	54.0 (12.2)	54.1 (12.2)	49.4 (9.6)	46.8 (8.2)	47.2 (8.4)	44.7 (7.0)	56.3 (13.5)	53.9 (12.1)	55.1 (12.8)
Average summer max daily temp °F (°C)	66.8 (19.3)	63.6 (17.5)	83.1 (28.3)	87.5 (30.8)	87.5 (30.8)	85.9 (29.9)	86.6 (30.3)	87.8 (31)	66.1 (18.9)
Average winter min temp °F (°C)	40.1 (4.5)	40.0 (4.4)	32.9 (0.5)	27.4 (-2.5)	30.1 (-1.05)	25.0 (-3.8)	36.4 (2.4)	34.9 (1.6)	28.9 (-1.7)
Cooling Degree Days	2	0.2	145.5	160.6	182.2	151.4	221.5	231.6	0.3
Period of record hottest daily average temp °F (°C)	84 (28.8)	76 (24.4)	99 (37.2)	103 (39.4)	103 (39.4)	100 (37.7)	102 (38.8)	102 (38.8)	80 (26.6)
Period of record coldest daily average temp °F (°C)	26 (-3.3)	26 (-3.3)	13 (-10.5)	9 (-12.7)	11 (-11.6)	3 (-16.1)	22 (-5.5)	21 (-6.1)	26 (-3.3)
Freezing nights	2.3	2.8	67.3	163	132.8	176.8	17.5	26.4	5.1
Annual precip inches (mm)	67.5 (1715)	40.7 (1034)	63.5 (1613)	38.3 (973)	54.3 (1380)	18.4 (467)	38.8 (986)	33.6 (853)	39.3 (998)
Days with measurable precip	113	112	103	89	99	81	76	71	88
Period of record max daily precip (inches)	2.9	2.3	3.2	2.1	3.1	1.2	2.9	2.7	2.5

Appendix 1.1 Supplemental Climate Science Figures



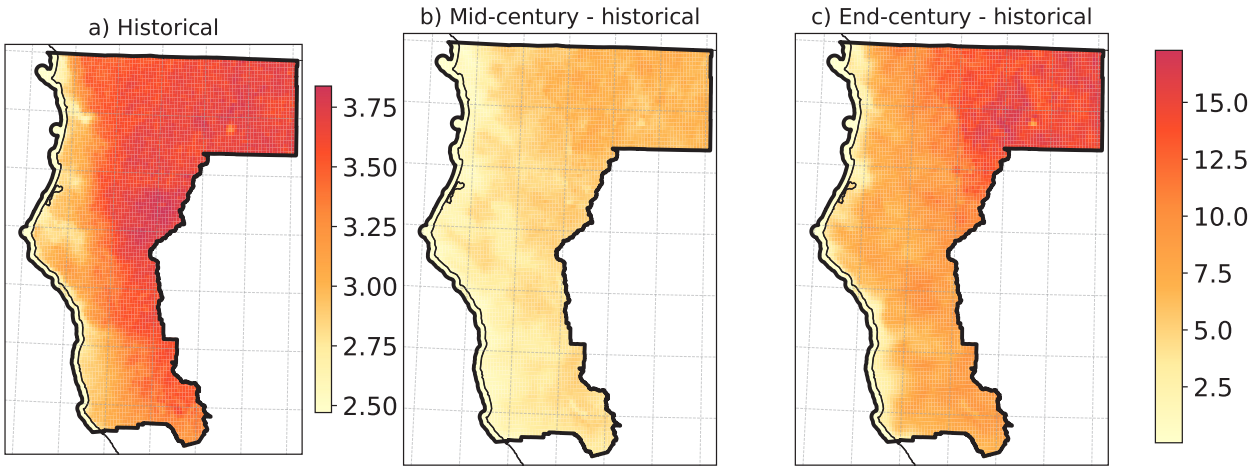
Appendix Figure 1.1A: *Projected number of extreme heat days.*

Map of mean number of days per year where daily maximum temperatures (extremely warm days) exceed one of four high temperature thresholds (80, 90, 100, 110 °F) over the historical (1981–2010), mid-century (2041–2070), and late-century (2071–2100) periods, as projected under the SSP3–7.0 Scenario. Contributor: Paul Ullrich



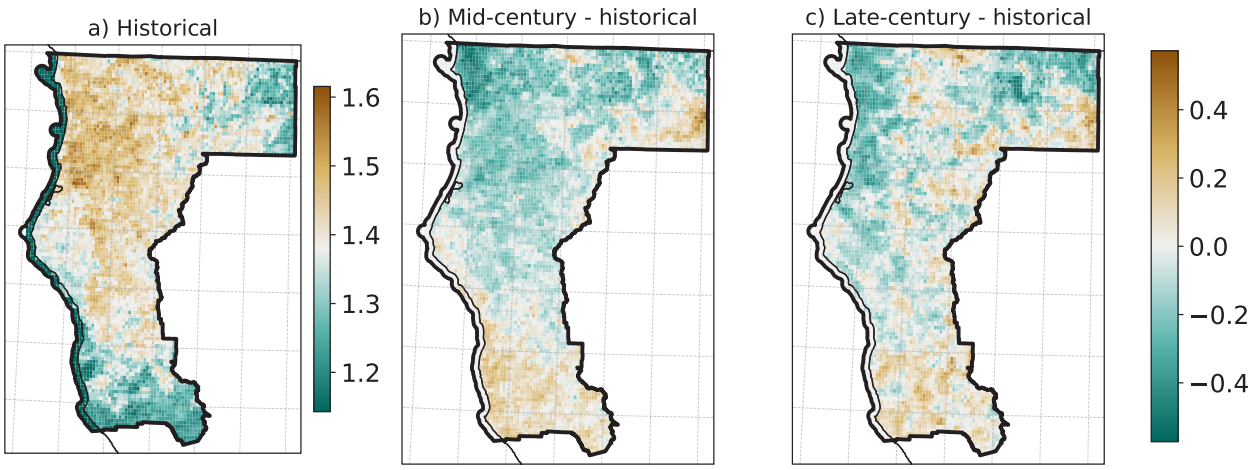
Appendix Figure 1.1B: *Projected number of extreme warm nights.*

Map of mean number of days per year where daily minimum temperatures (extremely warm nights) exceed one of three high temperature thresholds (60, 70, 80 °F) over the historical (1981–2010), mid-century (2041–2070), and late-century (2071–2100) periods, as projected under the SSP3–7.0 Scenario. Contributor: Paul Ullrich



Appendix Figure 1.1.C: *Projected change in length of heat waves.*

Change (compared to the 1981-2010 period) in the mean longest heat wave per year (defined as duration of consecutive days with temperature above 98th percentile of historical temperature distribution), as projected under the SSP3–7.0 scenario. Contributor: Samantha Stevenson



Appendix Figure 1.1.D: *Projected change in duration of the longest drought.*

Change in the duration of the longest drought from the historical period (1981-2010) to mid-century (2041-2070) and late-century (2071-2100) as projected under the SSP3–7.0 scenario. Drought was defined as water year precipitation below the 10th percentile of the historical distribution. Contributor: Samantha Stevenson

Appendix 1.2 Climate Predictions for Nine North Coast Cities

For readers seeking more detail for their area within the North Coast region, we have prepared graphs showing climate model predictions (LOCA-2, SSP 3–7.0) for the same nine cities as **Table 1.1**, from now through 2100, available for download on the North Coast regional report webpage. Seven climate variables are shown: maximum relative humidity, minimum relative humidity, average absolute humidity, precipitation, windspeed, and maximum and minimum daily temperature. Averages across four seasons are shown.

Appendix 2. Natural and Working Lands & Waters

Appendix 2.1 Terrestrial Systems

Appendix 2.1.A: Potential Impacts of Climate Change on Natural and Working Lands and Waters.

The following list lays out potential climate change impacts on natural and working lands and waters by topic.

- Temperature
  - Longer dryer seasons and increase in drought frequency and severity
  - Increase in heatwaves and number of days over 100 degrees
  - Increase evaporation rates
  - Decrease in relative humidity and precipitation
  - Increase in frequency and severity of droughts
- Rainfall
  - Decrease in spring and fall rainfall
  - Increase in frequency of both dry and wet years
  - Increase in seasonal sharpness (shortened fall-winter precipitation)
  - Increase in intensity of atmospheric rivers
  - Increased river and coastal flooding
  - Increase in landslides, road washouts, and erosion
- Coast and ocean
  - Sea level rise
  - Increase in coastal erosion, inundation, flooding, and habitat loss
  - Decrease in kelp beds
  - Increased ocean temperatures and acidification
  - Decrease in dissolved oxygen
- Fire
  - Increase in wildfire season, size and frequency
  - Increase of repeat burned areas
  - Decrease in fire deficits
  - Increase in air quality issues
- Forests
  - Increase in fire risk and loss of timber

- Decrease or variation in in or variable tree growth, yield, and forest canopy cover
- Increases in pathogens, insects and tree mortality
- Decrease in survival and growth of seedlings
- Increase in crown fires
- Decrease in wildlife habitat and timber species
- Expansion of fire prone species such as Knobcone pine
- Decrease in heterogeneity of plant communities impacting pollinators, availability of some culturally important plant species and overall truncation of ecological services
- Decrease in species diversity

- Rangelands, grasslands, meadows, vernal pools, chapparal
  - Increase in spread of novel pathogens and invasive species
  - Decrease in ecosystem function and cultural resources
  - Decrease in species diversity favoring warmer, drier-loving species
  - Increased competition between grazing and wildlife species like cattle, tule and Rosevelt elk
  - Decrease in populations of amphibians and invertebrates
  - Decrease in meadow inundation and biodiversity increasing grazing time
  - Increase in fire risk
  - Increase in phenological shifts, pest outbreaks, and pollinator mismatch
- Rivers
  - Modified flows, temperatures, habitat, function, species populations and biodiversity

Appendix Table 2.1.A: *Rangeland vegetation types and their abundance in the region.*

Rangeland Type	Del Norte	Humboldt	Mendocino	Trinity	Lake	Siskiyou
Grassland	0.80%	9.60%	10.60%	2.80%	5.90%	5.20%
Chaparral & Woodland	6.10%	1.50%	5.30%	8.00%	37.80%	11.30%
Sagebrush	0%	0%	0%	0%	0%	2.80%
Meadow	0.20%	0.10%	0.10%	0.30%	0.10%	2.00%
Coastal Scrub	1.00%	0.90%	0.50%	0%	0%	0%
Wetlands	0.50%	0.20%	0%	0%	0%	0%
Total Rangelands by County	8.70%	12.30%	16.50%	11.00%	43.70%	18.50%

Appendix Table 2.1.B: *Rangeland Ecosystems found in the North Coast Region (Adapted from Barbour et al., 2007).*

Ecosystem	Description	North Coast Regions	Notable Native Species
Coastal prairie	Grasslands with maritime fog influence that helps alleviate seasonal summer drought, supporting longer growing seasons dominated by perennial grasses with a large diversity of forb species including many culturally important plants (Taylor, Sigona, et al., 2024). Capable of producing high forage for grazing almost year-round.	Del Norte, Humboldt, Mendocino	*Calochortus spp., Camassia quamash, Cervus canadensis nannodes, Danthonia californica, Deschampsia cespitosa, Fragaria vesca, Trifolium* spp.
Inland grassland	Interior grasslands without coastal influence that are more arid and have high isothermality (temperature changes relatively little). Dominated by few perennial grasses and many annual species and supports wildflower superblooms (Eviner, 2016). Produces forage for range grazing during the growing season.	Del Norte, Humboldt, Lake, Mendocino, Siskiyou, Trinity	*Calochortus spp., Clarkia spp., Elymus glaucus, Eschscholzia californica, Festuca microstachys, Stipa pulchra, Sturnellaneglecta*
Oak Savannah	Grassland habitat with various oak tree species distributed throughout the landscape that can support high forage production for grazing and harbors important species for cultural resources (Long et al., 2017; Stromberg et al., 2007).	Del Norte, Humboldt, Lake, Mendocino, Siskiyou, Trinity	*Buteo spp., Quercus douglasii, Quercus garryana, Quercus kellogii* & similar herbaceous species as coastal or inland grasslands depending on proximity to coast
Vernal Pool	Ephemeral (short-lasting) wetlands with seasonal inundation, usually in areas with heavy clay soils that support unique and diverse ecological communities. Produces low forage but can benefit from grazing disturbance (Marty, 2005; Michaels et al., 2021).	Lake, Mendocino	*Branchinecta lynchi, Eryngium* spp., *Plagiobothrys* spp.
Alpine and Wet Meadows	Herbaceous plant communities that are seasonally flooded for long-portions of the hydrologic year that can support ephemeral species and rare fen habitats (Barbour et al., 2007). Can support high forage in some climates and soils but with short grazing periods due to saturated soils with long inundation periods.	Del Norte, Humboldt, Mendocino, Siskiyou, Trinity	*Castor canadensis, Camassia quamash, Carex* spp., *Darlingtonia californica, Juncus* spp. *Rana cascadae*
Chaparral	Shrub dominated habitat in rocky, semi-arid, mountainous areas with species that are typically adapted for drought and fire and are often considered culturally important. Low forage production but can support woody browsing.	Del Norte, Humboldt, Lake, Mendocino, Siskiyou, Trinity	*Arcostaphylos* spp., *Ceanothus* spp., *Cercocarpus betuloides*

Ecosystem	Description	North Coast Regions	Notable Native Species
Northern coast scrub	Wind-swept habitats which often consist of low-lying scrub habitat with perennial forbs and some grass species strongly shaped by water availability and salt deposition (Wrubel & Parker, 2018); important for pollinators. Low forage and browse production.	Del Norte, Humboldt, Mendocino	*Bombus* spp., *Eriophyllum staechadifolium, Erysimum menziesii, Iris douglasiana, Lupinus littoralis*
Sagebrush steppe	Shrubland characterized by sagebrush overstory with native bunchgrass understory and prevalent bare ground among shrubs. Provides important habitat for wildlife and spring/summer forage for livestock. Threatened by invasive species and juniper encroachment.	SiskiyouSiskiyou	*Antilocarpa americana, Artemesia tridentata, Purshia tridentata, Juniperus occidentalis, Elymus elymoides*

Appendix Case Study 2.1.A. Conifers Found Nowhere Else

In Northwest California's high-elevation forests, two conifers stand apart—not only for their beauty, but for the fragile, climate-sensitive niches they occupy. Brewer spruce (*Picea breweriana*), found nowhere else on Earth but the Klamath Mountains, drapes its long, pendulous branches like green waterfalls. A glacial relict, it clings to cool, moist ridges and north-facing slopes where fire is rare. These microclimates are shrinking under warming temperatures, shifting snowpack, and more frequent fire events, placing this already range-restricted conifer among the most climate-vulnerable trees on the planet (Kauffmann, 2012).

Port Orford-cedar (*Chamaecyparis lawsoniana*) grows in shaded, moisture-rich canyons from southern Oregon into the northern Klamath Mountains. Known for its rot-resistant wood and soft, feathered foliage, it thrives in fog-fed forests—habitats now threatened by extended summer droughts, reduced fog, and the spread of root disease accelerated by climate change (Kauffmann, 2012). In northwest California, they are keystone species that shape forest structure, regulate water cycles, influence fire behavior, and sustain biodiversity from canopy to forest floor (Farjon, 2008).

Safeguarding Brewer spruce and Port Orford-cedar is an act of climate adaptation. Protecting their refugia, controlling disease spread, buffering them from severe fire, and exploring assisted migration preserves not just rare species, but the entire ecological networks they anchor. In doing so, we give these ancient lineages—and the ecosystems they sustain—a fighting chance in a rapidly changing world.

Appendix Case Study 2.1.B. Community-Based Beneficial Fire Application

Wildfires can also provide opportunities to reintroduce beneficial fire to many forests, woodlands and their biota (Balch et al. 2024). During a few recent wildfires in the Klamath Mountains (e.g. 2023 Six Rivers Lightning Complex), community partners and Tribes collaborated to employ adaptive management strategies to promote beneficial fire that can reduce fuel hazards and promote varied stand structures. Continuation of efforts such as these, when appropriately

applied and in consultation with communities, can provide larger scale efforts to promote resilience and reduce the potential of future negative impacts from wildfire and drought. Broadening this approach to other parts of the North Coast and other regions in California holds much promise.

The North Coast region has rapidly enhanced and expanded the application of beneficial fire via prescribed burning and cultural burning over the past decade through various organizations and events. For instance, the North Coast region regularly has held numerous prescribed fire training exchanges, coordinated through The Nature Conservancy's Fire Learning Network. These events have provided essential opportunities to build local capacity, share knowledge, and foster collaboration among community members, Tribes, agency personnel, and non-governmental organizations. Through these efforts, many communities have been able to expand the implementation of prescribed burning within the North Coast and beyond.

Another important advancement in the application of beneficial fire within the North Coast region is through the development of Prescribed Burn Associations (PBAs). PBAs are local organizations composed of community members, volunteer fire departments, and landowners that help plan and implement prescribed burns on private property. In 2017, the Humboldt County Prescribed Burn Association became the first PBA in the western US and California. Since its formation, numerous PBAs have been established within California, Oregon, and Washington. PBAs in the North Coast continue to expand the use of prescribed fire in the region, helping to reduce fuel hazards, protect homes and communities, provide training opportunities, and extend other positive benefits through the reintroduction of fire.

The revitalization of cultural burning has also expanded the beneficial application of fire in the region. Through recent legislation (SB 310, Dodd, 2024), the state of California honors Tribal sovereignty and recognizes cultural fire practitioners, enabling federally-recognized Tribes to establish agreements to facilitate cultural burning within their aboriginal territory. Cultural burning is the intentional application of fire by indigenous communities, organizations, or practitioners, utilizing traditional knowledge and practices to achieve cultural and ecological benefits (e.g., Marks-Block et al. 2021, Connor et al. 2022). The Karuk Tribe recently became the first Tribe to enter an agreement with the state under this legislation and has already begun to conduct cultural burns on Karuk lands under this agreement. Likewise, expansion of cultural burning is also occurring in the region through the Cultural Fire Management Council, where fire practitioners are working with individual families and property owners within the Yurok Aboriginal Territory to prepare and conduct cultural burns and share knowledge and practices with local families. The goal is to bring two worlds of fire together - the dominant fire system regulated by the standards of state, federal, and Tribal governments, and Indigenous cultural burning centered on Yurok values and tradition. Over the coming years, it is expected that cultural burning will continue to increase as additional Tribes enter into similar agreements.

Appendix Case Study 2.1.C. Beavers Return—Restoring the Architects of Resilience

Once abundant across Northwest California, beavers were master architects of resilience. Their dams and ponds created dynamic wetland mosaics that slowed water, recharged aquifers, reduced wildfire risk, and sustained an extraordinary web of life—from amphibians to willows to

waterfowl (Pollock et al., 2003; Naiman et al., 1988). When the fur trade trapped them out in the 19th and 20th centuries, those systems unraveled. Streams incised and sped up, floodplains dried, and the natural buffers against climate extremes disappeared (Goldfarb, 2018).

Now, as the region faces unprecedented droughts, heatwaves, and erratic precipitation, beaver restoration is emerging as a powerful climate adaptation strategy. Led by Tribes like the Karuk who have long understood the beaver's role in wetland ecosystems (OEHHA, 2022, p.40), as well as conservation organizations, state and federal agencies, private land owners, and watershed practitioners, these efforts aim to restore not just a charismatic species, but the processes that stabilize ecosystems—slowing and storing water, recharging groundwater, shading streams, and spreading moisture across valley bottoms (Reeves et al., 2014). These functions directly counter the effects of warming temperatures, diminished snowpack, and increasing wildfire severity. The California Department of Fish and Wildlife has also been building out a comprehensive beaver conservation program that provides tools, solutions including relocation and partnerships across the state.

Indigenous knowledge systems—rooted in millennia of observation and stewardship—are guiding many of these projects (OEHHA, 2022). Recognizing beavers as keystone species and ecosystem engineers, practitioners are working to reestablish them in historical territories, monitor ecological responses, and ensure that restored hydrology builds resilience for fish, wildlife, and human communities alike. In a rapidly changing climate, beaver ponds are more than habitat—they are refuges. They hold water through dry seasons, cool surrounding landscapes, and create fire breaks that protect forests and communities. Across Northwest California, each reintroduced beaver represents a step toward reweaving the land's natural defenses, one pond at a time.

Appendix Case Study 2.1.D. Reclaiming Alpine Lakes—Trout Removal for Amphibian Recovery

For thousands of years, many of Northwest California's over 300 high-elevation lakes were fishless—cold, quiet waters where amphibians thrived without fish predators (Welsh et al. 2006). That changed in the 20th century, when rainbow, brook, and brown trout were stocked in these lakes to create new widespread recreational fishing opportunities across California's mountain ranges (Pister 2001). Non-native trout have disrupted fragile alpine ecosystems across the Western US, preying on larval frogs and salamanders that had evolved without predatory fishes (Kats and Ferrer 2003).

Species such as the southern long-toed salamander (*Ambystoma macrodactylum*) and the cascades frog (*Rana cascadae*) have likely suffered steep declines in lakes with introduced fishes, pushed to the edge by the combined quadruple threat of invasive trout (Welsh et al. 2006, Garwood et al. 2025), emerging infectious disease (De León et al. 2017), shrinking snowpack (Mote et al. 2018), and drying wetlands (Lee et al. 2015). As drought and climate change continue to alter mountain hydrology, these amphibians need permanent deep-water breeding habitats that are void of introduced fishes because shallower auxiliary habitats are becoming less reliable. (Ryan et al. 2014).

In response, conservationists and fisheries managers are working to restore balance. Fisheries managers recently ceased stocking these lakes with trout to protect cascades frogs which are

currently a candidate species under the California Endangered Species Act. Based on this policy change, many small lakes no longer maintain trout populations and many will no longer be stocked in the future. Targeted trout removal projects are also underway in select alpine lakes, guided by detailed ecological inventories and fishery value assessments (Garwood et al. 2023). These efforts aim to reestablish fishless conditions in key climate-resilient waters to support amphibian and lake ecosystem recovery while also maintaining low-impact fisheries in compatible waters. This work is more than species rescue—it's a model of climate-adaptive restoration, reconnecting sensitive wildlife to habitats where they once thrived and restoring the natural rhythms of mountain lakes in a changing world.

Appendix Case Study 2.1.E. Sustainable Livestock Production: Challenges and Opportunities

There is greater opportunity for more sustainable livestock production in coastal areas of Del Norte, Humboldt, and Mendocino Counties than in other parts of the state. The coastal climate supports higher forage production and longer duration of green forage, allowing for year-round grazing, unlike other parts of the state (Forero et al., 2021). On-site forage produced by regional rangelands requires no transport (no carbon emissions) and is a less expensive alternative than harvesting hay locally or out-of-region importing (Barry, 2021). Accordingly, the region is an important receiver of cow-calf pairs and stocker cattle from the greater western U.S. (CA, OR, NV, WA). Coastal grasslands generally have higher soil carbon stocks than other rangeland types due to the climate and greater abundance of perennial grasses (Carey et al., 2020; Koteen et al., 2011). Northern CA supports a greater proportion of perennial grasses than those on the central and south coast (Luong et al., 2023), indicating that the region may have some of the highest carbon storage potential of any grassland in the state. Recent work suggests that seaweed diet amendments for grazing beef cattle can reduce enteric methane production (Meo-Filho et al., 2024). Humboldt and Del Norte are uniquely poised to raise, process, and feed locally grown seaweed to livestock with minimal transportation, reducing greenhouse gas emissions associated with the industry. More research is needed to optimize the compound (bromoform) in seaweed species that can be grown in colder waters (Cunningham et al., 2025).

The main sustainability challenge for local producers is the high environmental (and financial) cost of livestock transportation for finishing and slaughter. Nearly 80% of cattle in the U.S. are transported to five Plains states for slaughter (Saitone et al., 2016). The greenhouse gases associated with transportation of livestock greatly reduces the sustainability of the land use. The one remaining slaughter facility in the region closed in 2024. Although Redwood Meats processed <20% of the region's beef, the closure of this facility represents a challenge toward achieving sustainable meat production in the region. Supporting a local slaughter facility would greatly increase the capacity for sustainable livestock production throughout the region.

Appendix Case Study 2.1.F. Climate Responses by Grassland and Rangeland Type

Coastal prairies have perennial species that are resistant to drought with adaptive traits, with some natives being drought sensitive, but their responses typically benefit from maritime climate buffering (Luong et al., 2021).

Contrarily, **inland grasslands** have native annual species that are adapted to ephemeral wet periods and extended hot and dry summers but also experience loss of more sensitive species (Prugh et al., 2018). North Coast grasslands will exhibit some resilience to droughts (Luong et al., 2021), but will likely exhibit reduced species diversity over time favoring "warmer, drier-loving" species (Zhu et al., 2024).

Wet meadows, alpine meadows and **vernal pools** will experience similar pressures as inland grasslands to drought (Swain, 2021; Swain et al., 2018). Vernal pools and meadows are at particularly high risk of loss with changing climate patterns due to shorter inundation times and less surface water (Albano et al., 2019; Montrone et al., 2019); reducing suitability for specialist plants and leaving the habitats susceptible to invasion, especially by annual grasses in vernal pools (Tang et al., 2023) and shrubs in alpine meadows (Ababneh & Woolfenden, 2010). Amphibian and invertebrate species will be particularly vulnerable to extirpation, including endangered species like fairy shrimp (Kneitel et al., 2017). In alpine meadows, drought and warmer conditions can facilitate phenological shifts that contribute to pest outbreaks and pollinator mismatch that reduce provisioning of ecosystem services (Inouye, 2020). Wet meadow inundation time may decrease, allowing for a longer grazing period, but these changes could also adversely affect bird diversity and facilitate novel species invasions that increase fire risk and decrease biodiversity (Londe et al., 2024; Williams-Jara et al., 2022; Middleton & Kleinebecker, 2012).

Sagebrush steppe species have evolved with low and variable precipitation, and thus are likely more resistant to the effects of aridification (Byrne et al., 2025). Sagebrush may buffer other species in the ecosystem from some of the effects of increased aridity through hydraulic redistribution of water from deeper to shallower soils during the summer dry period (Caldwell et al., 1998). However, drought may increase the cover of invasive annual grasses (Byrne et al., 2025; Nunes & Byrne, 2022) with low forage value (Bovey et al., 1961; Brummer et al., 2023) that can accelerate fire risk (Fernández-Guisuraga et al., 2023).

Chaparral species are often drought and fire-adapted but extended or repeated droughts may lead to population declines or local extinctions, as these species are slow to recover (Jacobsen & Pratt, 2018). Higher wildfire frequency could cause habitat conversion via annual grass invasion (D'Antonio & Vitousek, 1992; Grupenhoff, 2024; Swain, 2021), which would change grazing and browsing capacity but will also reduce availability of cultural resources (*e.g.*, manzanita species).

Northern coastal scrub is strongly shaped by maritime fog, water availability, and salinity (Wrubel & Parker, 2018). Thus, species associated with these habitats often require wetter environments and experience reduction in more arid conditions (Wrubel & Parker, 2018); therefore, increased local CWD (Ostoja et al., 2023) and decreased maritime fog (Johnstone & Dawson, 2010) will likely endanger northern coastal scrub ecosystems.

Appendix 2.2 Rivers and Lakes

Appendix Case Study 2.2.A. PG&E's Potter Valley Hydroelectric Project

Located at the headwaters of the Eel River, the Potter Valley hydroelectric project is now slated for decommissioning in the coming decade, potentially beginning as early as 2028 (PG&E 2023).

PG&E's surrender of its project license, issued by Federal Energy Regulatory Commission, after 100 years of operation, and the proposed decommissioning, marks an opportunity to remove the only two dams—Scott Dam and Cape Horn Dam—on the Eel River, improve fish passage conditions, and restore salmonid migratory access to the Eel River's headwaters and an estimated 288 miles (367 km) of high-quality fish spawning and rearing habitat above the dams. Dam removal will make the Eel River the longest free flowing, wild fish river in California. While there are many important restoration and conservation actions that can be done to support climate resilience and salmonid recovery in the Eel River watershed, restoring access to the cool water fish refugia above the Potter Valley Project dams by removing the barriers to that habitat is considered the most critical restoration action in the watershed (California Trout et al., 2024).

Potter Valley Project dam decommissioning will open up cold water refugia for anadromous fish in the Eel River watershed and that refugia will become even more critical for anadromous fish as stream temperatures increase across the watershed with projected climate change and continued irrigation diversions. The Eel River watershed has highly varied seasonal flows, with very low flows in the summer and very high flows in the winter (Power et al. 2024). Rising ambient air temperatures, increased winter precipitation and flows, and intensive irrigation diversions, are expected to increase Eel River stream temperatures in the late 21st century ranging from 1.2-2.4°C (2.16-4.32°F) in the summer to 0.58-3.46°C (1.04-6.2°F) in the winter (Liu et al., 2018). Anadromous cold water fish cannot survive in water above a certain temperature threshold that is already exceeded during summer in many locations in the Eel River watershed. Projected stream temperature increases could be catastrophic for the remaining native anadromous fish in the watershed.

The cooler headwaters above the Potter Valley Project dams may provide much needed refuge to fish as stream temperatures increase. However, anadromous fish still need to get from point A to point B. The anadromous fish in the Eel River watershed use different areas and different habitat types to express their varied life history diversity strategies. The locally invasive pikeminnow fish is a major predator of native anadromous fish in the lower sub watersheds (South Fork Eel, Van Duzen, Middle Fork Eel) where anadromous fish spend an important part of their life cycle. Pikeminnow thrive in slightly warmer temperatures than the native anadromous fish, thus they take advantage of the amenable water temperatures and food supply, ever increasing their presence and thus native fish predation.

Simply removing the dams and opening up more cold water habitat is not the only answer to restoring the Eel River watershed fisheries. Coordinated restoration actions including but not exclusive to dam removal are needed across the watershed and in key habitats that fish need throughout their lives. Meanwhile, improved management of irrigation water diversions and increased stream gauge monitoring may provide temporary stopgaps to mitigate accelerating water temperatures in the basin.



Appendix Figure 2.2: *Scott Dam*

Scott Dam, one of the two dams in the Potter Valley Hydroelectric Project. Photo by Mike Weir.

Appendix Case Study 2.2.B. Elk River Watershed

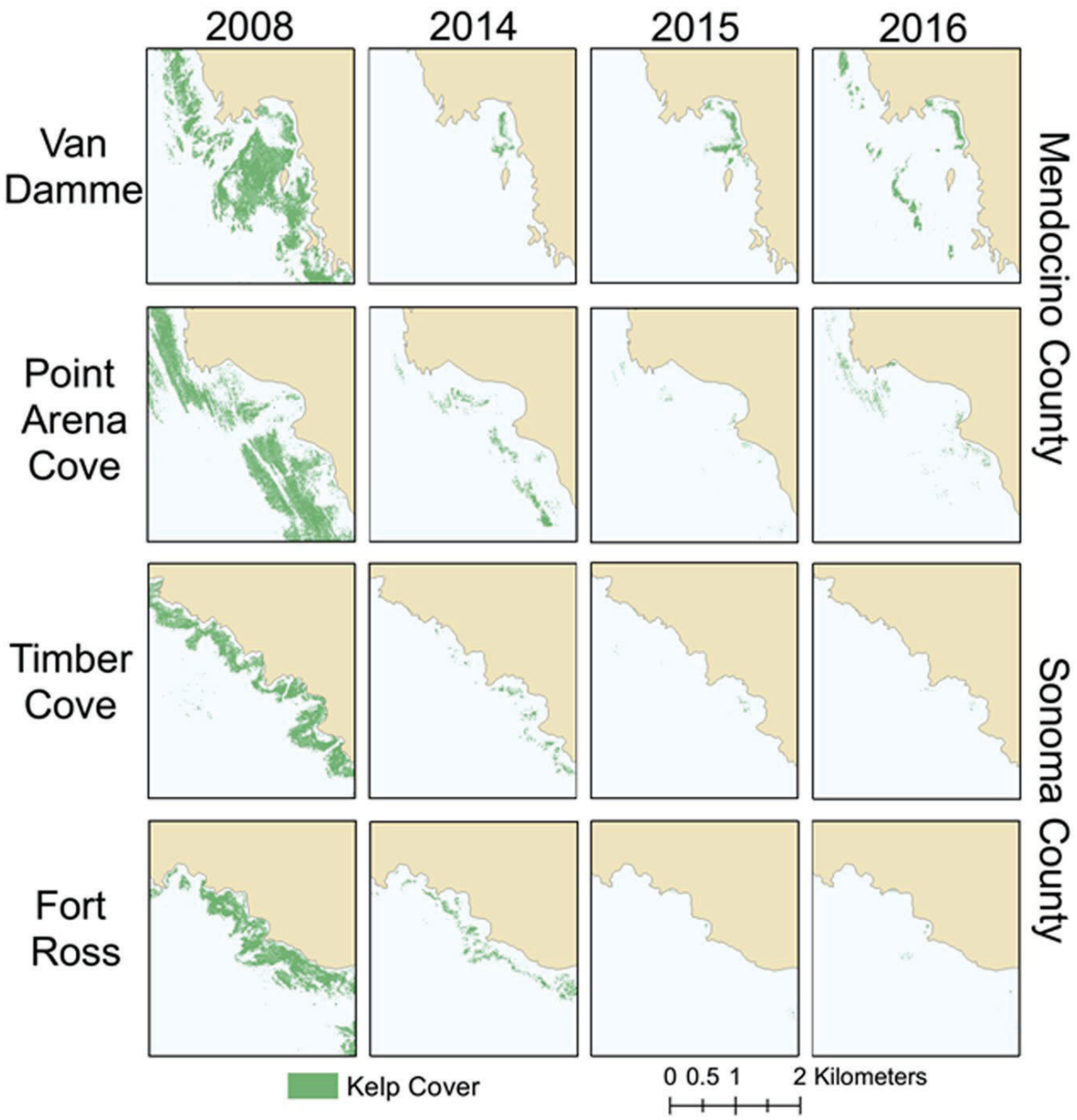
The Elk River Recovery program is a voluntary, multi-benefit program intended to achieve watershed health in support of ecosystem restoration and flood reduction. The program goals are: protection of existing agricultural uses, the recovery of water quality, sediment remediation, reduction of flooding, salmonid recovery, recovery of sensitive biological communities, and restoration of tidal marsh, estuarine, riparian, and riverine function. The program is led by CalTrout and a consulting team including Northern Hydrology and Engineering, Stillwater Sciences, and others. There are over 40 river adjacent landowners in the Elk River watershed. Several of these landowners have already seen a conversion of their pastures to salt marsh, making the pastures unsuitable for agriculture. In the upper Elk River watershed, further away from the SLR impacts, sediment deposits from anthropogenic landscape changes have increased flooding,

leaving many residents vulnerable to rising water levels. Climate impacts, including SLR and increases in peak flows, may make all the Elk River Recovery Program goals and objectives more difficult to achieve.

The nature-based solutions proposed to address watershed impairments are restoration actions that also increase climate resilience. In 2023, The Elk River Recovery project team identified key, near-term climate vulnerabilities in the Estuary along with some concepts to be incorporated into restoration designs. These near-term vulnerabilities include increased inundation of agricultural land, the movement of the stream-estuary ecotone upriver, and the impacts of SLR on the marsh plain. Landowner-supported actions in the Elk Estuary include managed retreat and levee removal to open formerly diked and drained land to a full tidal system, encouraging sediment deposition from the Elk River onto the restored marsh plain. This restored estuarine process may allow marsh area increases to keep pace with SLR, at least at current rates. If SLR accelerates in the future, marsh migration will be possible along the higher elevation gradient adjacent to the tidal channels. To increase resilience to SLR, restored marsh and wetland habitats will be composed of a diverse planting palette that will include species that have brackish to freshwater tolerances, allowing for the shifting salinities throughout the year and providing community resilience from the potential increased salinity over time (e.g., maintained vegetative cover that will retain habitat value for wildlife/sensitive species and abate nonnative weed establishment).

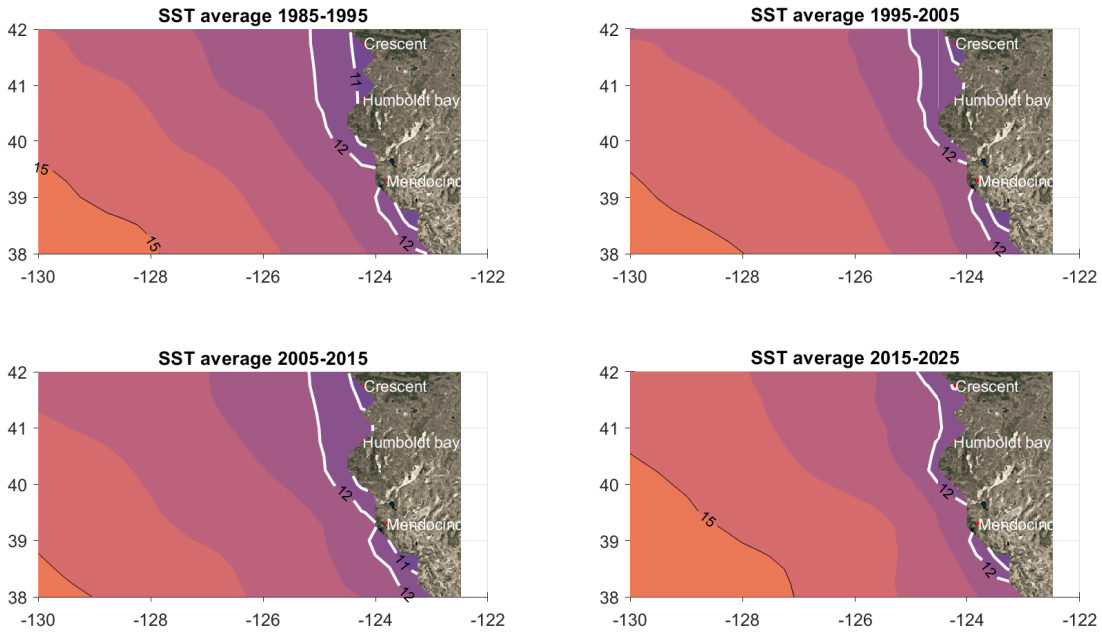
The effectiveness of these and other actions depends on the variability of coming climate changes and the timescale considered, and, under some climate scenarios, climate impacts would likely overwhelm restoration and sediment improvements. Although broader patterns of temperature change and other parameters with rising greenhouse gas emissions are relatively well understood, the response of the Elk River watershed and stewardship area to these broader changes is not (See climate change modeling technical memorandum in CalTrout 2022[3]). Further work will be needed to identify vulnerabilities systematically and robustly. We are developing assessments for focal aquatic species, habitats, or ecosystems to help identify key vulnerabilities that should be considered when planning and designing restoration actions. Assessing sensitivity, exposure, and adaptive capacity of target species to predicted climate change stressors would help in developing designs that mitigate impacts and allow for adaptation.

Appendix 2.3 Oceans and Estuaries



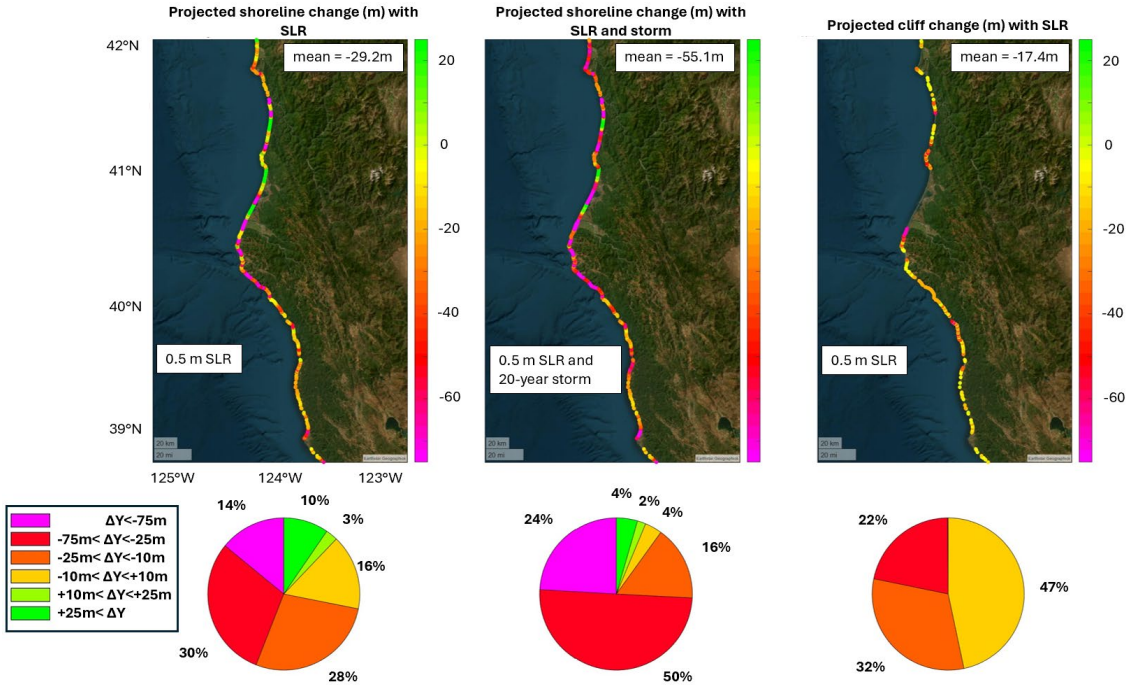
Appendix Figure 2.3.A: *Surface kelp canopy area.*

Pre- and post-impact from sites in Sonoma and Mendocino counties, Northern California from aerial surveys (2008, 2014–2016). Maps were made using ArcGIS Version 10.6 software by Esri. (Figure 3 in Rogers-Bennet and Catton 2019, Creative Commons)



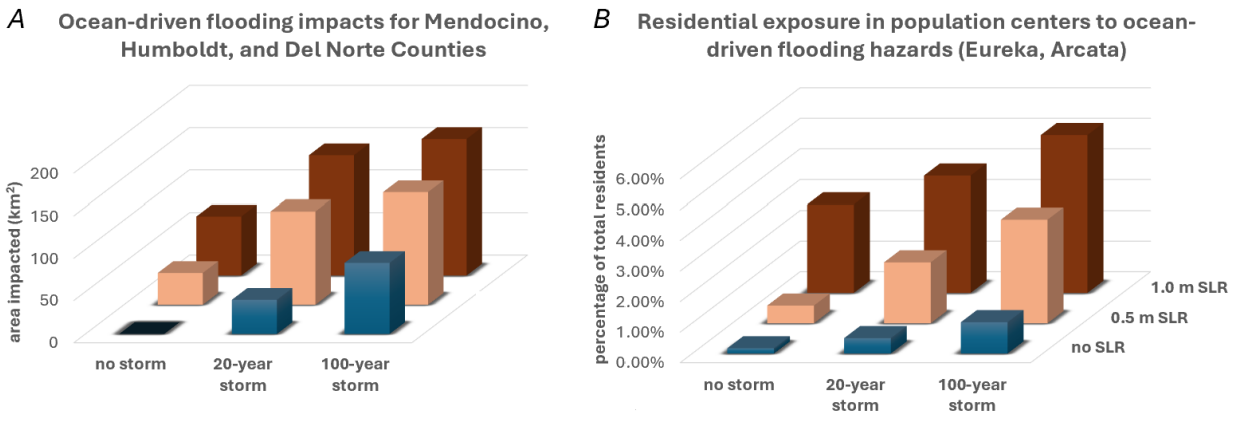
Appendix Figure 2.3.B: *Off Shore Sea Surface Temperatures, 1985-2025.*

Showing Coastal Squeeze of Cold Water Upwelling Zones. Each color represents a change in one degree Celsius. Map by Maria José Marín Jarrín.



Appendix Figure 2.3.C: *Projected shoreline change and cliff retreat with 0.5 m SLR.*

Shoreline changes are presented with SLR alone (left) and SLR with a 20-year coastal storm (middle).



Appendix Figure 2.3.D: *Ocean-drive flooding with SLR and storms.*

A) area of flooding hazard, b) percentage of residents in population centers exposed to ocean-driven flooding hazards.

Appendix Case Study 2.3.A. Case Study: Klamath River Estuary—A Tribal Perspective

Author: *Keith Parker*

The Klamath River estuary is the culmination of over 250 miles (402 km) of river flow beginning in Oregon. The estuary is a transitional zone essential for the life histories of out-migrating and return spawning anadromous fish such as salmon, Pacific lamprey, and sturgeon. Out-migrating salmonids may spend weeks or months in the estuary increasing body size and acclimating to marine temperature and salinity differences before entering the Pacific Ocean. Conversely, return spawner fish use the estuary to acclimate to warm freshwater conditions after spending years in cold saltwater.

The Yurok village of Rek-woy (Requa) is located at the estuary. As the first village encountered from the Pacific Ocean, Rek-woy holds significant cultural importance. The river mouth is protected by a spiritual rock named Oregos on the far north side of the estuary. Oregos watches over the safety of Yurok people as they harvest ney-puy (salmon), kaa-ka (sturgeon), ke'ween (pacific lamprey), kwor-ror (candlefish), pee-ee (mussels), chey-gel' (seaweed), and other foods. Rek-woy is also the location of the first salmon ceremony and brush dances each year.

Sailing ships entered the estuary to pick up barrels of salted salmon from the fish cannery located at Rek-woy beginning in 1876. Over time, poor logging and gold mining practices caused significant damage to the estuary ecosystem by introducing huge amounts of sediment. Sediment has shallowed the entire estuary to less than eight feet except for one deep channel in the middle. The sediment has also built-up significant sand spits on the north and south side of the river mouth. During low river flows in the fall, the mouth of the river often closes for weeks, preventing fish passage.

Sediment management is an important aspect of dam removal projects. The recent removal of four dams on the Klamath River has exacerbated estuary sedimentation by releasing massive amounts of impounded sediment built up over one hundred years. However, in all other aspects of estuary health, dam removal has transformed the ecosystem. Water quality, temperature, and flow have not been this healthy in this author's lifetime. River water temperatures are several degrees-F cooler than in previous years, which is important as temperature regulates almost all chemical and biological processes and is an important cue that affects when salmonids migrate upstream and spawn. Due to the cooler water temperatures observed in July, fall-run Chinook salmon began entering the river several weeks earlier than in previous years. Salmonid diseases such as ICH and *C. shasta*, which have devastated salmonid juvenile and returning adult populations for many years, were rarely observed in the year following dam removal. Consequently, increased fish health and meat quality is observed. Other key factors include the elimination of Klamath dams holding massive blobs of microcystin producing cyanobacteria and sediment beds that were prime habitat for intermediate hosts of *C. Shasta*. For many years, county health signs were posted annually warning of human health hazards from algal blooms. The lack of algal blooms has allowed Tribal gill net fishers to increase subsistence harvest and reduce time and energy in fishing. Prior to dam removal, fall of the year gill nets would plug up with algae within two-hours making them ineffective at harvesting fish. The nets would have to be rotated with clean nets and it would take hours to clean a dirty net. Post dam removal, this author fishes with the same net for consecutive days without a single piece of algae.

Increased SLR, coupled with increased sedimentation and lower river flows caused by drought, will be devastating to the Klamath River estuary. Impacts to indigenous people include inundation of traditional sites used for beach seining/netting of fish and shellfish harvest; burial site, ceremonial dance ground, and cultural artifact sea inundation; increased nearshore marine toxic algal blooms causing shellfish toxins; loss of red abalone for food and regalia; loss of dentalium shells used for Yurok money; saltwater kills of resident freshwater fishes and plants used for basketry and regalia; and other impacts. All of these climate change impacts will impair Tribal food gathering, significantly impacting Tribal food security and sovereignty. At the core of Tribal sovereignty is food sovereignty as it is the right of a community to define its own diet. Traditional foods feed much more than the physical body, these foods feed the Spirit. Traditional foods represent our living link with the land, thereby supporting a place-based identity. The traditional food web is interwoven into all aspects of Tribal society; food, language, art, religion, trade, etc. all evolved synchronously, not independently.

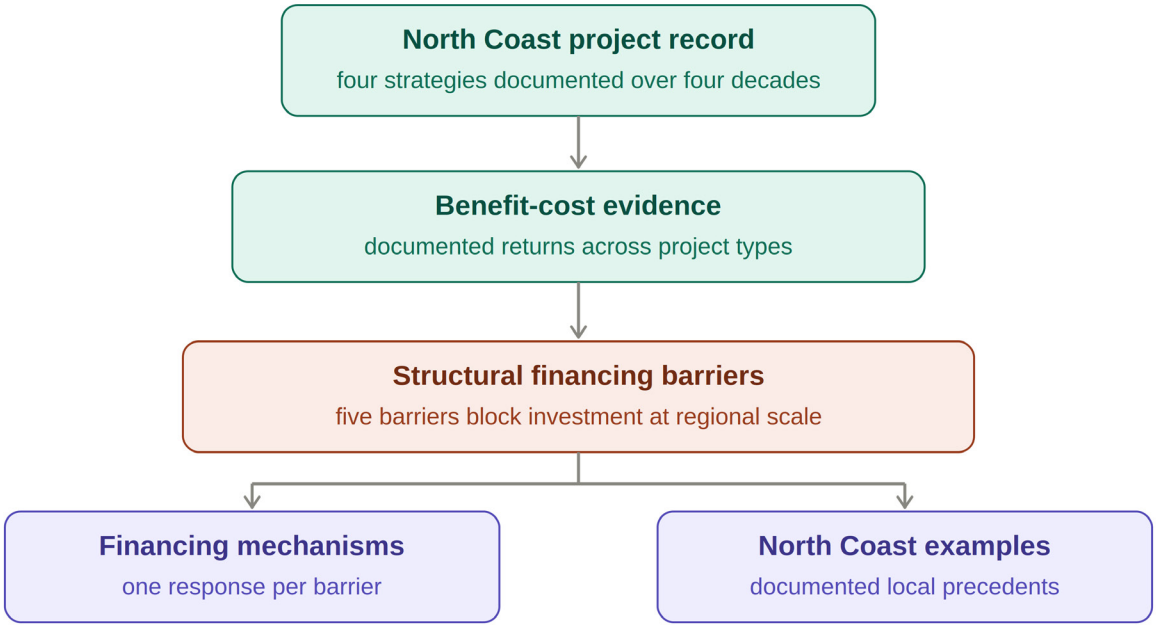
Appendix 3. Built Systems: Economic Framework for Climate-Resilient Infrastructure Investment

Appendix 3.1 Overview

This appendix develops the economic and financing dimensions of the policy directions in Chapter 3. It serves as an introduction to issues and guide to resources for further exploration. Each section below takes a barrier identified in the chapter, pairs it with a financing mechanism, and illustrates the possible use of the mechanism through application to a local project. The final section provides links to organizations, documents, and research for readers interested in getting more information (**Appendix Figure 3.1**).

As detailed in Chapter 3, the North Coast's operational record makes the economic case for nature-based infrastructure, distributed systems, adaptive management, and integrated multi-benefit approaches—strategies that repeatedly deliver measurable returns at lower cost than conventional alternatives. Conservative projections from North Coast projects suggest benefit-cost ratios of at least 2:1, and national and international studies of hazard mitigation and climate adaptation investments consistently show returns well above this range, though from project types and scales not directly comparable to North Coast conditions. But the directional finding is consistent across contexts: multi-benefit resilience investments tend to return more than they cost (Brandon et al., 2025). Despite this evidence, state and federal financing structures have not directed funds toward these approaches at the scale that documented project performance and regional climate exposure would warrant.

This appendix addresses five structural barriers that Chapter 3 identifies as particularly constraining: Proposition 218 reserve restrictions, short grant cycles, the treatment of distributed systems as supplemental, eligibility rules written for single-purpose projects, and insurance pricing that does not recognize risk reduction. Each barrier is addressed in the sections below, paired with a financing mechanism and illustrated with a local project. The table below is a quick-reference guide.



Appendix Figure 3.1: *Analytical framework for Appendix 3.*

The appendix begins with the North Coast's documented project record, establishes the benefit-cost case for climate-resilient approaches, identifies five structural financing barriers that prevent investment at regional scale, and addresses each barrier with a specific financing mechanism illustrated by a North Coast precedent. See **Appendix Table 3.1** *for the barrier-by-mechanism summary.*

Appendix Table 3.1 Quick-reference guide: Chapter 3 barriers, financing mechanisms, local examples, and appendix sections.

Chapter 3 Barrier	Financing Mechanism	Local Example	Sections
Prop 218/reserve accumulation	Green bank; bridge financing	BLR microgrid; Karuk solar	3.2.1; 3.4
Short grant cycles/patient capital	Environmental Impact Bonds; Forest Resilience Bonds	Mattole watershed; NCRP	3.2.2; 3.4
Distributed systems as supplemental	Regulatory reform plus Scenario-based evaluation (RDM)	TERAS project	3.2.3; 3.4
Funding eligibility exclusions/ multi-agency burden	Regional pooling (JPA); cross-program eligibility reforms	Arcata Marsh permitting; NCRP shared grant capacity	3.2.4; 3.4
Insurance pricing/risk reduction recognition	Performance-based premium credits; landscape-scale risk-reduction credits	Lake County; Humboldt Bay living shorelines	3.2.5; 3.4

Note: The Department of Energy (DOE) GRIP grant for TERAS was canceled in October 2025; the microgrid projects are moving forward with state and utility funding, with prospective federal support through tax credits and potential DOE programs.

Appendix 3.2 Barriers, Mechanisms, and Local Examples

3.2.1 Fiscal Capacity: Reserve Accumulation and Bridge Financing

The barrier. Proposition 218 bars water and wastewater agencies from charging ratepayers for potential or future use of a service (Cal. Const. art. XIII D, § 6(b)(4)), which means reserves must be tied to current, demonstrable service costs rather than anticipated climate adaptation needs (Hanak et al., 2016; Owen, 2025). Government Code §§ 53600–53609 further restricts how those reserves can be invested, requiring conservative, low-yield instruments. The practical effect: agencies cannot accumulate the patient capital that adaptive infrastructure management demands, and communities that qualify for grants often cannot cover upfront costs while reimbursements are processed. The result is a structural mismatch between the financing timeline that adaptation requires and the rate-setting constraints that govern how small districts can collect and hold funds.

The mechanism. Green banks address the financing gaps these constraints create. Because Proposition 218 prevents agencies from accumulating reserves for future adaptation needs, communities that qualify for grants often cannot cover upfront costs while waiting for reimbursements. A green bank can provide that bridge financing directly. Beyond bridging individual project gaps, green banks attract private investment alongside public funds by absorbing first losses so private lenders face less risk, giving small communities access to capital they could not reach through conventional financing alone.

Connecticut's Green Bank has deployed $3.11 billion in total clean energy investment on $463 million in public investment—about $6.70 in private investment for every $1 in public funds (Connecticut Green Bank, 2025). Michigan Saves has directed over $500 million to clean energy projects, with more than half reaching low- and moderate-income communities (Michigan Saves, 2024). California's IBank provides an existing institutional foundation that could be expanded into a full green bank function with funding specifically directed toward climate resilience investments, avoiding the need to create a new institution from scratch.

BLUE LAKE RANCHERIA (BLR) MICROGRID

Built with approximately $5 million in California Energy Commission grant funding and Tribal co-investment, the BLR microgrid generates $150,000–$200,000 in annual energy savings (depending on year and system configuration; US Department of Energy, Office of Indian Energy, 2020; Schatz Energy Research Center, 2024). During the October 2019 PSPS (a 28-hour outage) the microgrid maintained power for an estimated 10,000 people, roughly 10% of the county population. County officials credited the microgrid with saving four lives by providing power for eight people with acute medical needs housed at the Tribal hotel by request of the Humboldt County Department of Health and Human Services (Microgrid Knowledge, 2019). The project drew on a combination that standard programs rarely provide together: capital through the California Energy Commission's Electric Program Investment Charge (EPIC) program, and technical assistance through DOE Office of Indian Energy's Strategic Technical Assistance Response Team (START) program.

KARUK TRIBE SOLAR

The Karuk Tribe's 1.25 MW solar installation, completed in 2024 at $3.98 million, projects $13.4 million in 30-year savings under current energy rate assumptions. 75% of construction positions were filled by Tribal members and local contractors (US Department of Energy, Office of Indian Energy, 2024). The project illustrates both the employment effects of locally executed distributed energy and the financing pathway—Tribal energy program grants—that made it possible.

3.2.2 Short Grant Cycles and Patient Capital

The barrier. Short grant cycles create a persistent capacity problem. When experienced staff disperse—as documented in Dunsmuir following the end of a federal grant period (Community Advisory Board, 2024)—communities bear the cost of rebuilding capacity, a frequent pattern that North Coast projects document (Chapter 3). Short funding horizons are particularly damaging for nature-based and distributed systems, which often require several years before performance benefits materialize—a mismatch the outcome-based financing mechanisms described below are specifically designed to address.

The mechanism. Environmental Impact Bonds (EIBs) and Forest Resilience Bonds (FRBs) solve the timeline mismatch directly. Rather than disbursing funds upfront on a fixed schedule, they structure payments around independently verified outcomes over multi-year periods, keeping funders engaged until performance is demonstrated and designed to align financial incentives with project realities rather than administrative calendars.

For example, District of Columbia Water and Sewer Authority (DC Water)'s $25 million EIB (2016) was repaid in full in 2021 following independent validation of a nearly 20% reduction in stormwater runoff into Rock Creek (DC Water, 2021). Blue Forest (a non-profit conservation finance organization) has an FRB, now structured as a $50 million shared investment fund, that pays federal and state agency beneficiaries over time as restoration outcomes are achieved (Calvert Impact, 2024). The Colfax I FRB, launched in 2025, is the first Tribally-led bond of this type, modeling how conservation finance can align with and amplify Indigenous stewardship (Blue Forest, 2025). Blue Forest is also developing a Watershed Resilience Bond for the Southern Oregon–Northeastern California region, which would apply the same multi-beneficiary structure to a watershed near the North Coast study area (Blue Forest, 2025).

MATTOLE WATERSHED RESTORATION

The Mattole Restoration Council's Good Roads, Clear Creeks (GRCC) program has treated over 380 miles (612 km) of roads, preventing an estimated 2 million cubic yards (1.5 million cubic meters) of sediment from reaching salmon streams at 50–70% of the conventional engineering cost (Mattole Restoration Council, 2024). Most watershed restoration programs face a capacity-dispersal problem when grant cycles end; the GRCC program's longevity reflects sustained organizational investment that short-cycle funding structures rarely support.

Since 2004, the North Coast Resource Partnership (NCRP) has invested over $120 million across seven counties and 35 Tribal nations, leveraging over $160 million in matching funds—roughly $1.33 in total investment for every $1 in public funds—through voluntary coordination alone

(North Coast Resource Partnership, 2024). Further, 85% of projects benefit disadvantaged communities, and the partnership's scope spans watershed health, energy independence, climate adaptation, and economic development; this is the kind of cross-sector integration that is difficult for single-program funding structures to support. The partnership's two-decade continuity also illustrates the patient capital argument this section makes: sustained regional coordination produces compounding returns that short grant cycles cannot replicate.

3.2.3 Distributed Systems Treated as Supplemental

The barrier. Distributed energy systems and alternative water supplies have demonstrated primary infrastructure functions across the North Coast, yet funding and regulatory frameworks continue to treat them as supplements to centralized systems. Rate-setting proceedings optimize for expected conditions rather than testing performance across climate scenarios, which systematically favors conventional centralized investment over distributed alternatives that often perform better under uncertainty.

The mechanism. The barrier here is regulatory rather than financial: rate-setting structures have not established how to value distributed infrastructure, and without that regulatory foundation, financing mechanisms have no revenue stream to work with (NARUC/NASEO, 2021). The underlying problem is how utilities plan—they forecast a single expected future and optimize for it, rather than testing investments across a range of possible conditions. This systematically undervalues options that perform best when actual conditions diverge from predictions, which is precisely when distributed systems tend to outperform centralized ones. Scenario-based evaluation methods, including Robust Decision Making (RDM) developed by Lempert and colleagues at RAND (a non-profit research organization that develops solutions to public policy challenges), are designed to address this gap by asking which investment performs acceptably across the most futures rather than which one is optimal under the most likely one (Lempert & Groves, 2010). California's existing climate adaptation proceeding (CPUC R.18-04-019), which already requires climate vulnerability assessment in utility planning, could provide a regulatory vehicle for introducing this kind of evaluation for distributed alternatives.

Box A3.1: *Why Utilities Have Limited Incentive to Invest in Distributed Infrastructure*

Utilities earn revenue by owning physical infrastructure—power lines, substations, treatment plants, etc. The more capital they invest in these assets, the more they can charge customers through regulated rates. Distributed resources like micro-grids and community solar are often owned by someone other than the utility and do not count toward this revenue base, giving utilities little financial incentive to favor them even when they would perform better.

Compound this with how utilities plan: they forecast a single expected future and optimize for it, rather than testing investments across a range of possible conditions. This systematically undervalues options like distributed systems that perform best when actual conditions diverge from predictions—which is usually when communities need them most.

For readers interested in the regulatory mechanics behind these incentives, see: Costello (2013, 2014), Hempling (2021), and NARUC/NASEO (2021) in the references.

A parallel structural barrier operates at the investment level: renewable and distributed energy projects are frequently not bankable under existing private lending conditions even when they are cost-competitive, because high upfront costs and unpredictable revenue streams produce

profit margins (typically 5–8%) that fall below private lenders' minimum return expectations (Christophers, 2024). Christophers (2024) argues that public de-risking mechanisms—green banks, loan guarantees, long-term power purchase contracts—are therefore not optional supplements to market-led decarbonization but functional prerequisites for it. This finding is consistent with the structural character of the barriers documented here.

The Tribal Energy Resilience and Sovereignty (TERAS) project illustrates both problems in concrete terms. At roughly half the cost of undergrounding equivalent infrastructure for 142 miles (228 km)across Humboldt, Del Norte, and Siskiyou counties (Schatz Energy Research Center, 2024), the project's cost advantage was evident from standard comparison—but its projected resilience advantages under outage and wildfire conditions are precisely the kind of performance differential that scenario-based evaluation, rather than single-scenario cost comparison, is designed to capture.

3.2.4 Funding Eligibility Exclusions and Multi-Agency Burden

The barrier. Multi-benefit projects face disproportionate administrative costs on two fronts. First, each benefit stream typically requires a separate application, a separate reporting schedule, and compliance with a separate set of program rules. Second, the communities that rely most heavily on multi-benefit approaches frequently have the least administrative capacity to navigate the funding systems that would pay for them: a 2024 US Government Accountability Office (GAO) report found that federal agencies have not adequately identified or assisted applicants with limited administrative resources (US Government Accountability Office, 2024), and a Headwaters Economics analysis documented how match requirements and reimbursement rules systematically exclude the communities with the greatest need (Headwaters Economics, 2023).

The mechanism. Regional pooling of grant-writing, fiscal management, and compliance capacity addresses the administrative burden directly. At the state level, allowing a single application to access several funding streams for projects that deliver multiple benefits could reduce the administrative cost that currently makes competitive grants inaccessible to rural communities with limited staff capacity. California's existing Integrated Regional Water Management framework provides a partial model, but its scope does not extend to energy, transportation, or building systems, which is the kind of cross-sector integration that North Coast projects require (California Department of Water Resources, n.d.). A regional authority formalized as a Joint Powers Authority (a JPA is a legal structure under California law that allows multiple local governments to share powers, pool resources, and enter contracts they could not sustain independently) could add bonding capacity, shared technical staff, and the ability to enter long-term contracts that voluntary coordination alone cannot sustain.

ARCATA MARSH

The Arcata Marsh has treated wastewater for approximately 18,000 residents since 1983 at substantially lower operating cost than the conventional secondary treatment alternative it replaced (Gearheart et al., 1983; City of Arcata, 2023). Its decade-long permitting process—navigating the Regional Water Quality Control Board, State Water Resources Control Board, Coastal Conservancy, and Clean Water Act requirements simultaneously—illustrates how projects designed to serve multiple functions often face disproportionate regulatory burden. The facility's

performance through the 1992 Cape Mendocino earthquakes and multiple major atmospheric rivers demonstrates adaptive capacity that evaluations designed around a single infrastructure function cannot measure.

NORTH COAST RESOURCE PARTNERSHIP

The North Coast Resource Partnership (NCRP) demonstrates what shared regional capacity can achieve, even without formal authority. Through approximately $350,000 in cumulative technical assistance to member communities over two decades, NCRP has helped secure an estimated $50 million in funded projects—an estimated 140:1 return on coordination investment (calculated by comparing cumulative technical assistance costs to the total value of grants secured with NCRP support), based on NCRP reported figures—by reducing the application barriers that would otherwise price them out of competitive grant processes. Shared grant-writing and joint procurement already reduce costs for member communities (North Coast Resource Partnership, 2024). NCRP's two-decade record suggests what a more formally structured regional authority could achieve with greater legal and financial tools at its disposal.

3.2.5 Insurance Pricing That Does Not Recognize Risk Reduction

The barrier. Private insurers are withdrawing from high-risk areas across the North Coast, forcing property owners onto California's FAIR (Fair Access to Insurance Requirements) Plan, the state's insurer of last resort, which covers fire but not the comprehensive risks that conventional policies provide. FAIR Plan exposure grew from $112.75 billion to $724 billion between 2019 and December 2025 (California Assembly Insurance Committee, 2026), and policies in force increased 139% between September 2021 and March 2025 (California FAIR Plan, 2025).

Rising losses are driving insurers out of high-risk markets, but current pricing models do not recognize investments that reduce those losses—a gap that may compound the pressure on the FAIR Plan. At the building scale, homeowners who invest in fire-resistant retrofits often see no premium reduction. At the landscape scale, community investments in fuel reduction, living shorelines, and restored wetlands demonstrably reduce hazard exposure across multiple properties, but no pricing mechanism translates that collective risk reduction into premium relief. Whether insurers will recognize risk reduction at either scale—individual building retrofits or landscape-level fuel reduction and habitat restoration—remains unresolved. This gap reduces the financial incentive to invest in both, and may reflect structural constraints in how insurance markets are organized as much as the difficulty of verifying risk reduction itself (Collier et al., 2026).

The mechanism. Insurance discounts tied to verified risk reduction could close this gap at both scales. At the building scale, California Insurance Commissioner Lara's 2024 regulation requiring insurers to factor wildfire mitigation into their pricing establishes a state precedent (California Department of Insurance, 2024)—though early evidence suggests current discount levels remain too small to fully offset retrofit costs (Ludington et al., 2025). At the landscape scale, verification frameworks are less developed but emerging: Reguero et al. (2020) demonstrate how restored coastal habitats can be integrated into insurance products that credit the protective value of natural infrastructure, and The Nature Conservancy's reef insurance in Hawaii and Quintana Roo, which pays out automatically when wave height or storm intensity crosses a measurable threshold

(called parametric insurance), without requiring a damage assessment (see **Appendix Section 3.3.1**), provides the most developed real-world model for this approach.

LAKE COUNTY: INSURANCE WITHDRAWAL AND COMMUNITY RISK REDUCTION

Lake County illustrates what happens when insurance withdrawal intersects with extreme wildfire risk—70% of the County's land area has burned since 2015. As private insurers have withdrawn, residents have been forced onto expensive FAIR Plan coverage or left uninsured entirely. The county's extensive fuel reduction work and community wildfire protection planning represent real risk reduction, but nothing in current insurance pricing reflects it. The Lake County Home Hardening Program—part of a statewide pilot linking verified home retrofits to insurance discounts—is testing whether community-scale risk reduction can slow insurer withdrawal, though early evidence suggests current discount levels remain too small to fully offset retrofit costs (Ludington et al., 2025). The Lake County experience suggests that the barriers to insurance market recognition of risk reduction are less technical than structural. Verification frameworks matter, but the more fundamental constraint is the mismatch between annual policy cycles and the multi-year timescales over which fuel reduction, hardening programs, and landscape-scale restoration deliver measurable results.

That gap may be as much a structural problem as a verification problem. Insurers reprice every year; the benefits of fuel treatment, building hardening, and nature-based solutions like restored wetlands build up over decades. Even well-documented risk reduction does not fit neatly into an annual pricing cycle. This timing mismatch points toward approaches the state could consider alongside discount programs: insurance policies structured over multiple years rather than repriced annually, public mechanisms to keep private insurers engaged in high-risk markets, and financing tools that pay for risk reduction work through avoided losses rather than premium savings. These approaches are still largely untested at community scale in California but are drawing increasing attention in climate finance research (Brandon et al., 2025; Collier et al., 2026).

HUMBOLDT BAY LIVING SHORELINES

Along Humboldt Bay, practitioners are restoring salt marshes as living shorelines that absorb wave energy while providing habitat. Unlike hard barriers that erode and require replacement, salt marshes keep pace with rising seas by trapping sediment and building organic matter, growing taller over time and becoming more protective as vegetation takes hold (Kirwan et al., 2016; Morris et al., 2002). This protection reduces flood and erosion risk for adjacent properties and infrastructure—including the Highway 101 corridor—but current insurance pricing does not credit it. A performance-based framework that verified wave attenuation and flood reduction from restored marsh could translate that ecological function into premium relief for surrounding properties, potentially creating a revenue stream that could partially finance ongoing restoration.

Appendix 3.3 Additional Tools and Approaches

The following tools address financing and planning gaps relevant to the North Coast but go beyond the chapter's explicit policy directions. They are included as emerging mechanisms worth tracking rather than developed recommendations.

3.3.1 Parametric Insurance

As introduced in **Appendix Section 3.2.5**, parametric insurance pays automatically when an objective, measurable threshold is crossed, with no claims process and no adjuster—unlike traditional insurance, which requires a damage assessment before paying claims, a process that can take months. Jumpstart (a parametric earthquake insurance product now operated by Neptune Flood) demonstrates what this looks like in practice in California: when ground shaking at a policyholder's location exceeds a set intensity level as measured by USGS data, payment is deposited directly into their bank account, with no documentation required. Parametric insurance's potential applications for the North Coast extend beyond the coastal habitat model described in **Appendix Section 3.2.5**.

The Caribbean Catastrophe Risk Insurance Facility (CCRIF), established in 2007, shows how the same parametric logic can be applied at a regional pooling scale: rather than individual jurisdictions purchasing separate coverage, CCRIF pools disaster risk across small island nations, providing automatic payouts within 14 days. Since its founding, it has made 78 payouts totaling $390 million (CCRIF, 2024). The same pooling logic applied to rural water and energy systems across North Coast counties could provide rapid cash after disaster events, addressing the weeks-long gap between system failure and FEMA reimbursement that currently creates financial gaps small utilities may address through emergency borrowing or service interruption. Achieving this would require targeted regulatory reform to expand permissible trigger criteria and enable the pooling arrangements that current rules do not allow.

3.3.2 Ecosystem Service Markets

Natural infrastructure routinely provides water treatment, flood protection, carbon sequestration, and habitat—services that benefit surrounding communities but are not reflected in any revenue stream that would support their restoration or maintenance. Ecosystem service markets offer a mechanism for translating this value into revenue, though they remain an emerging tool for the North Coast. Water quality trading programs have operated under EPA guidance for over three decades, and carbon markets now offer a parallel pathway for coastal and wetland habitats: voluntary carbon registries provide standardized methods for verifying and crediting the carbon stored in restored wetlands, making it possible to generate revenue from restoration work. Verra, an international non-profit that develops carbon and environmental crediting standards, has developed a methodology covering tidal wetland and seagrass restoration that provides a framework applicable to North Coast coastal habitats, including the Humboldt Bay salt marsh and Eel River delta wetlands documented in Chapter 3.

The American Carbon Registry offers a complementary California-specific wetland carbon methodology through a CARB-approved registry. The gap is not market infrastructure at the national level but state-level aggregation platforms and standardized protocols that could make participation by small rural projects economically viable (Morrison et al., 2021). At Humboldt Bay, where USGS monitoring has documented the carbon storage potential of tidal marsh restoration, the technical groundwork exists but no active carbon credit project has yet been developed (Curtis et al., 2022).

3.3.3 Dynamic Adaptive Policy Pathways (DAPP)

Dynamic Adaptive Policy Pathways (DAPP) is a planning method that formalizes adaptive decision-making by identifying in advance the conditions that would trigger a shift from one infrastructure approach to another; for example: specifying the sea level threshold at which a community stops maintaining a shoreline road and begins rerouting it, rather than making that call in crisis. North Coast communities already practice this proactive decision-making informally: Fort Bragg shifted from treating desalination as emergency backup to accepting it as permanent supply when observed conditions made the original approach untenable. DAPP provides the way to turn ad hoc decisions into planned pathways (Haasnoot et al., 2013).

3.3.4 Tiered Infrastructure Standards

As a policy direction rather than an established program, tiered infrastructure standards could provide formal state-level recognition that appropriate service levels vary by population density, geography, and community capacity. North Coast counties have already adopted context-appropriate standards in their own planning documents—Trinity County's processed gravel standard for low-density roads (Trinity County DOT, 2024) and Humboldt County's explicit acceptance of reduced service levels for rural roads (Humboldt County, 2017)—but these locally adopted approaches have no counterpart in state funding frameworks. Independent research documents why this matters: federal and state infrastructure programs built around urban norms systematically disadvantage rural applicants through cost-effectiveness thresholds that calculate benefits based on population served, matching fund requirements that exceed small tax-base capacity, and administrative complexity that places rural jurisdictions at a structural disadvantage (Headwaters Economics, 2023; Urban Institute, 2023).

Formalizing tiered standards through state policy would not lower the bar for rural infrastructure, but rather would align the bar with the conditions communities actually face. Relevant resources include the Federal Highway Administration's Context Sensitive Solutions guidance (fhwa.dot.gov), Infrastructure Australia's Planning Framework, and Ontario's Asset Management Regulation (O. Reg. 588/17).

Appendix 3.4 Conclusions

The North Coast's four decades of operational experience with nature-based infrastructure, distributed networks, adaptive management, and integrated multi-benefit approaches provide a strong empirical basis for the economic claims in this appendix. The financing barriers identified here are structural rather than technical—products of statutes, regulations, and program designs rather than limits on what is physically or economically achievable. Each mechanism described above has operating precedents in existing institutions that could be adapted or expanded. Without these adjustments, the financing mismatches documented here will continue to produce the infrastructure failures documented in Chapter 3—failures whose costs fall disproportionately on communities with the fewest resources to absorb them.

Appendix 3.5 Resources for Further Information

The following resources are organized to match the barriers and mechanisms in **Appendix Table 3.1**. Most organizations offer technical assistance and model documents in addition to published research. Below, readers working on implementation will find direct contacts and practitioner guides as well as analytical material.

Green Banks and Resilience Finance

California Department of Water Resources, Integrated Regional Water Management:
https://water.ca.gov/Programs/Integrated-Regional-Water-Management
Administers California's IRWM grant program; provides a partial model for cross-program eligibility reforms that would allow single applications to access multiple funding streams for multi-benefit projects.

California Infrastructure Bank (IBank):
https://www.ibank.ca.gov
Existing California authority with overlapping mandate; relevant to bridge financing structures.

Coalition for Green Capital:
https://www.coalitionforgreencapital.com
National network supporting green bank development; Michigan Saves model documentation.

Connecticut Green Bank:
https://www.ctgreenbank.com
Annual reports include leverage ratios, product structures, and replication guidance.

EPA Water Infrastructure and Resiliency Finance Center:
https://www.epa.gov/waterfinancecenter
Tracks innovative water and stormwater infrastructure financing; case studies and model documents.

Environmental Impact Bonds and Forest Resilience Bonds

Blue Forest:
https://www.blueforest.org
Developer of the Forest Resilience Bond; active in Northern California. Colfax I Tribally-led FRB documentation on website.

Conservation Finance Network:
https://www.conservationfinancenetwork.org
Clearinghouse for conservation finance models; curates practitioner resources.

Quantified Ventures:
https://www.quantifiedventures.com
Originated the EIB model with DC Water; publishes full implementation documentation.

Policy Analysis and Research

Center for American Progress:
https://www.americanprogress.org
Research and policy analysis on rural economic development and federal program access; documents how federal funding design and cost-effectiveness thresholds create structural disadvantages for rural and Tribal applicants.

Lincoln Institute of Land Policy:
https://www.lincolninst.edu
Publishes on fiscal constraints and municipal resilience; tracks Proposition 218 and related issues.

National Institute of Building Sciences:
https://www.nibs.org
Natural Hazard Mitigation Saves series—most widely cited source for resilience benefit-cost ratios.

PPIC Water Policy Center:
https://www.ppic.org/water
Best single source for California water finance and governance; recent work on Proposition 218 and rural utility finance.

Resources for the Future:
https://www.rff.org
Independent research institution publishing applied economic analysis of climate risk, insurance markets, and wildfire mitigation policy; recent work includes empirical analysis of California's wildfire mitigation discount programs.

Rocky Mountain Institute:
https://www.rmi.org
Accessible cost comparisons for microgrid versus utility-scale alternatives.

Urban Institute:
https://www.urban.org
Applied policy research institution; work on federal infrastructure funding includes analysis of how matching requirements and administrative complexity affect small and rural communities' access to resilience investments.

World Resources Institute:
https://www.wri.org
Publishes applied research on climate adaptation finance including benefit-cost analysis of resilience investments; the Financing Adaptation report series is particularly relevant.

Parametric Insurance

Jumpstart Parametric Insurance (Neptune Flood):
https://www.jumpstartinsurance.com
Parametric earthquake insurance available in California, Oregon, and Washington pays out automatically when ground shaking exceeds a measurable threshold with no claims process. Useful as a real-world model for parametric trigger structures applicable to other hazards.

The Nature Conservancy, Insuring Nature:
https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/insuring-nature-resilient-future
Hawaii and Quintana Roo reef insurance are the most developed real-world models for natural infrastructure parametric coverage.

Ecosystem Service Markets

American Carbon Registry:
https://www.americancarbonregistry.org
CARB-approved registry; involved in California wetland carbon methodology development.

Ecosystem Marketplace (Forest Trends):
https://www.ecosystemmarketplace.com
Annual State of Voluntary Carbon Markets report; best single source for market size and structure.

Verra / Verified Carbon Standard:
https://www.verra.org
VM0033 methodology covers tidal wetland and seagrass restoration; applicable to North Coast coastal habitats. Registry and methodology documentation available on website.

North Coast Regional Resources

Mattole Restoration Council:
https://www.mattole.org
Operates Good Roads, Clear Creeks; longest-running bioengineering and sediment control program in the region.

North Coast Resource Partnership:
https://www.northcoastresourcepartnership.org
Seven-county collaborative; 2004–2024 outcomes report on website.

Schatz Energy Research Center, Cal Poly Humboldt:
https://schatzcenter.org/
Technical resource for distributed energy systems in Tribal and rural communities; BLR microgrid and TERAS documentation.

Watershed Research and Training Center:
https://www.thewatershedcenter.com/
Trinity County-based; workforce training, technical assistance, and watershed restoration project implementation.

Federal Programs

DOE Grid Deployment Office, Grid Resilience State and Tribal Formula Grants:
https://www.energy.gov/gdo/grid-resilience-statetribal-formula-grants-program
Bipartisan Infrastructure Law formula grants specifically including Tribal governments; funds grid hardening, islanding capability, distributed generation, and storage.

DOE Office of Indian Energy:
https://www.energy.gov/indianenergy
Primary federal program for Tribal energy development; funded Karuk solar and TERAS. Searchable Tribal projects database on website.

FEMA, BRIC:
https://www.fema.gov/grants/mitigation/building-resilient-infrastructure-communities
Pre-disaster hazard mitigation grants. Updated benefit-cost guidance allows ecosystem service benefits in applications.

Appendix 3.6 References for Appendix 3: Built Systems

Blue Forest. (2025). Colfax I FRB. https://www.blueforest.org/our-impact/our-projects/colfax-i-frb/

Brandon, C., Aggarwal, A., Kratzer, B., Laxton, V., & Novenario, C. (2025, November 19). Financing adaptation: 11 financial instruments that help build climate resilience. World Resources Institute. https://www.wri.org/technical-perspectives/climate-adaptation-finance-financial-instruments

California Assembly Insurance Committee. (2026, January 28). Oversight hearing: The California FAIR Plan. California State Assembly. https://ains.assembly.ca.gov/system/files/2026-01/1.28.26-fair-plan-background-final.pdf

California Department of Insurance. (2024). CDI Press Release: In a California "first," Commissioner Lara announces enforcement of regulation to expand insurance coverage across the state. https://www.insurance.ca.gov/0400-news/0100-press-releases/2024/release062-2024.cfm

California Department of Water Resources. (n.d.). Integrated Regional Water Management. https://water.ca.gov/Programs/Integrated-Regional-Water-Management

California FAIR Plan. (2025, May). FAIR Plan increases transparency by expanding public access to financial and operational information. https://www.cfpnet.com/fair-plan-increases-transparency-by-expanding-public-access-to-financial-and-operational-information/

Calvert Impact. (2024). Forest resilience bond investment overview. https://calvertimpact.org/resources/success-story-forest-resilience-bond

CCRIF SPC. (2024). About us. Caribbean Catastrophe Risk Insurance Facility SPC. https://www.ccrif.org/about-us?language_content_entity=en

Christophers, B. (2024). The price is wrong: Why capitalism won't save the planet. Verso.

City of Arcata. (2023). Arcata Marsh and Wildlife Sanctuary annual report. City of Arcata.

Community Advisory Board. (2024). Meeting notes from North Coast 5th Climate Assessment community advisory board meetings. California Natural Resources Agency. [Unpublished meeting notes.

Connecticut Green Bank. (2025). Strategy and impact. https://www.ctgreenbank.com/strategy-impact/

Costello, K. (2013). Future test years: Challenges posed for state utility commissions (NRRI Report No. 13-08). National Regulatory Research Institute.

Costello, K. (2014). Alternative rate mechanisms and their compatibility with state utility commission objectives. National Regulatory Research Institute/NARUC. https://pubs.naruc.org/pub/FA86C519-AF31-D926-BE12-2AC7AE0CD8D6

Curtis, J. A., Thorne, K. M., Freeman, C. M., Buffington, K., & Drexler, J. Z. (2022). A summary of water-quality and salt marsh monitoring, Humboldt Bay, California (Open-File Report 2022-1076). U.S. Geological Survey. https://pubs.usgs.gov/publication/ofr20221076/full

DC Water. (2021). Environmental impact bond results. https://www.dcwater.com/environmental-impact-bond

EcoTipping Points Project. (n.d.). USA — California (Arcata): Constructed wetland. https://www.ecotippingpoints.org/our-stories/indepth/usa-california-arcata-constructed-wetland-wastewater.html

Gearheart, R. A., Klopp, F., & Allen, G. (1983). Constructed free surface wetlands to treat and receive wastewater: Pilot project to full scale. In P. E. Godfrey et al. (Eds.), Ecological considerations in wetlands treatment of municipal wastewaters (pp. 121–137). Van Nostrand Reinhold.

Hanak, E., Gray, B., Lund, J., Mitchell, D., Chappelle, C., Fahlund, A., Jessoe, K., Medellín-Azuara, J., Misczynski, D., Nachbaur, J., & Suddeth, R. (2014). Paying for water in California. Public Policy Institute of California. https://www.ppic.org/publication/paying-for-water-in-california/

Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global Environmental Change, 23(2), 485–498. https://doi.org/10.1016/j.gloenvcha.2012.12.006

Headwaters Economics. (2023, August). How match requirements and reimbursement rules limit funding access for underserved communities. https://headwaterseconomics.org/equity/match-requirements/

Hempling, S. (2021). Regulating public utility performance: The law of market structure, pricing and jurisdiction (2nd ed.). American Bar Association.

Kirwan, M. L., Temmerman, S., Skeehan, E. E., Guntenspergen, G. R., & Fagherazzi, S. (2016). Overestimation of marsh vulnerability to sea level rise. Nature Climate Change, 6, 253–260. https://doi.org/10.1038/nclimate2909

LaCommare, K., Eto, J., Dunn, L., & Skumanich, M. (2017). Evaluating proposed investments in power system reliability and resilience (LBNL-2001044). Lawrence Berkeley National Laboratory.

Lempert, R. J., & Groves, D. G. (2010). Identifying and evaluating robust adaptive policy responses to climate change. Technological Forecasting and Social Change, 77(6), 960–974.

Lempert, R. J., Groves, D. G., Popper, S. W., & Bankes, S. C. (2006). A general, analytic method for generating robust strategies and narrative scenarios. Management Science, 52(4), 514–528. https://doi.org/10.1287/mnsc.1050.0472

Ludington, E., Liao, Y., & Walls, M. A. (2025, December 10). From risk to reward: Insurance discounts for wildfire mitigation. Resources for the Future. https://www.rff.org/publications/working-papers/from-risk-to-reward-insurance-discounts-for-wildfire-mitigation/

Malone, E., Hotchkiss, E., McNamara, A., & Miller, M. (2020). Distributed energy resources: Grid modernization at the distribution system level (NREL/TP-6A20-74412). National Renewable Energy Laboratory.

Mattole Restoration Council. (2024). The Mattole watershed. https://mattole.org/the-mattole-watershed/

Michigan Saves. (2024). Annual report. https://annualreport.michigansaves.org/

Microgrid Knowledge. (2019, November 11). Life won thanks to the Blue Lake Rancheria microgrid. https://www.microgridknowledge.com/editors-choice/article/11429301/life-won-thanks-to-the-blue-lake-rancheria-microgrid

Morris, J. T., Sundareshwar, P. V., Nietch, C. T., Kjerfve, B., & Cahoon, D. R. (2002). Responses of coastal wetlands to rising sea level. Ecology, 83(10), 2869–2877.

Morrison, R., Lubell, M., & Clary, J. (2021). Payments for ecosystem services within the hybrid governance model. Ecology and Society, 26(1), Article 19.

NARUC/NASEO Microgrids State Working Group. (2021). Private, state, and federal funding and financing options to enable resilient, affordable, and clean microgrids. National Association of Regulatory Utility Commissioners & National Association of State Energy Officials. https://www.naseo.org/data/sites/1/documents/publications/v2_NASEO_MicroGrid.pdf

National Institute of Building Sciences. (2019). Natural hazard mitigation saves: 2019 report. https://nibs.org/wp-content/uploads/2025/04/mitigationsaves2019_complete.pdf

North Coast Resource Partnership. (2024). Dashboard of outcomes. https://northcoastresourcepartnership.org/site/assets/uploads/2024/05/NCRP-dash-board-draft-11x17-1.pdf

Owen, D. (2025, August 27). Prop 218's ongoing impacts on California water. Public Policy Institute of California. https://www.ppic.org/blog/prop-218s-ongoing-impacts-on-california-water/

Reguero, B. G., Bresch, D. N., Beck, M. W., Calil, J., & Meliane, I. (2020). Financing coastal resilience by combining nature-based risk reduction with insurance. Ecological Economics, 169, 106487. https://doi.org/10.1016/j.ecolecon.2019.106487

Schatz Energy Research Center. (2024). DOE funding enables transformative energy solution for rural Northern California tribes. Cal Poly Humboldt.

U.S. Department of Energy, Office of Indian Energy. (2020). Tribal microgrids support tenuous lifelines during grid shutdowns. https://www.energy.gov/indianenergy/articles/tribal-microgrids-support-tenuous-lifelines-during-grid-shutdowns

U.S. Department of Energy, Office of Indian Energy. (2024). Tribal energy projects database. https://www.energy.gov/indianenergy/tribal-energy-projects-database

U.S. Government Accountability Office. (2024, December). Federal grants: Agencies should enhance efforts to identify and assist applicants with limited resources (GAO-25-107674). https://www.gao.gov/assets/gao-25-107674.pdf

Wolff, A. S. (2024). Characterizing the beneficial uses of the Arcata Marsh constructed wetland treatment system [Master's thesis, Cal Poly Humboldt].

Appendix 4. Social Systems and Cultural Resources

Appendix 4.1 Employment and Labor Demographics

Appendix Table 4.1 A: Employment and Labor Demographics for the North Coast

Author: *Julie Sorfleet*

Metric	Del Norte County	Humboldt County	Lake County	Mendocino County	Siskiyou County	Trinity County	California
Population[1]	27,000	135,000	68,000	91,000	44,000	16,000	39,243,000
Population 65+[1]	20%	20%	24%	24%	27%	29%	15%
American Indian and Alaska Native Population[1 1*]	10%	9%	7%	7%	8%	6%	3%
Population 25+ with Bachelor's Degree or Higher[2]	21%	32%	18%	25%	23%	18%	37%
Median Household Income[3]	$67,000	$61,000	$59,000	$65,000	$55,000	$53,000	$96,000
American Indian and Alaskan Native Median Household Income[4 2+]	$50,000	$51,000	$38,000	$53,000	$50,000	$59,000	$79,000
Employment Rate[5 3±]	47%	53%	45%	51%	47%	37%	59%
Public Sector Jobs as % of Total[6 4§]	29%	23%	22%	17%	25%	23%	15%
Covered Employer Establishments (Q4 2024)[7 5**]	869	7,996	3,814	4,652	1,864	455	1,903,898
Labor Force in 2024[8 6++]	8,990	60,200	25,970	36,500	16,280	5,420	19,644,100
Employment in 2024[8 ++]	8,430	57,100	24,150	34,470	15,140	5,110	18,600,900
Unemployment in 2024[8 ++]	560	3,100	1,820	2,020	1,140	310	1,043,100
Unemployment Rate in 2024[8 ++]	6.20%	5.20%	7.00%	5.50%	7.00%	5.80%	5.30%
Change in Unemployment Rate 2019 to 2024[8 7±±]	+0.0 pts	+1.5 pts	+1.0 pts	+1.2 pts	+0.1 pts	+0.6 pts	+1.2 pts
Top 3 Non-Governmental Industries by Employment (Annual 2024)[9 8§§]	Education and Health Services (EHS); Trade, Transportation, and Utilities (TTU); Leisure and Hospitality (LH)	EHS; TTU; LH	EHS; TTU; LH	EHS; TTU; LH	EHS; TTU; LH	EHS; TTU; LH	EHS; TTU; Professional and Business Services (PBS)
Top 3 Non-Governmental Industries by Payroll (Total Annual Payroll 2024)[9 9***]	EHS; TTU; LH	EHS; TTU; Construction (C)	EHS; TTU; C	EHS; TTU; Manufacturing (M)	EHS; TTU; LH	EHS; TTU; M	PBS; TTU; EHS

Sources

1 U.S. Census Bureau. (2023). ACS Demographic and Housing Estimates. *American Community Survey, ACS 5-Year Estimates Data Profiles, Table DP05.* https://data.census.gov/table/ACSDP5Y2023.DP05

2 U.S. Census Bureau. (2023). Educational Attainment. *American Community Survey, ACS 5-Year Estimates Subject Tables, Table S1501.* https://data.census.gov/table/ACSST5Y2023.S1501

3 U.S. Census Bureau. (2023). Income in the Past 12 Months (in 2023 Inflation-Adjusted Dollars). *American Community Survey, ACS 5-Year Estimates Subject Tables, Table S1901.* https://data.census.gov/table/ACSST5Y2023.S1901

4 U.S. Census Bureau. (2023). Median Household Income in the Past 12 Months (in 2023 Inflation-Adjusted Dollars) (American Indian and Alaska Native Alone Householder). *American Community Survey, ACS 1-Year Estimates Detailed Tables, Table B19013C.* https://data.census.gov/table/ACSDT1Y2023.B19013C

5 U.S. Census Bureau. (2023). Selected Economic Characteristics. *American Community Survey, ACS 5-Year Estimates Data Profiles, Table DP03.* https://data.census.gov/table/ACSDP5Y2023.DP03

6 U.S. Census Bureau. (2023). Occupation by Class of Worker for the Civilian Employed Population 16 Years and Over. *American Community Survey, ACS 5-Year Estimates Subject Tables, Table S2406.* https://data.census.gov/table/ACSST5Y2023.S2406

7 U.S. Bureau of Labor Statistics. (2025, June 17). *County employment and wages in California—Fourth quarter 2024* [News release]. https://www.bls.gov/regions/west/news-release/countyemploymentandwages_california.htm

8 California Employment Development Department, Labor Market Information Division. (n.d.). *Labor force data search tool* [Data query tool]. https://labormarketinfo.edd.ca.gov/cgi/dataAnalysis/AreaSelection.asp?tableName=Labforce&orderBy=area

9 California Employment Development Department, Labor Market Information Division. (n.d.). *Quarterly Census of Employment and Wages (QCEW)* [Data selection tool]. https://labormarketinfo.edd.ca.gov/qcew/CEW-Select.asp

Notes

Income numbers may be understated due to unreported income from marijuana. Margins of error in ACS 5-Year Estimates may be larger in counties with smaller populations, due to smaller sample sizes and greater sampling variability. Percentages and other figures retrieved from the US Census Bureau are reported in this table as rounded values, with percentages to the nearest whole percent and other figures to the nearest thousand.

Appendix Table 4.1 B: Race /Ethnicity Breakdown, North Coast Region, and California Comparison

Author: *Jen Marlow*

Race/Ethnicity	North Coast Population	North Coast %	California %	California Total Population
White (alone)	274,743	72%	44.0%	
Black or African American (alone)	5,745	2%	6%	
American Indian and Alaska Native (alone)	13,875	4%	1%	
Asian (alone)	8,967	2%	15%	
Native Hawaiian and Other Pacific Islander (alone)	1,057	0.3%	0.4%	
Hispanic or Latino (of any race)	71,411	19%	40%	
Some Other Race (alone)	28,115	7%	17%	
Two or More Races	48,777	13%	16%	
Regional Total Population	381,279			
State Total Population				39,242,785

Source

U.S. Census Bureau. (2023). *American Community Survey 5-Year Estimates Detailed Tables B02001 (Race) and B03002 (Hispanic or Latino Origin by Race).* Retrieved from https://data.census.gov/. Accessed May 14, 2026.

Notes

North Coast regional estimates were calculated by aggregating county-level counts for Del Norte, Humboldt, Lake, Mendocino, Siskiyou, and Trinity counties and calculating percentages from summed regional totals. Race categories represent race alone. Hispanic or Latino ethnicity may overlap with racial categories; therefore, percentages do not sum to 100%. Estimates of the American Indian and Alaska Native population differ between **Appendix Tables 4.1.A and 4.1.B** because **Table 4.1.A** uses the Census category "American Indian and Alaska Native alone or in combination with one or more other races," whereas **Table 4.1.B** reports "American Indian and Alaska Native alone" only.

Appendix 4.2 Communications and Capacity Building

Appendix Case Study 4.2. California Trout North Coast

Author: *Christine Davis*

Covering 6,500 square miles (603 square meters) across Glenn, Humboldt, Lake, Mendocino, and Trinity counties, the Eel River watershed—the 3rd largest watershed in California—supports diverse ecosystems and communities. Through the California Trout North Coast (CalTrout) Eel River Watershed Restoration and Conservation Program, CalTrout facilitates coordination across this broad area, guiding multiple groups to align restoration efforts with shared goals, rather than duplicating work. This program serves as a model for encouraging climate resilience at the watershed-scale. The program promotes capacity building by interweaving best available science and Tribal Ecological Knowledge. Climate resilience strategies include restoring hydrological connectivity, prioritizing riparian revegetation, prescribing fire to manage drought-related fire risks, and protecting biodiversity.

Effective communication is central to the program's success. One standout initiative is the Eel River Expo: A Source to Sea Community Event, co-hosted by CalTrout and the Rotary Club of Eureka. The Expo brings together about 30 groups working on restoration, recreation, and conservation in the watershed. Through exhibition tables and interactive activities, the public engages directly with watershed professionals, learning about native and invasive species, habitat restoration, and climate strategies. The Expo is designed to be lively and engaging. Events include a salmon parade featuring AmeriCorps members and Round Valley youth, live music, and a photography contest. These activities build public trust, support, and inspiration—fostering future collaborations and strengthening community networks. As one Expo participant shared, "Restoration can only happen at the pace of relationships."

A checklist of best practices for engaging communications and capacity building at a watershed scale follows below:

Communications

- Listen to learn
- Make events engaging and relevant, using formats like photo contests
- Lead by example—highlight successful restoration projects that inspire replication.
- Include a wide mix of stakeholders: public service, Tribal governments, nonprofits, agencies, and underserved communities.
- Use diverse engagement tools: storytelling, networking, activity tables, art, speaking events, and open forums.
- Create resource archives—maps, photos, and stories—to connect people emotionally to the places they live, work and play. Ask audiences why people love the place that needs to be protected or restored and align resilience efforts with what people value.

Capacity Building

- Build trust through sustained engagement and shared responsibility.
- Use community mapping to encourage inclusive participation.
- Engage groups not typically included in science conversations, especially disadvantaged or minoritized populations.
- Offer funding for Tribes and underserved populations to attend, speak, and participate in key events and conferences.

Appendix 4.3 Climate Finance and Insurance

Appendix Case Study 4.3.A. Lessons for Other Regions from the North Coast

Author: *Selena Rowan*

From grant strategy to climate workforce development, North Coast leaders offer climate finance advice to other regions:

- **Dana Stoltzman (SRF)** emphasizes patience and selectivity. "We have a near 100% grant success rate, but we don't chase money," she notes. Project readiness, grounded in strong pre-project ecological monitoring and community input, is critical.
- **Casey (Happy Day Farm)** frames grants as the "third leg" of the business model alongside cannabis and vegetables. Relationships are a financial asset and core to success: "Whatever we touch, or whatever touches us, we aim to strengthen it." Adaptation is as much social as ecological. Keeping the focus on collaboration is how these projects succeed.
- **Karen Gaffney (North Coast Resource Partnership) (NRCP)** advises other communities to think long and hard about their regional organization's governance structure. NCRP exemplifies how governance and equity structures must evolve alongside finance mechanisms. Its leadership model, which is democratic, co-led by appointees from North Coast Tribes and counties, and grounded in local decision-making, ensures that funding strategies are shaped by those closest to the land.

Sector-Level Spotlights: Financing Resilience in California's North Coast

Across California's North Coast, community-rooted projects are demonstrating how targeted investment in food systems, forest health, watershed restoration, and Indigenous-led climate strategies can drive transformative outcomes. The following case studies highlight innovative models of climate resilience finance, each grounded in local knowledge, ecological stewardship, and long-term commitment.

REGENERATIVE AGRICULTURE & RURAL FOOD SECURITY

Case Study: *Happy Day Farms – Laytonville, Mendocino County - Casey O'Neill*

Diversified investments sustain regenerative rural economies

Happy Day Farms, a multigenerational family operation located above 3,000 feet (914 meters) on Mail Ridge near Laytonville, Mendocino County, demonstrates how small, diversified farms serve as anchors of rural resilience. Laytonville, a community with limited food access and recent wildfire threats—including two of the state's three largest fires (CAL FIRE, 2024)—relies on local producers like the O'Neill family. The farm provides year-round vegetables and flowers to farmers' markets, schools, and food banks, and produces Sun+Earth-certified regenerative cannabis. The O'Neills are recognized leaders in sustainability and community engagement within the cannabis industry and have invested substantial time and effort on wildlife habitat enhancement, water conservation, and renewable energy deployment on the farm. Climate change has amplified labor demands on the farm, requiring more hand-watering, shade cloth deployment, and fire-readiness, all of which reduce family and community time. The O'Neill brothers Casey, Lito, and Ben are also volunteer firefighters, responding to an increasing number of local incidents, including one that damaged their farm infrastructure.

A patchwork of funding sources has supported the farm's climate adaptation and community leadership, and the farm has greatly benefited from the facilitation of local organizations in applying for and managing state funds. Mainspring Consulting and the Mendocino County Resources Conservation District obtained funding from CDFW Cannabis Restoration Grant Program, Point Blue Conservation Science regranted Wildlife Conservation Board funding, and the Mendocino County Equity Program distributed funds from California cannabis equity funds. They also received key funding from the CDFA Farm to School program and the Good Farm Fund, a local foundation.

The Cannabis Restoration Grant Program is especially notable, as it is entirely funded by the cannabis excise tax collected at point of sale, and represents financial investment by the cannabis industry into climate resilience through land and community stewardship.

COMMUNITY-LED FOREST STEWARDSHIP

Case Study: *Watershed Research & Training Center – Trinity County - Clarke Stevenson*

Investments in forest health yield benefits that extend far beyond the canopy

In the upper Trinity River headwaters (THW), the Watershed Research and Training Center (WRTC), a local nonprofit in Trinity County, recently purchased 11,000-acres operating under a Working Forest Conservation Easement managed by Pacific Forest Trust. The property is noted as a critical source of California's water supply, known for its globally significant biodiversity, and will be managed to preserve wildlife habitat and promote old growth characteristics throughout the property. With the objective to demonstrate the potential of a community-led working forest, WRTC will lead the full spectrum of planning, survey, implementation, and retention of the property. It is part of an integrated network of conserved forests at the source of the Sacramento and Trinity rivers.

This project integrates climate resilience, workforce training, and downstream water benefits. It aims to develop community-based forest stewardship practices that can retain revenue from active land management to support stewardship workforce training while also testing the latest forest and silvicultural science for the Klamath Mountain Range ecoregion.

Restoring dense forests back to pre-colonial conditions requires an uneven age silvicultural regime in addition to mechanical thinning. Research in the Sierra Nevada has shown that reducing forest stand density across a watershed can lead to a measurable increase in water quantity to downstream reservoirs under certain conditions. The THW acquisition is part of an integrated implementation and funding strategy being carried out by the WRTC—in partnership with regional partners like the Trinity County RCD—to support forest resilience and wildfire risk reduction in the Upper Trinity River Watershed, which drains into Trinity Lake and is impounded by the Lewiston Dam. Water conveyance from Trinity Lake to the Sacramento River presents an opportunity to engage with downstream water users on financially supporting upriver restoration through "pay-for-performance" models.

These projects are also funded through a blend of state, federal, and philanthropic grants, partnership agreements with the US Forest Service, and philanthropic support from Weyerhaeuser Company and the National Fish and Wildlife Foundation.

WATERSHED RESTORATION & WATER RESILIENCE

Case Study: *Salmonid Restoration Federation – Redwood Creek, Humboldt County - Dana Stolzman*

In Redwood Creek, a critical tributary of the South Fork Eel River, the Salmonid Restoration Federation (SRF) is addressing reduced stream flows in critical salmon habitat with a complex augmentation project designed by Stillwater Sciences. On a 3,000-acre parcel owned by the largest landholder (The Marshall Ranch) in the watershed, SRF constructed two large engineered ponds storing 10 million gallons of water, enough to release cold flows into the creek for five months during the dry summer season.

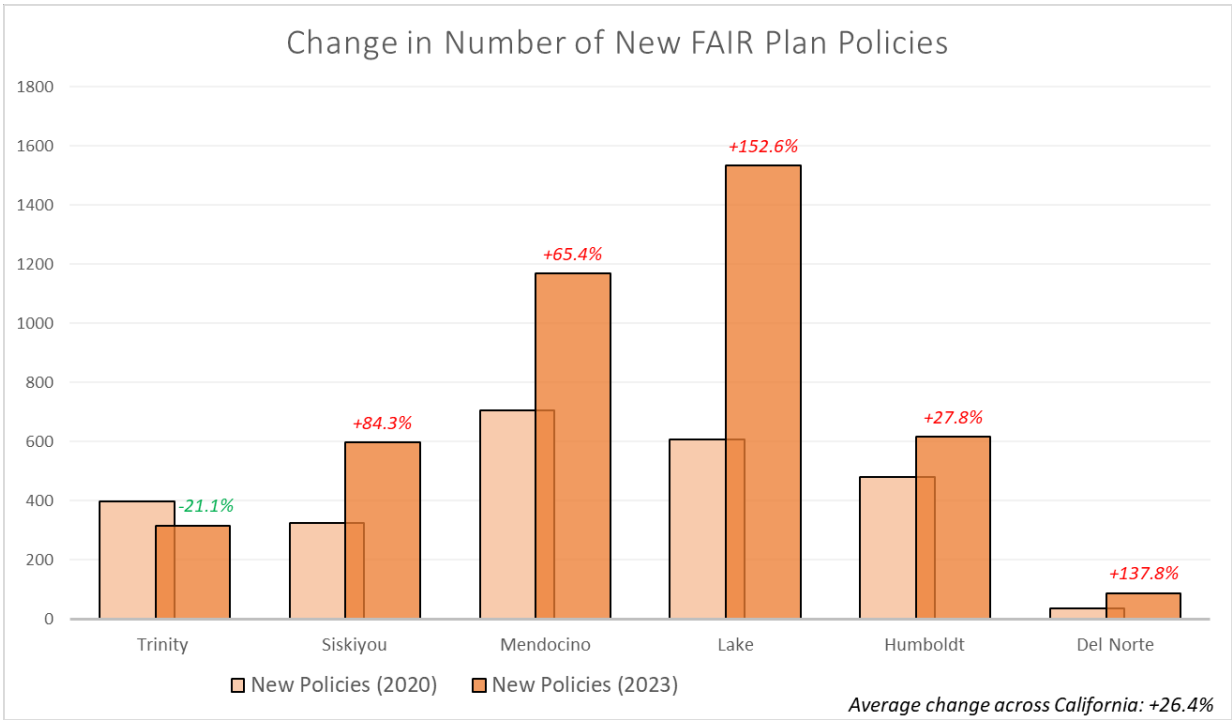
The project is already restoring perennial connectivity that had been interrupted for decades: salmon redds are reappearing, and snorkel surveys showed Coho juveniles utilizing pools into September. Real-time flow, dissolved oxygen and flow monitoring informs the flow release strategy.

Funding came almost entirely from the Wildlife Conservation Board's Streamflow Enhancement Program, which SRF Executive Director Dana Stolzman praised for its flexibility in budgeting, allowing the organization to be nimble and responsive when encountering the real-world

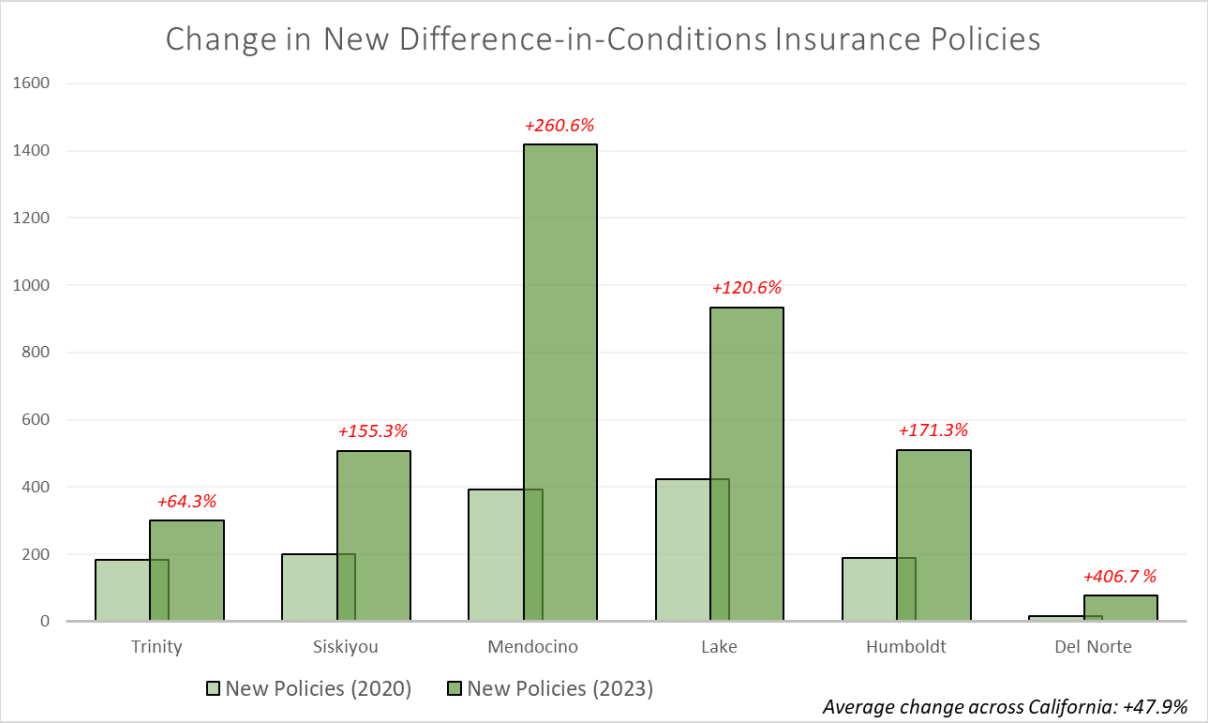
problems common to large infrastructure projects, such as inflation or unanticipated technical challenges. Additional support included NRCS funding for five water storage projects downstream of the Marshall Ranch for neighboring landowners. The White Lily Clan of the Wailaki Tribe have consulted on these flow enhancement projects. This innovative project required years of planning and assessments, community engagement, and a strong state partner.

Appendix Case Study 4.3.B: Insurance Market Trends

Author: *Alec Brown*



Appendix Figure 4.3.B.1: *Year-over-year change in number of new FAIR plan policies by county for the North Coast region (2020–2023).* From Residential insurance policy analysis by county, 2020–2023, by California Department of Insurance, 2024. County-level data were used to calculate percentage changes; statewide mean change shown for comparison.



Appendix Figure 4.3.B.2: *Year-over-year change in number of private Difference-in-Conditions Insurance policies by county for the North Coast region (2020–2023).* From Residential insurance policy analysis by county, 2020–2023, by California Department of Insurance, 2024. County-level data were used to calculate percentage changes; statewide mean change shown for comparison.

Appendix Case Study 4.3.C: Catastrophic Wildfire Risk Assessment Modeling

Author: *Eric Riggs*

Insurance access is essential to California's economic stability, particularly given growing exposure to catastrophic wildfires. Since 2015, fire severity, size, and frequency have increased dramatically across the state, including in the heavily forested North Coast. Accurate risk assessment is key to pricing insurance coverage for large-scale hazards—but modeling wildfire risk is uniquely complex.

In wildland settings, fire behavior is shaped by microclimate, moisture, forest conditions, and mitigation efforts. The challenge increases in the wildland-urban interface, where fire interacts with structures, firefighting actions, and infrastructure. While Southern California's wildland-urban interface fires often receive national attention, the North Coast is also highly vulnerable. Dramatic climate gradients across the region—from cool, wet coastal zones to dry interior forests—produce distinct fire regimes. Communities within North Coast landscapes area also have generally smaller urban footprints and are often deeply embedded in forested landscapes and feature a wide range of quality of mitigation and hardening against fire.

Currently, the private catastrophe models that insurers use are not transparent. The public cannot assess how fire risk is calculated or how local mitigation actions affect insurance pricing. A public, non-governmental wildfire risk model is urgently needed. Such a model would provide a shared benchmark to inform mitigation decisions, increase accountability, and better reflect regional differences and individual efforts. It would help guide insurance markets in ways that reward community-scale resilience.

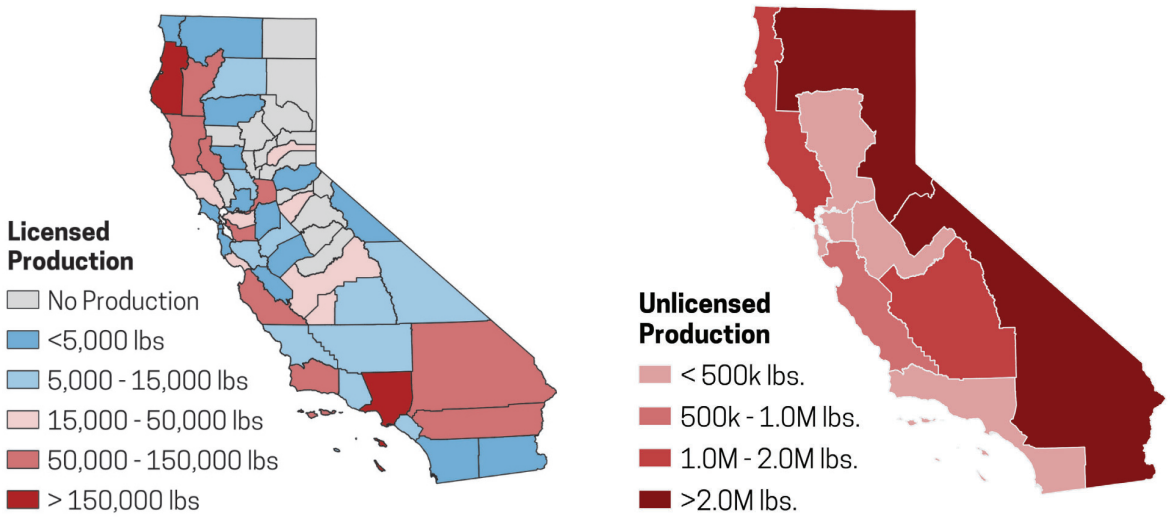
In 2024–25, a working group of academic modelers and public-interest groups—convened by Cal Poly Humboldt at the request of Insurance Commissioner Ricardo Lara—developed a strategy for building a public catastrophe model. The resulting report, Future Directions and Considerations of Modeling Wildfire Risk, recommends the state fund a nonprofit or university-led consortium to begin developing this tool. This includes building and collecting public datasets, constructing the model, and educating the public on the results.

The effort is expected to take 5–10 years due to the complexity of modeling and data gaps. Starting now is critical. The sooner a group like this can begin this work, the sooner the North Coast and the entire state of California will have a useful public benchmark for wildfire risk pricing and insurability in the face of the mounting effects of climate change.

Appendix 4.4 Cannabis

Author: *Evan Mills*

Cannabis is California's largest cash crop, valued at approximately $20 billion annually. Roughly 90% of that production occurs in the unlicensed market. Overall, California accounts for about one-quarter of total US cannabis production.[10] With two-thirds exported out of state (DCC, 2025a), California plays an outsized role in the sector's greenhouse-gas emissions and resilience challenges (**Appendix Figure 4.4.A**).



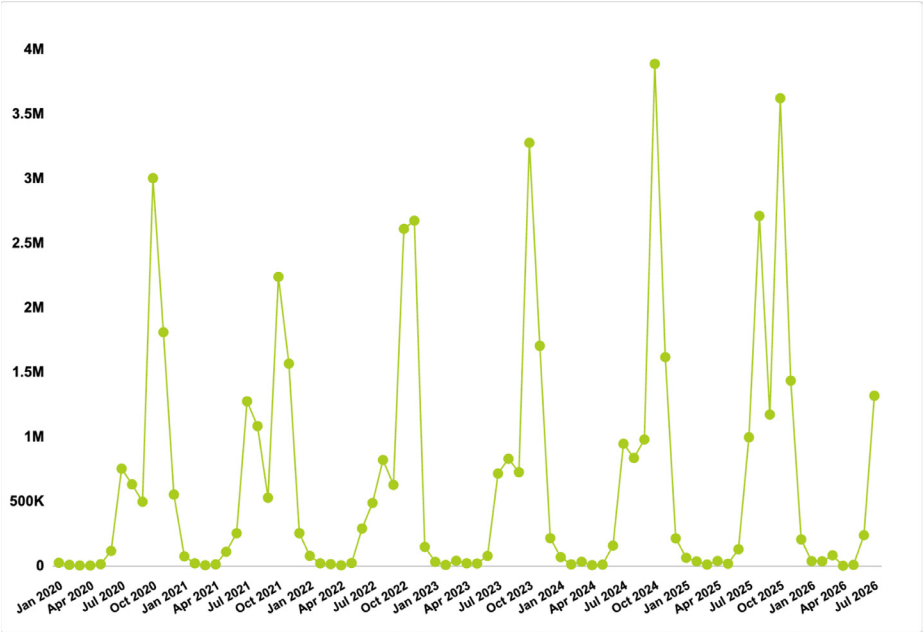
Cannabis production by county and legal status

Appendix Figure 4.4.A: *The quantity and regionality of cannabis production varies widely across the state. Licensed (left), as of 2024 (DCC, 2025a), and unlicensed (right), average 2019–2024 (DCC, 2025b).*

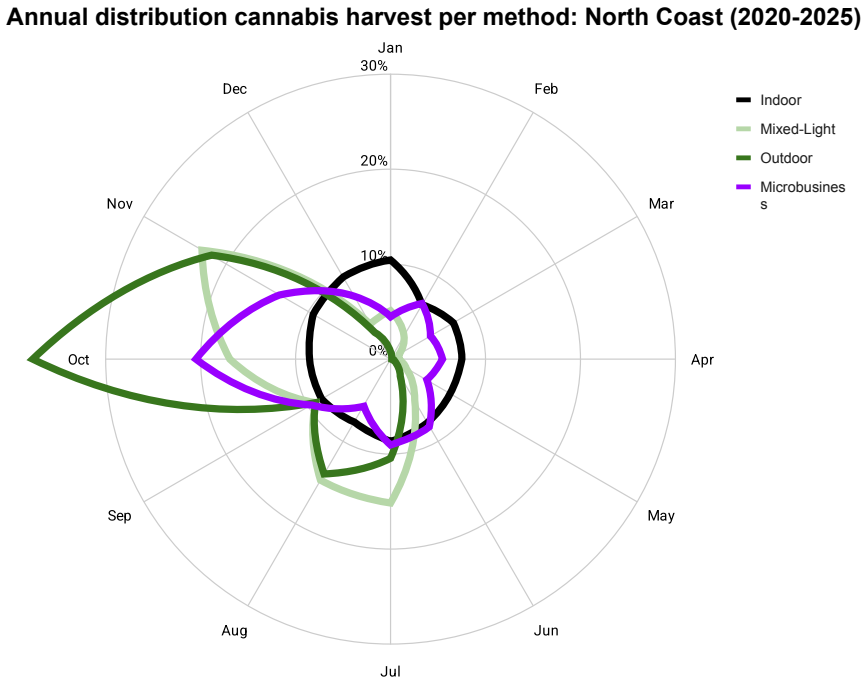
Of relevance to both climate mitigation and resilience, US cannabis cultivation uses more energy than all other crops combined (Mills, 2025b), emitting 44 million metric tons of carbon dioxide equivalent (MT CO2e) in 2023, equivalent to ~10 million passenger vehicles and four-times that of beverages-and-tobacco manufacturing (Mills, 2025c). In Humboldt County, ~3% of total electricity is consumed by licensed large growers (defined as cultivators using >5,000 kWh/month) according to Redwood Coast Energy Authority's Richard Engel and Matias Concoby (personal communication, March 6, 2026), compared to ~1% nationally. Fuels are also used (e.g., for space-heating) but are regionally unquantified.

Cannabis producers' cost sensitivity limits support for energy-efficiency regulations and voluntary emissions-reduction investments (Mills, 2025a). In 2025, only 1 of 32 large licensed Humboldt growers (about 3%) opted into the utility's 100% renewable REpower+ tariff to comply with county carbon neutrality mandates (R. Engel & M. Concoby, personal communication, March 10, 2026). This inertia likely extends to climate-resilience investments.

Climate change's impacts on cannabis producers' energy load include increasing indoor-cultivation energy use in cooling-dominated inland areas, and decreasing it in heating-dominated mountain and coastal areas. For data on seasonality of harvests for indoor and outdoor cultivation methods in the North Coast, see **Appendix Figure 4.4.B**.



Monthly Outdoor Cannabis Harvest (Wet Weight, Pounds), North Coast Counties



Appendix Figure 4.4.B: *Top panel: Outdoor cultivation has the most seasonality of any cultivation method, with implications for vulnerability (Wet Weight, Pounds), North Coast Counties, 2020–2025 (DCC, 2026b). Lower panel: Seasonality of production varies considerably depending on cultivation method (DCC, 2026b). Indoor facilities exhibit much more variance within a given 12-month period than indicated by the smoothed averages here. Microbusinesses utilize a mix of cultivation strategies.*

Appendix 4.5 Public Health

Author: *Wendy Ring*

Drinking water contamination - Climate change amplifies the conditions that favor toxic algal blooms (see **Appendix Case Study 2.3.A**). Toxic algae blooms occur annually in the lakes and rivers of all six counties (CWQMC, 2025). The most common freshwater toxin, microcystin, causes rashes with skin contact. Ingestion causes liver damage and cancer. Although public water system treatment can remove microcystin, it is expensive and testing is not required. Small water systems that draw from surface water may only test when a water source is visibly affected, even though the sensitivity of visual observation is poor and levels can be high after algae has died and no evidence of a bloom is visible (Pierce & Schnetzer, 2023; Almuhtaram et al., 2021).

Microcystin can migrate from surface water into groundwater (Mutoti, 2023). The USGS identified 48,000 domestic wells in the Northern Coastal Range hydrologic region serving 16% of households (Johnson, 2015). A smaller number of households rely on surface water with some level of treatment. In 2022 microcystin levels above EPA safety limits were found in 58% of private water intakes from Clear Lake and cyanobacteria were identified in tap water from surrounding wells (Solomon, 2022). Whether and how often this occurs in other locations is unknown since private water systems are not regulated. Well water is also at risk of contamination from fecal pathogens like norovirus and Hepatitis A when heavy rainfall and saltwater intrusion bring septic systems into contact with groundwater.

Appendix 4.6 Climate Risks to Priority Populations in the Redwood Coast Region

Appendix 4.6.A Critical Climate Risks to Priority Populations

Population	Number of People	Percent of Total Population	Critical Risks
Under 5	17,421	5.4%	Extreme heat, air quality
Over 65	65,563	32.9%	Extreme heat, air quality, reduced evacuation ability
People of color	79,956	64.6%	Extreme heat, air quality
People in poverty	56,819	17.8%	Extreme heat, air quality, reduced evacuation ability, water shortages (i.e., dry wells), extreme precipitation events
Nonworking people (aged 16-64)	58,611	29.4%	Extreme heat, air quality, reduced evacuation ability, water shortages (i.e., dry wells)
Households with no car	8,104	6.6%	Extreme heat, air quality, reduced evacuation ability, water shortages (i.e., dry wells), extreme precipitation events
People with disabilities	58,697	18.4%	Extreme heat, air quality, reduced evacuation ability, power outages
People without health insurance	25,042	7.9%	Extreme heat, air quality

Appendix Figure 4.6.A: *Priority populations and associated climate risks in the Redwood Coast Region (defined as Tribal Lands, Del Norte, Humboldt, Lake, and Mendocino counties). Population counts and percentages are calculated using the relevant population base (e.g., households for "no vehicle available"). Data derived from Redwood Region Regional Plan Part 1 (California Center for Rural Policy, 2025) and Sierra Business Council tabulations based on US Census Bureau, American Community Survey (2022). Visualization created by the California Center for Rural Policy with Datawrapper. Reprinted with permission.*

Appendix Case Study 4.6.B: Toxic Tides and Shawir Darrudaluduk

Author: *Jennifer Kalt*

Wigi (the Wiyot name for Humboldt Bay) is home to hundreds of species of birds, fish, and marine mammals, and is the center of the ancestral territory of the Wiyot Tribe.[11] The Humboldt Bay area continues to be the region's population center, including the Wiyot Tribe's Table Bluff Reservation. Wigi's toxic sites are vulnerable to rising sea level and groundwater, which can mobilize dioxins, PCBs, heavy metals, and petroleum products into the bay and its tributary streams. Dioxins are some of the most toxic, long-lasting chemicals ever manufactured. They continue to enter Humboldt Bay through ground disturbance, erosion, and poorly-planned development.

Humboldt Waterkeeper and the Wiyot Tribe are among the leaders working to address the potential health and environmental justice impacts from legacy contamination from low-lying and other industrial sites around Humboldt Bay susceptible to sea level rise inundation. These initiatives redress the disproportionate burden of climate change impacts on historically oppressed, low-income, and politically marginalized communities. For example, through its Toxics Initiative, Humboldt Waterkeeper is building an inventory of sites with known, potential, or suspected contamination whose impacts will be exacerbated by sea level rise. The goal is to identify priority ecologically and culturally valuable sites for remediation and clean up; some sites Humboldt Waterkeeper has identified are not represented on state wide mapping tools (such as the Toxic Tides Project map), pointing to critical data gaps in tools generated outside the region. Humboldt Waterkeeper's inventory is a resource for local Tribes, like the Wiyot, whose Shawir

Darrudaluduk (Natural Resources) department is leading several of its own ecological and cultural restoration projects to clean up contaminants and monitor water pollution in Wigi.



Appendix Figure 4.6.B: *Contaminated site in North Humboldt Bay. At left is a snapshot of Humboldt Waterkeeper's toxic sites inventory showing a known contaminated site in North Humboldt Bay (Humboldt County) where a former lumber mill used a wood preservative containing dioxins and furans. 3.2 feet or 1 m of SLR—the intermediate scenario by the end of the century according to the California Sea Level Rise Guidance 2024 Science and Policy Update (represented by purple on this map) threatens to mobilize these toxic contaminants into Mad River Slough and Humboldt Bay, putting the ecosystem, people, and Tribal Cultural Resources at risk.* ***Map Credit: Sylvia van Royen, Humboldt Waterkeeper.***

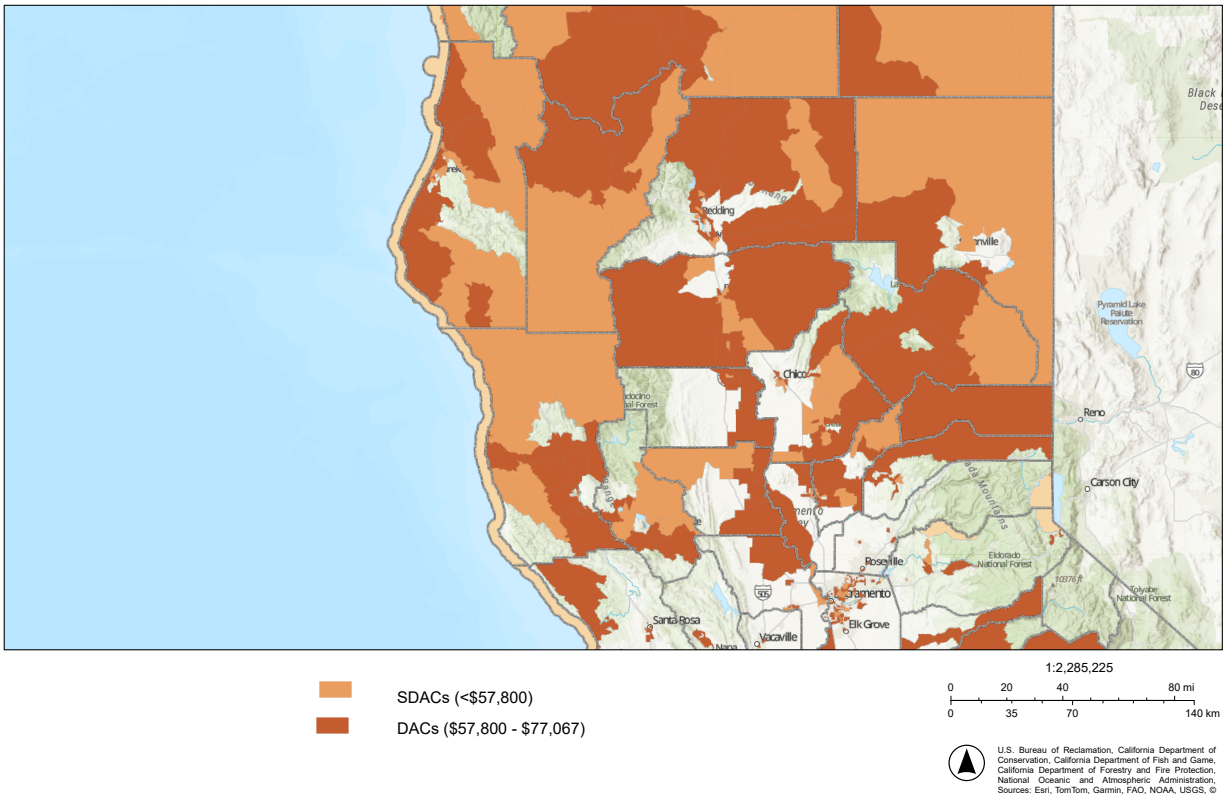
Appendix Case Study 4.6.C.: Metrics Measuring Disadvantaged and Severely Disadvantaged Communities

Author: *Jen Marlow*

Notably, a majority of the North Coast falls within a low-income region as defined by AB 1550; in some areas, median income falls below two-times the federal poverty level (California Coastal Commission, n.d.). Based on aggregated county-level American Communities Survey (ACS) 2023 5-Year poverty estimates (ACS Table S1701), approximately 17% of the North Coast population live below the federal poverty line, compared to 12.0% statewide (US Census Bureau, 2023). Despite the region's high poverty rate, the North Coast ranks low on CalEnviroScreen, which uses 21 statewide indicators to characterize pollution burden and sensitive populations. Reasons include low industrial development and failure to account for rural residential patterns where people of different incomes are not as intensively segregated. Additionally, CalEnviroScreen does not count pollution from wildfires (smoke inhalation and toxic sediment runoff), or factor in higher energy

and heat-related health burdens facing energy poor rural communities (Hoffmann, 2025). Unlike CalEnviroScreen, other tools measuring climate and environmental justice burden, such as the EJScreen (formerly hosted by EPA), include indicators important to the region. Specifically, the EJScreen used PM2.5 exposure percentiles that include rather than exclude wildfire smoke.

The state Department of Water Resources and other state agencies use census tract data on economic disadvantage that more accurately reflects North Coast demographics (see **Appendix Figure 4.6.C**), as standardized metrics applied in a straight-forward fashion can broadly discriminate against rural regions. Although **Appendix Figure 4.6.C** reveals some data gaps, the map documents far more Disadvantaged Community (DAC)/Severely Disadvantaged Community (SDAC) coverage than CalEnviroScreen or the California Air Resources Board California Climate Investments Priority Populations map, which depict much of the North Coast as not DAC or climate vulnerable. Furthermore, given existing data gaps, it is important to emphasize that "no data" does not equal "no risk."



Appendix Figure 4.6.C: *Tukman Geospatial on behalf of the North Coast Resource Partnership, 2025, based on the California Department of Water Resources (DWR) approach.* DWR utilizes the US Census ACS 5-Year Data to obtain median household income (MHI) information for communities at the census tract, census block group, and census place levels. DWR compares the MHI of these geographic areas to the statewide MHI to determine whether they meet the Disadvantaged Community or Severely Disadvantaged Community thresholds.

In sum, due to conflicting nomenclature, metrics, and criteria used by state and federal agencies to determine economic disadvantage and climate investment priority, distorted rankings may result in the unjustified disqualification of deserving areas in our region for urgently needed funding. For these reasons, a more nuanced and integrated approach to thinking about equity more broadly could prove more inclusive of our region's needs. One possible approach may be to allow the North Coast to convene a process that designates criteria most meaningful to the region, and then work to demonstrate how these criteria might apply. Such an approach may increase the region's eligibility to receive billions of dollars in needed funding.

Appendix Case Study 4.6.D California Coastal Commission Engagement with the Grassroots Institute

Author: *Brandon Quintana*

Mendocino County provides an example of locally meaningful engagement. Through a partnership with the nonprofit Grassroots Institute (GRI), the California Coastal Commission has worked to increase civic engagement and build public awareness of sea level rise and land use decisions. GRI's convening of public forums and active participation in Commission meetings has helped demystify permitting processes and encourage participation. Since 2022, Commission staff have attended GRI's public events to clarify policies, answer questions, and build relationships.

Mendocino's Local Coastal Program (LCP) updates, funded by state grants, now integrate sea level rise risk assessment and outreach. GRI facilitates community-wide conversations with regulatory agencies across Fort Bragg, Point Arena, and other cities, with support from Commission staff who share tools like the Coastal California Environmental Justice Mapping Tool to support environmental justice considerations in planning. Commission staff participation in these recurring meetings has helped clarify roles across agencies and foster a shared understanding of how community members can engage in and shape coastal planning.

Several factors contributed to the success of the California Coastal Commission's partnership with the Grassroots Initiative that could be replicated by climate justice allies, agencies, and nonprofits serving priority populations inland and in other parts of the region. These include adopting:

1. best practices for *meaningful* community engagement, such as those profiled in toolkits like NOAA's;
2. offering opportunities for underrepresented and marginalized communities to directly influence decision making, such as trainings on making public comments and navigating government processes;
3. approaching standardizing state-wide metrics of vulnerability with nuance, since wholesale application of state-wide standards can have discriminatory impacts on our region (see **Appendix 4.6**); and elevating Traditional Knowledge in decision making.

Appendix 5. Lists of Tables, Figures, Case Studies, Appendices

List of Tables

Table 1.1 Projected changes in key climate statistics for nine cities in the North Coast Region. Projected changes in climate for 2041-2070 relative to 1981-2010. All measures reflect annual averages for the period 1991-2020 using a multi-model averaging approach with SSP 3-7.0 LOCA2 Hybrid data. Measures were calculated as the average value of an approximately 15x15 km area centered around each city. Winter averages are calculated for December through February and summer averages for June through August.

Table 1.2 Long-term linear relative sea level (RSL) and vertical land motion (VLM) rates for the Crescent City, North Spit, and Arena Cove NOAA tide stations. Long-term linear relative sea level (RSL) and vertical land motion (VLM) rates for the Crescent City, North Spit, and Arena Cove NOAA tide stations.

Table 3.1 Community-identified climate resilience strategies organized by recurring themes.

Table 3.2 How one infrastructure failure triggers system-wide consequences across power, water, transportation, and emergency services.

Table 3.3 Comparing Nature-Based and Conventional Infrastructure: North Coast Implementation Examples.

Table 4.1 Select fire-impacted communities and their attributes.

List of Figures

Figure 1.1 Topographic variability across the six counties of the North Coast region.

Figure 1.2 Spatial patterns of changes in temperature and precipitation of the North Coast Region. Map of (a,d) historical and (b-c) change (compared to 1981-2010) in mean annual temperature (°F), (e-f) precipitation (in/yr), and (g-h) precipitation (% of 1981-2010 in/yr), as projected under the SSP370 scenario for mid-century and late 21st century. Contributor: Paul Ullrich

Figure 1.3 North Coast Region Observed historical change in temperature and water-year precipitation. Historical change in (a) mean annual (Jan-Dec) temperature from nClimgrid for the region is reported as anomalies from the historical period (1981-2010); (b) water year (Oct-Sep) precipitation anomalies.

Figure 1.4 North Coast Region projected trends in annual temperature and precipitation. Mean annual (a) temperature and (b) precipitation likely range estimated by LOCA2 downscaled global climate models over the historical period (1950-2014; gray) and future periods (2015-2100) under three climate scenarios (cyan/blue/red).

Figure 1.5 North Coast Projected changes in monthly temperature and precipitation. Seasonal change from historical (1981-2010) to future monthly (a) temperature (°F), (b) precipitation (in/day), and (c) precipitation (% of 1981-2010 in/yr) projected under the SSP370 scenario. Contributor: Paul Ullrich

Figure 1.6 Projected change in variability of precipitation. Map of absolute (top) and percent (bottom) change in precipitation variability under the rainiest day of the year (in/day) from the historical (1981-2010) to future (SSP370 scenario) period. Contributor: Paul Ullrich

Figure 1.7 Projected change in agricultural drought measures. Multi-model mean (a) change in annual evaporative demand (ETo), and the percent change in the annual likelihood of extreme drought for (b) 12-month Standardized Precipitation-Evapotranspiration Index (SPEI), and (c) 36-month SPEI for mid-century (2041-2070) under SSP2-4.5.

Figure 1.8 Projected change in the rainiest day of the year. Map of absolute (top) and percent (bottom) change in the rainiest day of the year (in/day) from the (a) historical (1981-2010) to (b-e) future (SSP370 scenario) period.

Figure 1.9 Mid-century (2041-2070) predictions of burn area likelihood for the North Coast region. Sum of stochastically modeled fire years (2000 per calendar year) that shows predicated areas of the North Coast region with likelihood to experience more or less burn area (hectares) for the mid–century period (2041-2070) for the 4 LOCAS2 wildfire data using the SSP 3-7.0 scenario.

Figure 1.10 NOAA Tide Station Map. NOAA tide stations (Crescent City; North Spit; Arena Cove) are shown relative to the 5th Climate Change Assessment North Coast Region counties.

Figure 1.11 North Spit tide station observations. Monthly sea level observations (gray line), long-term average trend (dashed black line), ~5-yr running average (gold line), and periods of SLR suppression (blue lines) and SLR acceleration (red lines).

Figure 1.12 Different SLR trends from 1990 to 2025; and the low, intermediate-low, intermediate, intermediate-high, and high sea-level rise scenarios from 2020 to 2050 for (a) Crescent City, (b) North Spit, and (c) Arena Cove tide stations relative to Year 2000. Trends include linear rate, quadratic fit, GMSL-VLM, and modified OPC (2024) SLR scenarios.

Figure 2.1 Vegetation cover across the North Coast Region. CalVeg data layers.

Figure 2.2 Humboldt Bay, major rivers and vegetation types. Contributor: Chris Gressierer

Figure 2.3 Rapid Shoreline retreat and Freshwater Wetland Conversion at Elk River Spit Humboldt Bay.

Figure 3.1 Arcata Marsh treatment ponds and wetlands—processing wastewater naturally while supporting 300+ bird species and public trails. Source: Appropedia, Creative Commons

Figure 4.1 Year-over-year homeowners insurance policy counts by county for the North Coast region (2020–2023).

Figure 4.2 Year-over-year change in private homeowners' insurance premiums for six North Coast counties.

Figure 4.3 Trends in Licensed Cannabis Production (wet weight), North Coast (left) and California (right).

Figure 4.4 Heat Health Index (HHI) for California ZIP Code Tabulation Areas (ZCTAs). The U.S. Centers for Disease Control and Prevention (CDC)

Figure 4.5 Heat Health Index (HHI) for California ZIP Code Tabulation Areas (ZCTAs).

Figure 4.6 Climate impacts on vulnerable populations in the Redwood Coast Region (2025).

Figure 4.7 King Salmon, California, projected mean monthly maximum water with 1 foot or .3 m of SLR, showing (in blue) daily tidal inundation in nearly all residential areas on a monthly basis. Right: Projected mean monthly maximum water with 3.2 feet or 1 m of SLR, showing near total inundation of residential areas, assets, and transportation routes on a monthly basis.

List of Appendix Tables

Appendix Table 1.A. Recent climatology of key cities in the North Coast Region

Appendix Table 2.1.A: Rangeland vegetation types and their abundance in the region

Appendix Table 2.1.B: Rangeland Ecosystems found in the North Coast Region (Barbour et al., 2007)

Appendix Table 3.1. Quick-reference guide: Chapter 3 barriers, financing mechanisms, local examples, and appendix sections

Appendix Table 4.1.A: Employment and Labor Demographics for the North Coast

Appendix Table 4.1.B: Race /Ethnicity Breakdown, North Coast Region, and California Comparison

List of Appendix Figures

Appendix Figure 1.1.A Projected number of extreme heat days

Appendix Figure 1.1.B Projected number of extreme warm nights

Appendix Figure 1.1.C Projected change in length of heat waves

Appendix Figure 1.1.D Projected change in duration of the longest drought

Appendix Figure 2.2 Scott Dam

Appendix Figure 2.3.A Surface kelp canopy area

Appendix Figure 2.3.B Off Shore Sea Surface Temperatures, 1985-2025

Appendix Figure 2.3.C Projected shoreline change and cliff retreat with 0.5 m SLR

Appendix Figure 2.3.D Ocean-drive flooding with SLR and storms. A - area of flooding hazard, B - percentage of residents in population centers exposed to ocean-driven flooding hazards

Appendix Figure 3.1 Analytical framework for Appendix 3

Appendix Figure 4.4.A The quantity and regionality of cannabis production varies widely across the state. Licensed (left), as of 2024 (DCC, 2025a) and unlicensed (right), average 2019-2024 (DCC, 2025b)

Appendix Figure 4.4.B Top panel: Outdoor cultivation has the most seasonality of any cultivation method, with implications for vulnerability (Wet Weight, Pounds), North Coast Counties, 2020–2025 (DCC, 2026b). Lower panel: Seasonality of production varies considerably depending on cultivation method (DCC, 2026b).

Appendix Figure 4.6.A Priority populations and associated climate risks in the Redwood Coast Region (defined as Tribal Lands, Del Norte, Humboldt, Lake, and Mendocino Counties)

Appendix Figure 4.6.B Contaminated site in North Humboldt Bay at risk

Appendix Figure 4.6.C Tukman Geospatial on behalf of the North Coast Resource Partnership, 2025, based on the California Department of Water Resources (DWR) approach

References

Ababneh, L., & Woolfenden, W. (2010). Monitoring for potential effects of climate change on the vegetation of two alpine meadows in the White Mountains of California , USA. Quaternary International, 215(1–2), 3–14. https://doi.org/10.1016/j.quaint.2009.05.013

Abatzoglou, J.T. & Williams, A.P. (2016). Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences, 113, 11770–11775. https://www.pnas.org/doi/10.1073/pnas.1607171113

Abatzoglou, J.T., Battisti, D.S., Williams, A.P., Hansen, W.D., Harvey, B.J. & Kolden, C.A. (2021). Projected increases in western US forest fire despite growing fuel constraints. Communications Earth & Environment, 2, 227. https://www.nature.com/articles/s43247-021-00299-0

ACEs Aware. (2025). *Data report: ACE screening of Medi-Cal members.* https://www.acesaware.org/data-reports/

Aguilera, R., Corringham, T., Gershunov, A., & Benmarhnia, T. (2021). Wildfire smoke impacts respiratory health more than fine particles from other sources: Observational evidence from Southern California. *Nature Communications, 12*(1), 1493. https://doi.org/10.1038/s41467-021-21708-0

Aguilera, R., Corringham, T., Gershunov, A., Leibel, S., & Benmarhnia, T. (2024). Mortality attributable to PM2.5 from wildland fires in California from 2008 to 2018. Science Advances, 10(13). https://doi.org/10.1126/sciadv.adl1252

Alari A., Ballester J., Milà C., Benmarhnia T., Sofiev M., Uppstu A., Hänninen R., Tonne C. (2025). Quantifying the short-term mortality effects of wildfire smoke in Europe: A multicountry epidemiological study in 654 contiguous regions. *The Lancet Planetary Health, 9*(8), e629–e639. https://doi.org/10.1016/S2542-5196(25)101296-4

Albano, C. M., Soulard, C. E., Mcclure, M. L., Gross, S. E., Kitlasten, W., Morton, C., & Huntington, J. (2019). Spatial patterns of meadow sensitivities to interannual climate variability in the Sierra Nevada. Ecohydrology, 12, e2128. https://doi.org/10.1002/eco.2128

Allen, M. A., Roberts, D. A., & McFadden, J. P. (2021). Urban Climate Reduced urban green cover and daytime cooling capacity during the 2012 – 2016 California drought. Urban Climate, 36, 100768. https://doi.org/10.1016/j.uclim.2020.100768

Almuhtaram, H., Kibuye, F. A., Ajjampur, S., Glover, C. M., Hofmann, R., Gaget, V., Owen, C., Wert, E. C., & Zamyadi, A. (2021). State of knowledge on early warning tools for cyanobacteria detection. Ecological Indicators, 133, 108442. https://doi.org/10.1016/j.ecolind.2021.108442

Akins, D. B., & Bauer, W. J., Jr. (2021). We Are the Land: A History of Native California. University of California Press.

Anderson, K. (2005). Tending the wild: Native American knowledge and the management of California's natural resources. University of California Press.

Anderson, J.K. 2015. Humboldt Bay: Sea Level Rise, Hydrodynamic Modeling, and Inundation Vulnerability Mapping, Final Report for State Coastal Conservancy and Coastal Ecosystems Institute of Northern California, 110 pp., https://digitalcommons.humboldt.edu/hsuslri_geospatial/4/

Anderson Valley Health Center. (n.d.). The Building. https://www.avhc.org/about/the-building/

Arledge, D., & Flynn, D. (2023). California's Rural North: Health Equity Landscape Scan. California Center for Rural Policy at Cal Poly Humboldt. February 2023.

Armstrong, J. B., Fullerton, A. H., Jordan, C. E., Ebersole, J. L., Bellmore, J. R., Arismendi, I., ... & Reeves, G. H. (2021). The importance of warm habitat to the growth regime of cold-water fishes. Nature Climate Change, 11(4), 354-361.

Asarian, J. E., & Walker, J. D. (2016). Long-term trends in streamflow and precipitation in Northwest California and Southwest Oregon, 1953-2012. Journal of the American Water Resources Association 52, 241-261.

Balch, J. A., et. al., (2024). The fastest-growing and most destructive fires in the U.S. (2001-2020). Science 386: 425-431. DOI: 10.1126/science.adk5

Barbour, M. G., Keeler-Wolf, T., & Schoenherr, A. A. (2007). Terrestrial Vegetation of California (3rd ed.). University of California Press.

Bardeen, S. (2024, July 8). Does Managed Retreat Make Sense in Wildfire-Prone Lands? Public Policy Institute of California Blog. https://www.ppic.org/blog/doesmanaged-retreat-make-sense-in-wildfire-prone-lands/

Bardeen, S. (2025, August 27). Prop 218's ongoing impacts on California water. Public Policy Institute of California. https://www.ppic.org/blog/prop-218s-ongoing-impacts-on-california-water/

Barnard, P.L., Erikson, L.H., Foxgrover, A.C., Limber, P.L., Nederhoff, K., O'Neill, A.C., Thomas, J.A., Vitousek, S., & Sarfraz, A. (2022) Coastal Storm Modeling System (CoSMoS) for Northern California 3.2 (ver. 1g, April 2025). U.S. Geological Survey data release, 10.5066/P9048D1S.

Barry, S. (2021). Livestock Mobility Through Integrated Beef Production-Scapes Supports Rangeland Livestock Production and Conservation. Frontiers in Sustainable Food Systems, Volume 4-. https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2020.549359

Becker, R. (2024, March 28). California gas prices are rising, but climate policies impact low-income communities the most. Inside Climate News. https://insideclimatenews.org/news/28032024/california-gas-prices-hike-impact-low-income-communities/

Beckmann, J.J., Sherriff, R.L., Kerhoulas, L.P. & Kane, J.M. (2021). Douglas-fir encroachment reduces drought resistance in Oregon white oak of northern California. Forest Ecology and Management, 498, 119543.

Beeby, J., Moore, S., Taylor, L., & Nderitu, S. (2020). Effects of a one-time organic fertilizer application on long-term crop and residue yields, and soil quality measurements using biointensive agriculture. Frontiers in Sustainable Food Systems, 4, 503814.

Befus, K. M., Barnard, P. L., Hoover, D. J., Finzi Hart, J. A., & Voss, C. I. (2020). Increasing threat of coastal groundwater hazards from sea-level rise in California. Nature Climate Change, 10, 946-952. https://doi.org/10.1038/s41558-020-0874-1

Bell, M., Gasparrini, A., & Benjamin, G. (2024). Climate change, extreme heat, and health. *The New England Journal of Medicine, 390*(19), 1793–1801. https://doi.org/10.1056/NEJMra2210769

Berg, N., & Hall, A. (2015). Increased interannual precipitation extremes over California under climate change. Journal of Climate, 28(16), 6324-6334.

Bernal, A.A., Kane, J.M., Knapp, E.E., Zald, H.S.J., 2023. Tree resistance to drought and bark beetle-associated mortality following thinning and prescribed fire treatments. Forest Ecology and Management 530, 120758.

Berrill, J.P., O'Hara, K.L. & Kichas, N.E. (2020). Bark thickness in coast redwood (Sequoia sempervirens (D.Don) Endl.) varies according to tree- and crown size, stand structure, latitude and genotype. Forests, 11, 637.

Biblin, S., Russell, W. & Wilkin, K. (2025). Long-term influence of prescribed burning on subsequent wildfire in an old-growth coast redwood forest. Fire Ecology, 21, 11.

Big Valley Band of Pomo Indians. (n.d.). Clear Lake cyanobacteria and cyanotoxins monitoring program. Big Valley Band of Pomo Indians Environmental Protection Department. https://www.bvrancheria.com/clearlakecyanotoxins

Bomford, M. (2023). More bytes per acre: Do vertical farming's land sparing promises stand on solid ground? Agriculture and Human Values, 40, 879–895.

Bond, W. J., & van Wilgen, B.W. (1996). Why and how do ecosystems burn? In Fire and Plants. Chapman & Hill. https://doi.org/10.1007/978-94-009-1499-5_2

Bos, M.S., Fernandes, R.M.S., Williams, S.D.P., and Bastos, L. (2013). Fast Error Analysis of Continuous GNSS Observations with Missing Data. J. Geod., Vol. 87(4), 351–360, doi:10.1007/s00190-012-0605-0.

Bos, M.S., Williams, S.D.P., Araújo, I.B., and Bastos, L. (2014). The effect of temporal correlated noise on the sea level rate and acceleration uncertainty. Geophysical Journal International, 196:1423–1430.

Bovey, R. W., Le Tourneau, D., & Erickson, L. C. (1961). The Chemical Composition of Medusahead and Downy Brome. Weeds, 9(2), 307–311. https://doi.org/10.2307/4040420

Brabec, M. M., Germino, M. J., Shinneman, D. J., Pilliod, D. S., Mcilroy, S. K., & Arkle, R. S. (2015). Challenges of Establishing Big Sagebrush (Artemisia tridentata) in Rangeland Restoration: Effects of Herbicide, Mowing, Whole-Community Seeding, and Sagebrush Seed Sources. Rangeland Ecology & Management, 68(5), 432–435. https://doi.org/10.1016/j.rama.2015.07.001

Breen, M.J., Kebede, A.S., & Konig, C.S. (2022) The Safe Development Paradox in Flood Risk Management: A Critical Review. Sustainability. 14(24):16955. https://doi.org/10.3390/su142416955

Brewitt, K. S., Danner, E. M., & Moore, J. W. (2017). Hot eats and cool creeks: juvenile Pacific salmonids use mainstem prey while in thermal refuges. Canadian Journal of Fisheries and Aquatic Sciences, 74(10), 1588-1602.

Briske, D., Archer, S., Burchfield, E., Burnidge, W., Derner, J., Gosnell, H., Hatfield, J., Kazanski, C., Khalil, M., Lark, T., Nagler, P., Sala, O., Sayre, N., & Stackhouse-Lawson, K. (2023). Supplying ecosystem services on US rangelands. Nature Sustainability, 6, 1524–1532. https://doi.org/10.1038/s41893-023-01194-6

Bromirski, P.D., Miller, A.J., Flick, R.E. & Guillermo, A. (2011). Dynamical Suppression of Sea Level Rise Along the Pacific Coast of North America: Indications for Imminent Acceleration. Journal of Geophysical Research. 116. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010JC006759

Brummer, F., Morris, L. R., & Laarman, A. (2023). Forage Quality of Ventenata dubia in a Southeastern Oregon Meadow System. Rangeland Ecology and Management, 91(1), 87–94. https://doi.org/10.1016/j.rama.2023.08.006

Brunson, M., & Huntsinger, L. (2008). Ranching as a conservation strategy: Can old ranchers save the new west? Rangeland Ecology and Management, 61(2), 137–147. https://doi.org/10.2111/07-063.1

Burgette, R.J., Watson, C.S., Church, J.A., White, N.J., Tregoning, P. & Coleman, R. (2013). Characterizing and minimizing the effects of noise in tide gauge time series: relative and geocentric sea level rise around Australia, Geophysical Journal International, Volume 194, Issue 2, Pages 719–736. https://doi.org/10.1093/gji/ggt131

Byrne, K. M., Luong, J. C., & Kaczynski, K. M. (2025). Divergent drought responses in two cold desert shrublands. Ecosphere, 16(3), e70211. https://doi.org/https://doi.org/10.1002/ecs2.70211

C-Span. (2017, August 3). Rural California and state policy [Video]. YouTube. https://www.youtube.com/watch?v=QlqvOgP1440

CAL FIRE. (2019). Camp Fire investigation report. California Department of Forestry and Fire Protection.

California Air Resources Board. (2024). *Maps of state and federal area designations.* https://ww2.arb.ca.gov/resources/documents/maps-state-and-federal-area-designations

Cal Poly Humboldt. (2024). Infrastructure Projects. https://www.humboldt.edu/about/polytechnic/infrastructure-projects

Cal Poly Humboldt. (2024). Tribal Energy Resilience and Sovereignty (TERAS) Program Study. Schatz Energy Research Center.

Cal Poly Humboldt. (n.d.). Utilities: Energy, water, & buildings. https://www.humboldt.edu/sustainable-campus/campus-operations/utilities-energy-water-buildings

Caldwell, M. M., Dawson, T. E., & Richards, J. H. (1998). Hydraulic lift: consequences of water efflux from the roots of plants. Oecologia, 113(2), 151–161. https://doi.org/10.1007/s004420050363

Calhoun, K.L., Goldstein, B.R., Gaynor, K.M., McInturff, A., Solorio, L. & Brashares, J.S. (2023). Mammalian resistance to megafire in western U.S. woodland savannas. Ecosphere, 14, e4613.

California Air Resources Board. (2024). *Maps of state and federal area designations.* https://ww2.arb.ca.gov/resources/documents/maps-state-and-federal-area-designations

California Assembly Insurance Committee. (2026, January 28). Oversight hearing: The California FAIR Plan. California State Assembly. https://ains.assembly.ca.gov/system/files/2026-01/1.28.26-fair-plan-background-final.pdf

California Coastal Commission. (2024, November 13). Sea level rise policy guidance: Interpretive guidelines for addressing sea level rise in Local Coastal Programs and coastal development permits (Final Adopted 2024 Update). https://documents.coastal.ca.gov/assets/slr/guidance/2024/2024AdoptedSLRPolicyGuidance Update.pdf

California Coastal Commission. (n.d.). Environmental justice mapping tool. https://www.coastal.ca.gov/env-justice/ccej-tool/

California Department of Food and Agriculture. (2026). Cannabis Appellations Program (CAP). https://www.cdfa.ca.gov/oars/cap/

California Department of Insurance. (2024, April). Residential Insurance Policy Analysis by County, 2020 to 2023 (Report). https://www.insurance.ca.gov/01-consumers/200-wrr/upload/Residential-Insurance-Policy-Analysis-by-County-2020-to-2023-2.pdf

California Department of Insurance (2024). CDI Press Release: In a California "first," Commissioner Lara announces enforcement of regulation to expand insurance coverage across the state. California Department of Insurance. https://www.insurance.ca.gov/0400-news/0100-press-releases/2024/release062-2024.cfm

California Department of Public Health. (2024). County Health Status Profiles 2024. https://www.cdph.ca.gov/Programs/CHSI/CDPH%20Document%20Library/CHSP-2024.pdf

California Department of Water Resources. (2024). Drought planning for small water suppliers and rural communities (SB 552). https://water.ca.gov/Programs/Water-Use-And-Efficiency/SB-552

California Energy Commission. (2019). Demonstrating a secure reliable low-carbon community microgrid at Blue Lake Rancheria (Publication No. CEC-500-2019-011).

California Energy Commission. (2020). Smart Ventilation for Advanced California Homes. Walker, I., Sherman, M., & Less, B. Lawrence Berkeley National Laboratory. CEC-500-2020-049.

California Energy Commission. (2021). California residential appliance saturation study (Publication No. CEC-200-2021-005-PO).

California Energy Commission. (2023, December 13). CEC awards $30 million to 100-hour, long-duration energy storage project [Press release]. https://www.energy.ca.gov/news/2023-12/cec-awards-30-million-100-hour-long-duration-energy-storage-project

California Energy Commission. (2024). Offshore wind energy strategy report. https://www.energy.ca.gov/

California Governor's Office of Emergency Services (Cal OES). (2025). California Wildfire Mitigation Program. https://www.caloes.ca.gov/office-of-the-director/operations/recovery-directorate/hazard-mitigation/california-wildfire-mitigation-program/

California Ocean Protection Council. (2024). State of California sea level rise guidance: 2024 science and policy update. California Natural Resources Agency.

California Office of Emergency Services. (2023). After-action report: Atmospheric river sequence December 31, 2022-January 16, 2023. https://www.caloes.ca.gov/after-action-reports

California Public Utilities Commission. (2020, April 30). Public report on the late 2019 Public Safety Power Shutoff events. https://www.cpuc.ca.gov/-/media/cpuc-website/files/uploadedfiles/cpucwebsite/content/news_room/newsupdates/2020/sed-public-report-on-the-late-2019-psps-events.pdf

California Public Utilities Commission. (2021). Safety enforcement initiative for electric facilities. Resolution E-5117.

California Public Utilities Commission. (2021, November 22). CPUC issues citations to PG&E for safety code violations [Press release]. https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-issues-citations-to-pge-for-safety-code-violations

California Public Utilities Commission. (2024). Electric system reliability annual reports. https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/electric-reliability/electric-system-reliability-annual-reports

California Residential Mitigation Program. (2024). Retrofit cost estimates and program guidelines. https://www.californiaresidentialmitigationprogram.com/

California Sea Level Rise Science Task Force, California Ocean Protection Council, & California Ocean Science Trust. (2024). California sea level rise guidance: 2024 science and policy update. https://opc.ca.gov/wp-content/uploads/2024/05/California-Sea-Level-Rise-Guidance-2024-508.pdf

California Trout, Stillwater Sciences, Applied River Sciences, and U.C. Berkeley. 2024. Eel River Restoration and Conservation Plan—Phase 1: Planning—of the Eel River Watershed Restoration and Conservation Program. Prepared for California Department of Fish and Wildlife. June 2024.

California Water Quality Monitoring Council. (2025). *HAB reports map.* https://mywaterquality.ca.gov/habs/resources/reports-map/

California Wildfire & Forest Resilience Task Force. (2024). SB 310 implementation guidelines for cultural burning on ancestral lands. California Natural Resources Agency.

Cal Poly Humboldt. (2021, November 29). *"Poly-TEK?" Celebrated "Braiding Sweetgrass" author to discuss Indigenous knowledge.* https://now.humboldt.edu/news/poly-tek-celebrated-braiding-sweetgrass-author-to-discuss-indigenous-knowle

Caltrans (California Department of Transportation). (2018). Last Chance Grade economic impact of US-101 closure: A regional impact analysis. Transportation Economics Branch.

Caltrans (California Department of Transportation). (2021). Climate change vulnerability assessment statewide summary report. https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/office-of-smart-mobility-and-climate-change/caltrans-climate-change-vulnerability-assessment-statewide-summary-feb2021-a11y.pdf

Caltrans (California Department of Transportation). (2024, June 13). Caltrans selects tunnel alternative for Last Chance Grade project. https://dot.ca.gov/caltrans-near-me/district-1/d1-news/d1-news-release-2024-06-13

Caltrans (California Department of Transportation). (2025). Mendocino County evacuation route projects: Brooktrails Second Access Route and Redemeyer Road Extension progress report. California Department of Transportation.

Carey, C. J., Weverka, J., DiGaudio, R., Gardali, T., & Porzig, E. L. (2020). Exploring variability in rangeland soil organic carbon stocks across California (USA) using a voluntary monitoring network. Geoderma Regional, 22, e00304. https://doi.org/https://doi.org/10.1016/j.geodrs.2020.e00304

Carlson, S. M., Pregler, K. C., Obedzinski, M., Gallagher, S. P., Rhoades, S. J., Woelfle-Hazard, C., ... & Power, M. E. (2025). Anatomy of a range contraction: Flow–phenology mismatches threaten salmonid fishes near their trailing edge. Proceedings of the National Academy of Sciences, 122(14), e2415670122.

Carroll, A.L., Sillett, S.C. & Kramer, R.D. (2014). Millennium-scale crossdating and inter-annual climate sensitivities of standing California redwoods. PLoS ONE, 9, e102545.

Casey J.A., Kioumourtzoglou M.A., Padula A., González D.J.X., Elser H., Aguilera R., Northrop A.J., Tartof S.Y., Mayeda E.R., Braun D., Dominici F., Eisen E.A., Morello-Frosch R., Benmarhnia T. (2024). Measuring long-term exposure to wildfire PM2.5 in California: Time-varying inequities in environmental burden. *Proceedings of the National Academy of Sciences, 121*(8), e2306729121. https://doi.org/10.1073/pnas.2306729121

CCRP. (2025). Redwood Region Regional Plan Part 1 California Center for Rural Policy at Cal Poly Humboldt. https://ccrp.humboldt.edu/sites/default/files/rrrise_regional_plan_part_1_revised_may_2025-_0.pdf

Centers for Disease Control and Prevention. (2025). *Heat health tracker.* https://ephtracking.cdc.gov/Applications/heatTracker/

Chang, E. K., Guo, Y., & Xia, X. (2012). CMIP5 multimodel ensemble projection of storm track change under global warming. Journal of Geophysical Research: Atmospheres, 117(D23).

Checkley Jr, D. M., & Barth, J. A. (2009). Patterns and processes in the California Current System. Progress in Oceanography, 83(1-4), 49-64

Chen, C., Schwarz, L., Rosenthal, N., Marlier, M. E., & Benmarhnia, T. (2024). Exploring spatial heterogeneity in synergistic effects of compound climate hazards: Extreme heat and wildfire smoke on cardiorespiratory hospitalizations in California. Science Advances, 10(5), eadj7264.

Christopher, B. (2025, April 30). Welcome to the first fire-resistant neighborhood. Now what about the rest of California? CalMatters. https://calmatters.org/housing/2025/04/california-fire-home-hardening/

Ciara, E., Richmond, L., Casali, L., Severy, M. and Jacobson, A. (2020). Stakeholder Benefits and Concerns. In M. Severy, Z. Alva, G. Chapman, M. Cheli, T. Garcia, C. Ortega, N. Salas, A. Younes, J. Zoellick, & A. Jacobson (Eds.) California North Coast Offshore Wind Studies. Humboldt, CA: Schatz Energy Research Center. schatzcenter.org/pubs/2020-OSW-R21.pdf.

City of Arcata. (2023). Arcata Marsh and Wildlife Sanctuary. https://www.cityofarcata.org/340/Arcata-Marsh-Wildlife-Sanctuary

City of Arcata. (2023). Salt marsh project. https://www.cityofarcata.org/1056/Salt-Marsh

City of Ferndale. (2024, November 21). Potential major flooding for Eel River at Fernbridge. https://ci.ferndale.ca.us/potential-major-flooding-for-eel-river-at-fernbridge/

Clark, S., Tripp, B., Hankins, D., Rossier, C., Varney, A., & Nairn, I. (2024). Good Fire II: Current barriers to the expansion of cultural burning and prescribed fire in California and recommended solutions (Karuk Tribe report). The Karuk Tribe. https://karuktribeclimatechangeprojects.wordpress.com/wp-content/uploads/2024/03/good-fire-ii-march-2024.pdf

Cluett, A.A., Bograd, S.J., Jacox, M.G., Pozo Buil, M., & Hazen, E. (in review). Pan-basin warming now overshadows robust Pacific Decadal Oscillation.

Cocking, M. I., Varner, J. M., & Sherriff, R.L. (2012). California black oak responses to fire severity and native conifer encroachment in the Klamath Mountains. Forest Ecology and Management 270: 25-34. https://doi.org/10.1016/j.foreco.2011.12.039

Collier, B. L., Keys, B. J., & Mulder, P. (2026, March). A proposal for a US federal property reinsurer. The Hamilton Project, Brookings Institution. https://www.hamiltonproject.org

Community Advisory Board. (2024). Meeting notes from North Coast 5th Climate Assessment community advisory board meetings. California Natural Resources Agency. [Unpublished meeting notes.

Connor, T., Tripp, E., Tripp, B., Saxon, B. J., Camarena, J., Donahue, A., Sarna-Wojcicki, D., Macaulay, L., Bean, T., Hanbury-Brown, A., & Brashares, J. (2022). Karuk ecological fire management practices promote elk habitat in northern California. Journal of Applied Ecology, 59, 1874–1883. https://doi.org/10.1111/1365-2664.14194

Conway, M., & Giloth, R. (2014). Connecting people to work: Workforce intermediaries and sector strategies. Aspen Institute.

Coppoletta, M., Merriam, K.E. & Collins, B.M. (2016). Post-fire vegetation and fuel development influences fire severity patterns in reburns. Ecological Applications, 26, 686–699.

Cordoleani, F., Phillis, C. C., Sturrock, A. M., FitzGerald, A. M., Malkassian, A., Whitman, G. E., ... & Johnson, R. C. (2021). Threatened salmon rely on a rare life history strategy in a warming landscape. Nature Climate Change, 11(11), 982-988.

Corn, P. S. & Bury, R. B. (1989). Logging in western Oregon: responses of headwater habitats and stream amphibians. Forest Ecology and Management, 29(1-2), 39-57.

Corn, P. S. (2005). Climate change and amphibians. Animal Biodiversity and Conservation, 28(1), 59-67.

Council of American Indian Faculty and Staff. (2021). Statement on PolyTech University Development and Indigenous Knowledge/Indigenous Science/ Traditional Ecological Knowledge. https://digitalcommons.humboldt.edu/cgi/viewcontent.cgi?article=1219&context=hjsr

Cunningham, S.R., Gardner, L., Grand, M.M., Metter, J., Salmi, A., Simpson, E., Graham, M., Hamilton, S.L., Schuppenhauer, M.R., and Gossard, D.J. (2025). Optimizing bromoform content in Gracilaria parvispora: the role of environmental stressors. Journal of Applied Phycology. https://doi.org/10.1007/s10811-025-03602-0

Curtis, J. A., Johnson, G. S., Cahill, J. D., Genzoli, L., Dahm, C. N., Schenk, L. N., & Oberholzer, J. R. (2025). 2022 McKinney rain-on-wildfire event, dissolved oxygen sags, and a fish kill on the Klamath River, California. Scientific Reports, 15, Article 24668. https://doi.org/10.1038/s41598-025-08179-9

Cutter, S.L., Boruff, B.L., & Shirley, W.L. (2003). Social vulnerability to environmental hazards. Social Science Quarterly, p. 243. https://doi.org/10.1111/1540-6237.8402002.

Cutter, S.L., Emrich, C.T., Hanney (Webb), J.J. & Morath, D. (2009). Social Vulnerability to Climate Variability Hazards: A Review of Literature. Final Report to Oxfam America. 1-44.

D'Antonio, C. M., & Vitousek, P. M. (1992). Biological Invasions by Exotic Grasses, the Grass/Fire Cycle, and Global Change. Annual Review of Ecology and Systematics, 23, 63–87. http://www.jstor.org/stable/2097282

Dagley, C.M., Berrill, J.P., Leonard, L.P. & Kim, Y.G., (2018) Restoration thinning enhances growth and diversity in mixed redwood/Douglas-fir stands in northern California, U.S.A.: Redwood ecosystem responses to restoration thinning. Restoration Ecology 26, 1170–1179. https://doi.org/10.1111/rec.12681

Dangendorf, S., Hay, C., Calafat, F.M., Marcos, M., Piecuch, C.G., Berk, K. & Jensen, J. (2019). Persistent acceleration in global sea-level rise since the 1960s. Nat. Clim. Chang. 9, 705–710. https://doi.org/10.1038/s41558-019-0531-8

Davies, K. W., & Johnson, D. D. (2017). Established perennial vegetation provides high resistance to reinvasion by exotic annual grasses. Rangeland Ecology & Management 70: 748-754. https://doi.org/10.1016/j.rama.2017.06.001

Davis, K.T., Peeler, J., Fargione, J., Haugo, R.D., Metlen, K.L., Robles, M.D., Woolley, T., 2024. Tamm review: A meta-analysis of thinning, prescribed fire, and wildfire effects on subsequent wildfire severity in conifer dominated forests of the Western US. Forest Ecology and Management 561, 121885. https://doi.org/10.1016/j.foreco.2024.121885

De León, M. E., Vredenburg, V. T., & Piovia-Scott, J. (2017). Recent emergence of a chytrid fungal pathogen in California Cascades frogs (Rana cascadae). EcoHealth, 14(1), 155-161.

DellaSala, D. A., Reid, S. B., Frest, T. J., Strittholt, J. R. (1999). A global perspective on the biodiversity of the Klamath-Siskiyou Ecoregion. Natural Areas Journal 19: 300-319.

Dennett, J. M., Carrión, D., Fiellin, D. A., & Gonsalves, G. S. (2025). Heat exposure and drug overdose mortality in the USA. *Addiction, 120*(4), 746–755. https://doi.org/10.1111/add.70191

Department of Cannabis Control. (2025a). Executive summary: California cannabis market: 2024 report (Prepared by ERA Economics). https://cdn.cannabis.ca.gov/wp-content/uploads/sites/2/2025/03/California-Cannabis-Market-Outlook-Executive-Summary-FNL.pdf

Department of Cannabis Control. (2025b). California cannabis market outlook: 2024 report (Prepared by ERA Economics). https://abp.assembly.ca.gov/system/files/2025-03/5-california-cannabis-market-outlook-full-report.pdf

Department of Cannabis Control. (2026a). Sales and price per unit report. https://www.cannabis.ca.gov/resources/data-dashboard/daily-sales-units-by-item-category-report/

Department of Cannabis Control. (2026b). Harvest report. https://www.cannabis.ca.gov/resources/data-dashboard/harvest-report/

Deryugina, T., & Rees, D. (2024). Distributed effects of climate policy: A machine learning approach (CEEPR Working Paper No. 2024-002). MIT Center for Energy and Environmental Policy Research. https://ceepr.mit.edu/workingpaper/distributed-effects-of-climate-policy-a-machine-learning-approach/

DeSiervo, M.H., Jules, E.S., Bost, D.S., De Stigter, E.L. & Butz, R.J. (2018). Patterns and drivers of recent tree mortality in diverse conifer forests of the Klamath Mountains, California. Forest Science, 64, 371–382.

Desmet, F., Gruber, N., Köhn, E. E., Münnich, M., & Vogt, M. (2022). Tracking the space-time evolution of ocean acidification extremes in the California Current System and Northeast Pacific. Journal of Geophysical Research: Oceans, 127(5), e2021JC018159.

Dettinger, M. D., Ralph, F. M., Das, T., Neiman, P. J., & Cayan, D. R. (2011). Atmospheric rivers, floods, and the water resources of California. Water 3, 445-478.

DeWaard, J., Din, A. M., McConnell, K., & Fussell, E. (2024). Population change in wildfire-affected areas in the United States: Evidence from U.S. Postal Service residential address data. Population Research and Policy Review, 43, Article 59. https://doi.org/10.1007/s11113-024-09904-4

Di, Q., Wang, Y., Zanobetti, A., Wang, Y., Koutrakis, P., Choirat, C., Dominici, F., & Schwartz, J. D. (2017). Air pollution and mortality in the Medicare population. *New England Journal of Medicine, 376*(26), 2513–2522. https://doi.org/10.1056/NEJMoa1702747

Diez, J. M., D'Antonio, C. M., Dukes, J. S., Grosholz, E. D., Olden, J. D., Sorte, C. J. B., Blumenthal, D. M., Bradley, B. A., Early, R., Ibáñez, I., Jones, S. J., Lawler, J. J., & Miller, L. P. (2012). Will extreme climatic events facilitate biological invasions? Frontiers in Ecology and the Environment, 10(5), 249–257. https://doi.org/10.1890/110137

Diffenbaugh, N. S., Swain, D. L. & Touma, D. (2015). Anthropogenic warming has increased drought risk in California. Proceedings of the National Academy of Sciences 112, 3931-3936.

Dillis, C., McIntee, C., Butsic, V., Le, L., Grady, K., & Grantham, T. (2020). Water storage and irrigation practices for cannabis drive seasonal patterns of water extraction and use in Northern California. Journal of Environmental Management, 272, 110955.

Dillis, C., Butsic, V., Martin, J. V., Reiman, A., Starrs, G., & Grantham, T. E. (2023). Wildfire smoke exposure has significant economic impacts on California's licensed cannabis industry. Environmental Research Letters, 18(9), 094069.

Doubledee, R.A., Muller, E.B., & Nisbet, R.M. (2003). Bullfrogs, disturbance regimes, and the persistence of California red-legged frogs. The Journal of Wildlife Management, 67(2), 424-38.

Downing, W.M., Dunn, C.J., Thompson, M.P., Caggiano, M.D. & Short, K.C. (2022). Human ignitions on private lands drive USFS cross-boundary wildfire transmission and community impacts in the western US. Scientific Reports, 12, 2624.

Dralle, D. N., Hahm, W. J., & Rempe, D. M. (2023). Inferring hillslope groundwater recharge ratios from the storage-discharge relation. Geophysical Research Letters, 50(14), e2023GL104255.

Dura, T., Chilton, W., Small, D., Gavin, A. J., Hutchinson, A., Melgar, D., Engelhart, S. E., Strain, L. M., Witter, R. C., Nelson, A. R., Kelsey, H. M., Allan, J. C., Bruun, D., Dockrill, J., Polenz, M., Briggs, R. W., White, R., Litton, S., Wood, M., & Horton, B. P. (2025). Increased flood exposure in the Pacific Northwest following earthquake-driven subsidence and sea-level rise. Proceedings of the National Academy of Sciences, 122(18), e2424659122. https://doi.org/10.1073/pnas.2424659122

EcoTipping Points Project. (n.d.). USA — California (Arcata): Constructed wetland. https://www.ecotippingpoints.org/our-stories/indepth/usa-california-arcata-constructed-wetland-wastewater.html

Erickson, W., Lee, C., & von Schrader, S. (2025). *Disability statistics from the American Community Survey (ACS)*. Cornell University, Yang-Tan Institute on Employment and Disability. https://disabilitystatistics.org/acs-census

Erikson, L.H., Storlazzi, C.D., Barnard, P.L., Hegermiller, C.E., & Shope, J.B. (2016). Wave and wind projections for United States Coasts; Mainland, Pacific Islands, and United States-Affiliated Pacific Islands. U.S. Geological Survey data release, https://doi.org/10.5066/F72B8W3T

Erikson, L.H., Herdman, L., Flanary, C., Engelstad, A., Pusuluri, P., Barnard, P.L., Storlazzi, C.D., Beck, M., Reguero, B. & Parker, K. (2022) Ocean wave time-series data simulated with a global-scale numerical wave model under the influence of projected CMIP6 wind and sea ice fields (ver. 2.0, October 2024). U.S. Geological Survey data release, https://doi.org/10.5066/P9KR0RFM

Estes, B.L., Knapp, E.E., Skinner, C.N., Miller, J.D. & Preisler, H.K. (2017). Factors influencing fire severity under moderate burning conditions in the Klamath Mountains, northern California, USA. Ecosphere, 8, e01794.

Eviner, V. T. (2016). Grasslands. In H. A. Mooney & E. S. Zavaleta (Eds.), Ecosystems of California (pp. 393–428).

Farjon, A. (2008). A Natural History of Conifers. Timber Press. Portland, OR.

Federal Emergency Management Agency. (2023). California severe winter storms, flooding, landslides, and mudslides (DR-4683-CA). https://www.fema.gov/disaster/4683

Federal Energy Regulatory Commission. (2022). Order approving surrender of license and removal of project facilities. Docket No. P-2082 (Klamath Hydroelectric Project).

Felitti, V. J., Anda, R. F., Nordenberg, D., Williamson, D. F., Spitz, A. M., Edwards, V., Koss, M. P., & Marks, J. S. (1998). Relationship of childhood abuse and household dysfunction to many of the leading causes of death in adults: The Adverse Childhood Experiences (ACE) Study. American Journal of Preventive Medicine, 14(4), 245–258. https://doi.org/10.1016/S0749-3797(98)00017-8

Fernández-Guisuraga, J. M., Calvo, L., Fernandes, P. M., Hulet, A., Perryman, B., Schultz, B., Jensen, K. S., Enterkine, J., Boyd, C. S., Davies, K. W., Johnson, D. D., Wollstein, K., Price, W. J., & Arispe, S. A. (2023). Estimates of fine fuel litter biomass in the northern Great Basin reveal increases during short fire-free intervals associated with invasive annual grasses. Science of The Total Environment, 860, 160634. https://doi.org/https://doi.org/10.1016/j.scitotenv.2022.160634

Fineran, K., 2024. Longevity of prescribed fire effectiveness in mixed-evergreen forests of the Klamath Mountains. California State Polytechnic University, Humboldt, Arcata, CA.

Flavelle, C., & Rojanasakul, M. (2024, December 18). Insurers are deserting homeowners as climate shocks worsen. The New York Times. https://www.nytimes.com/2024/12/18/climate/home-insurance-climate-risk-california-florida.html

Forero, L., Barry, S. J., & Larson, S. (2021). Beef cattle on California annual grasslands: production cycle and economics. https://doi.org/10.3733/ucanr.8687

Fox-Kemper, B., Hewitt, H.T., Xiao, C., Aðalgeirsdóttir, G., Drijfhout, S.S., Edwards, T.L., Golledge, N.R., Hemer, M., Kopp, R.E., Krinner, G., Mix, A., Notz, D., Nowicki, S., Nurhati, I.S., Ruiz, L., Sallée, J.B., Slangen, A.B.A., and Yu, Y. 2021: Ocean, Cryosphere and Sea Level Change. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R., and Zhou, B. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1211–1362, doi:10.1017/9781009157896.011.

Frankel, A. D., Petersen, M. D., Mueller, C. S., Haller, K. M., Wheeler, R. L., Leyendecker, E. V., Wesson, R. L., Harmsen, S. C., Cramer, C. H., Perkins, D. M., & Rukstales, K. S. (2002). Documentation for the 2002 update of the national seismic hazard maps (Open-File Report 2002-420). U.S. Geological Survey. https://doi.org/10.3133/ofr02420

Frederikse, T., Landerer, F., Caron, L. The cau, Adhikari, S., Parkes, D., Humphrey, V., Dangendorf, S., Hogarth, P., Zanna, L., Cheng, L. & Wu, Y. (2020). The causes of sea-level rise since 1900. Nature 584, 393–397. https://doi.org/10.1038/s41586-020-2591-3

Fredston, A. L., Cheung, W. W., Frölicher, T. L., Kitchel, Z. J., Maureaud, A. A., Thorson, J. T., Auber, A., Merigot, B., Palacios-Abrantes, J., Palomares, M., Pecuchet, L., Shackell, N. & Pinsky, M. L. (2023). Marine heatwaves are not a dominant driver of change in demersal fishes. Nature, 621(7978), 324-329.

Freeman, J., and Rossi, J. (2012). Agency coordination in shared regulatory space.

Frest, T. & Johannes, E. J. (1995). Ex. 277-US-404. In re Klamath River (Klamath Tribe). 20. https://digitalcommons.law.uidaho.edu/klamath/20

Frisch, M., & Sanford, T. (2022, March 15). *Fire reduction, response, and restoration careers.* Sierra Business Council. https://www.sierrabusiness.org/archives/fire-reduction-response-and-restoration-careers/

Furniss, M., Keller, G., & de la Fuente, J. (2025). Infrastructure vulnerability assessment, adaptation, and resilience on northwestern California forests. In Northern California climate vulnerability assessment and adaptation strategy (Chapter 4). U.S. Department of Agriculture, Forest Service.

Gao, X., Schlosser, C. A., & Morgan, E. R. (2017). Potential impacts of climate change on transformer lifetime: A case study for the US Northeast. Climatic Change, 140(2), 147-160.

García-Reyes, M., Sydeman, W. J., Schoeman, D. S., Rykaczewski, R. R., Black, B. A., Smit, A. J., & Bograd, S. J. (2015). Under pressure: Climate change, upwelling, and eastern boundary upwelling ecosystems. Frontiers in Marine Science, 2, 109.

Garwood, J., Cunningham, G., Peri, F., & Leaderman, R. (2025). Brook trout predation on dispersing cascades frogs shows invasive fish populations can impact amphibian recruitment from the broader landscape. California Fish and Wildlife, 111, doi.org/10.51492/cfwj.111.2.

Garwood, J., Nordstrom, A. & Herman, B. (2023). Sensitive Amphibian Population Recovery Actions in Climate Resilient Habitats Across the Klamath Mountains: 2024-2025 Project Update. California Department of Fish and Wildlife (pp. 1-33).

Gilio-Whitaker, D. (2019). As long as grass grows: The Indigenous fight for environmental justice, from colonization to Standing Rock. Beacon Press.

Glebocki, R., 2015. Fuel loading and moisture dynamics in thinned coast redwood–Douglas-fir forests in Headwaters Forest Reserve, California. Humboldt State University.

Goff, G. S., Kerhoulas, L. P., Beckmann, J. J., Kerhoulas, N. J., Kane, J. M., & Sherriff, R. L. (2025). Influences of conifer encroachment and removal on oak woodland ecophysiology and biodiversity — a case study. Restoration Ecology, 33(3). https://doi.org/10.1111/rec.14361

Goldfarb, B. (2018). Eager: the surprising, secret life of beavers and why they matter. Chelsea Green Publishing. New York, NY.

Goldfinger, C., Nelson, C. H., Morey, A. E., Johnson, J. E., Patton, J. R., Karabanov, E., Gutiérrez-Pastor, J., Eriksson, A. T., Gràcia, E., Dunhill, G., Enkin, R. J., Dallimore, A., & Vallier, T. (2012). Turbidite event history—Methods and implications for Holocene paleoseismicity of the Cascadia subduction zone (Professional Paper 1661-F). U.S. Geological Survey. https://doi.org/10.3133/pp1661F

Goss, M., Swain, D. L., Abatzoglou, J. T., Sarhadi, A., Kolden, C. A., Williams, A. P., & Diffenbaugh, N. S. (2020). Climate change is increasing the likelihood of extreme autumn wildfire conditions across California. Environmental Research Letters, 15(9), 094016. https://doi.org/10.1088/1748-9326/ab83a7

Grabinski, Z.S., Sherriff, R.L. & Kane, J.M. (2017). Controls of reburn severity vary with fire interval in the Klamath Mountains, California, USA. Ecosphere, 8, e02012.

Great Redwood Trail Agency. (2024). Annual progress report: 25% completion milestone. GRTA.

Greenson, T. (2020, August 6). *The island's return. North Coast Journal.* https://www.northcoastjournal.com/news-2/the-islands-return-15494902/

Griffin, D., & Anchukaitis, K. J. (2014). How unusual is the 2012-2014 California drought? Geophysical Research Letters 41, 9017-9023.

Griggs, G., Árvai, J., Cayan, D., DeConto, R., Fox, J., Fricker, HA., Kopp, RE., Tebaldi, C., & Whiteman, E. (2017). Rising seas in California: An update on sea-level rise science. California Ocean Protection Council Science Advisory Team. http://www.opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf

Grupenhoff, A. R. (2024). High fire frequency in California chaparral reduces postfire shrub regeneration and native plant diversity. Ecosphere, 15, e70128. https://doi.org/10.1002/ecs2.70128

Guirguis, K., Gershunov, A., Shulgina, T., Clemesha, R. E. S., Ralph, & F. M. (2019). Atmospheric rivers impacting Northern California and their modulation by a variable climate. Climate Dynamics, 52, 6569-6583.

Gunton, T., Werker, E., & Markey, S. (2021). Community benefit agreements and natural resource development: Achieving better outcomes. Resources Policy, 73, 102155. https://doi.org/10.1016/j.resourpol.2021.102155

Haggerty, N. (2025, February). California tribe enters first-of-its-kind agreement with the state to practice cultural burns. Los Angeles Times.

Halsch, C. A., Shapiro, A. M., Fordyce, J. A., Nice, C. C., Thorne, J. H., Waetjen, D. P., & Forister, M. L. (2021). Insects and recent climate change. Proceedings of the National Academy of Sciences of the United States of America, 118(2), e2002543117. https://doi.org/10.1073/pnas.2002543117

Hamlington, B.D., Frederikse, T., Thompson, P.R., Willis, J.K., Nerem, R.S. & Fasullo, J.T. (2021). Past, present, and future Pacific sea-level change. Earth's Future, 8, e2020EF001839. https://doi.org/10.1029/2020EF001839

Hamlington, B.D., Chambers, D.P., Frederikse, T., Dangendorf, S., Fournier, S., Buzzanaga, B. & Nerem, R.S. (2022). Observation-based trajectory of future sea level for the coastal United States tracks near high-end model projections. Commun Earth Environ 3, 230. https://doi.org/10.1038/s43247-022-00537-z

Hamlington, B. D., Bellas-Manley, A., Willis, J. K., Fournier, S., Vinogradova, N., Nerem, R. S., Piecuch, C. G., Thompson, P. R., & Kopp, R. (2024). The rate of global sea level rise doubled during the past three decades. Communications Earth & Environment, 5, Article 601. https://doi.org/10.1038/s43247-024-01761-5

Harris, L.B. & Taylor, A.H. (2022). MODIS-based smoke detection shows that daily smoke cover dampens fire severity in initial burns but not reburns in complex terrain. International Journal of Wildland Fire, 31, 1002–1013.

Headwaters Economics. (2023, August). How match requirements and reimbursement rules limit funding access for underserved communities. https://headwaterseconomics.org/equity/match-requirements/

Heaney, A., Walker, E. S., & Lipkowitz, M. (2022). Impacts of fine particulate matter from wildfire smoke on respiratory and cardiovascular health in California. GeoHealth, 6(6), e2021GH000578. https://doi.org/10.1029/2021GH000578

Heller, N. E., & Zavaleta, E. S. (2009). Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological conservation, 142(1), 14-32.

Hickman, C., Marks, E., Pihkala, P., Clayton, S., Lewandowski, R. E., Mayall, E. E., Wray, B., Mellor, C. & Van Susteren, L. (2021). Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey. The Lancet Planetary Health, 5(12), e863-e873.

Hoff, K., & Segal, K. (2023). Offshore wind & Community Benefits Agreements in California. Issue Brief. Berkeley Law, Center for Law, Energy, and the Environment. https://www.law.berkeley.edu/wp-content/uploads/2023/06/CBA-Policy-Paper.pdf

Hoffmann, M. M. (2025). *Targeting parallel vulnerabilities first: Are energy poor communities in California experiencing greater heat-wave related health burdens? Sustainable Cities and Society, 131*, 106461. https://doi.org/10.1016/j.scs.2025.106461

Holl, K. D., Luong, J. C., & Brancalion, P. H. S. (2022). Overcoming biotic homogenization in ecological restoration. Trends in Ecology & Evolution, 1–12. https://doi.org/10.1016/j.tree.2022.05.002

Hood, C. M., Gennuso, K. P., Swain, G. R., & Catlin, B. B. (2016). County health rankings: Relationships between determinant factors and health outcomes. *American Journal of Preventive Medicine, 50*(2), 129–135. https://doi.org/10.1016/j.amepre.2015.08.024

Hopkinson, P., Hammond, M., Bartolome, J. W., & Macaulay, L. (2020). Using consecutive prescribed fires to reduce shrub encroachment in grassland by increasing shrub mortality. Restoration Ecology, 28(4), 850–858. https://doi.org/10.1111/rec.13138

Howell, J., & Elliott, J. R. (2019). Damages Done: The Longitudinal Impacts of Natural Hazards on Wealth Inequality in the United States. Social Problems, 66(3), 448–467.

Hughes, K., Bellis, M. A., Hardcastle, K. A., Sethi, D., Butchart, A., Mikton, C., Jones, L., & Dunne, M. P. (2017). The effect of multiple adverse childhood experiences on health: A systematic review and meta-analysis. The Lancet Public Health, 2(8), e356–e366. https://doi.org/10.1016/S2468-2667(17)30118-4

Humboldt County. (2017). Humboldt County General Plan: Circulation element. Humboldt County Community Development Services. https://humboldtgov.org/DocumentCenter/View/61984/Chapter-7-Circulation-Element-PDF

Humboldt County. (2025). Living shorelines implementation plan for Highway 101 corridor through Humboldt Bay. Humboldt County Public Works.

Humboldt County Fire Safe Council. (2019). Humboldt County Community Wildfire Protection Plan: Upper Yurok Reservation Planning Unit Action Plan (Chapter 4.2). https://humboldtgov.org/DocumentCenter/View/70727/42-Upper-Yurok-Reservation-Humboldt-County-CWPP-Final

Humboldt County Sheriff's Office. (2023). Marijuana enforcement team operation near McClellan mountain. https://humboldtgov.org/m/newsflash/home/detail/5209

Hunt, L. J. H., Fair, J., & Odland, M. (2018). Meadow restoration increases baseflow and groundwater storage in the Sierra Nevada Mountains of California. Journal of the American Water Resources Association, 54(5), 1127–1136. https://doi.org/10.1111/1752-1688.12675

Huntsinger, L., Hruska, T. V, Oviedo, J. L., Shapero, M. W. K., Nader, G. A., Ingram, R. S., & Beissinger, S. R. (2017). Save water or save wildlife? Water use and conservation in the central Sierran foothill oak woodlands of California, USA. Ecology and Society, 22(2). https://doi.org/10.5751/ES-09217-220212

Huybrechs, F., Bastiaensen, J., & Van Hecken, G. (2019). Exploring the potential contribution of green microfinance in transformations to sustainability. Current Opinion in Environmental Sustainability, 41, 85–92.

Hysen, L.B., Cushman, S.A., Fogarty, F.A., Kelly, E.C., Nayeri, D. & Wan, H.Y. (2023). Northern spotted owl nesting habitat under high potential wildfire threats along the California Coastal Redwood Forest. Science of The Total Environment, 890, 163414.

Iberle, B.G., Van Pelt, R., Sillett, S.C., 2020. Development of mature second-growth Sequoia sempervirens forests. Forest Ecology and Management 459, 117816. https://doi.org/10.1016/j.foreco.2019.117816

Ikendi, S., Roche, L., Woodmansee,G., Schohr, T., Koundinya, V., Pinzon, N., Parker, L., Cooper, M., Zaccaria, D., Ostoja, S. & Pathak, T. (2025). Climate and Weather Variability Experiences and Extension Education Needs among Ranchers in Northern California. https://www.researchgate.net/publication/392472661_Climate_and_Weather_Variability_Experiences_and_Extension_Education_Needs_among_Ranchers_in_Northern_California#fullTextFileContent

Inouye, D. W. (2020). Effects of climate change on alpine plants and their pollinators. Annals of the New York Academy of Sciences, 1469(1), 26–37. https://doi.org/10.1111/nyas.14104

Insurance Institute for Business & Home Safety. (2024, April). "Wildfire Prepared Home: Fact sheet". https://wildfireprepared.org/wp-content/uploads/WFPH_FactSheet_Apr2024.pdf

Insurance Journal. (2024, October 7). How flood risk is driving an insurance protection gap in the US. https://www.insurancejournal.com/magazines/mag-features/2024/10/07/795710.htm

International Institute for Sustainable Development. (2021). How can investment in nature close the infrastructure gap? https://www.iisd.org/publications/investment-in-nature-close-infrastructure-gap

IPCC. (2022). in Shukla, P.R., Skea, J., Slade, R., Al Khourdajie, A., van Diemen, R., McCollum, D., Pathak, M., Some, S., Vyas, P., Fradera, R., Belkacemi, M., Hasija, A., Lisboa, G., Luz, S., & Malley, J. (Eds.). Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://doi.org/10.1017/9781009157926

Jacobsen, A. L., & Pratt, R. B. (2018). Extensive drought-associated plant mortality as an agent of type-conversion in chaparral shrublands. New Phytologist, 219(2), 498–504. https://doi.org/10.1111/nph.15186

Jacobson, A. (2025). Power behind the Redwood Curtain: A history of electric transmission and natural gas infrastructure in Humboldt County. Schatz Energy Research Center, Cal Poly Humboldt.

Jin T., Amini H., Kosheleva A., Danesh Yazdi M., Wei Y., Castro E., Di Q., Shi L., Schwartz J. (2022). Associations between long-term exposures to airborne PM2.5 components and mortality in Massachusetts: Mixture analysis exploration. *Environmental Health, 21*, 96. https://doi.org/10.1186/s12940-022-00907-2

Johnsen, R. L., Butsic, V., & Huntsinger, L. (2020). Evaluating ecosystem services values and return on investment of conservation easements held by the California Rangeland Trust. https://doi.org/10.1007/BF00044405

Johnson, T., & Belitz, K. (2015). Identifying the location and population served by domestic wells in California. *Journal of Hydrology: Regional Studies, 3*, 31–86. https://doi.org/10.1016/j.ejrh.2014.09.002

Johnstone, J. A., & Dawson, T. E. (2010). Climatic context and ecological implications of summer fog decline in the coast redwood region. Proceedings of the National Academy of Sciences, 107(10), 4533–4538. https://doi.org/10.1073/pnas.0915062107

Jolley, A., & Blackmer, E. (2025). Advancing wildfire resilience workforce & career development in California: Recommendations to support and invest in workforce, career pathways, and workplace culture. Sierra Business Council & Watershed Research and Training Center. https://www.sierrabusiness.org/wp-content/uploads/2025/11/Advancing-Wildfire-Resilience-Workforce-Career-Development-in-California_finalNov25.pdf

Jones, G. M., Keyser, A. R., Westerling, A. L., Baldwin, W. J., Keane, J. J., Sawyer, S. C., Clare, J. D. J., Gutiérrez, R. J., & Peery, M. Z. (2022). Forest restoration limits megafires and supports species conservation under climate change. Frontiers in Ecology and the Environment, 20(4), 210–216. https://doi.org/10.1002/fee.2450

Jordan, A., Huitema, D., Hildén, M., van Asselt, H., Rayner, T. J., Schoenefeld, J. J., Tosun, J., Forster, J., & Boasson, E. L. (2015). Emergence of polycentric climate governance and its future prospects. Nature Climate Change, 5(11), 977–982. https://doi.org/10.1038/nclimate2725

Jordan, A., Huitema, D., Schoenefeld, J., van Asselt, H., & Forster, J. (2018). Governing climate change polycentrically: Setting the scene. Cambridge University Press.

Jose, E., Agarwal, P., & Zhuang, J. (2023). A data-driven analysis and optimization of the impact of prescribed fire programs on wildfire risk in different regions of the USA. Natural Hazards, 118, 181–207. https://doi.org/10.1007/s11069-023-05997-w

Joyce, L. A., Briske, D. D., Brown, J. R., Polley, H. W., McCarl, B. A., & Bailey, D. W. (2013). Climate change and North American rangelands: Assessment of mitigation and adaptation strategies. Rangeland Ecology and Management, 66(5), 512–528. https://doi.org/10.2111/REM-D-12-00142.1

Jules, E.S., DeSiervo, M.H., Reilly, M.J., Bost, D.S. & Butz, R.J. (2022). The effects of a half century of warming and fire exclusion on montane forests of the Klamath Mountains, California, USA. Ecological Monographs, 92, e1543.

Kalies, E.L., Yocom Kent, L.L., 2016. Tamm Review: Are fuel treatments effective at achieving ecological and social objectives? A systematic review. Forest Ecology and Management 375, 84–95. https://doi.org/10.1016/j.foreco.2016.05.021

Kane, J.M., & Carrasco, J. (2025). Tree and stand characteristics moderate wildfire severity and promote resilience in secondary coast redwood forests. Forest Ecology and Management, 596: 123078.

Karuk Tribe Climate Change Projects. (2024). Karuk Good Fire Report. https://karuktribeclimatechangeprojects.com/good-fire/

Kats, L. B., & Ferrer, R. P. (2003). Alien predators and amphibian declines: review of two decades of science and the transition to conservation. Diversity and Distributions 9, 99-110. https://doi/10.1046/j.1472-4642.2003.00013.x

Kauffmann, M. (2012). Conifer Country. Backcountry Press. Kneeland, CA.

Kauffmann, M. & Garwood, J. (2022) The Klamath Mountains: A Natural History (pp. 98-117). Backcountry Press.

Keddy, P. A., & Laughlin, D. C. (2022). A Framework for Community Ecology: Species Pools, Filters and Traits. Cambridge University Press.

Kemp, K. (2017, February 17). Heading East? Hwy 20 closed due to flooding near Williams. Redheaded Blackbelt. https://kymkemp.com/2017/02/17/heading-east-hwy-20-closed-due-to-flooding-near-williams/

Keppeler, E., Wagenbrenner, J., Dymond, S., & Dralle, D. (2024). Streamflow response to drought in a managed coast redwood catchment. JAWRA Journal of the American Water Resources Association, 60(5), 928-952.

Keys, B. J., & Mulder, P. (2024). Property insurance and disaster risk: New evidence from mortgage escrow data (Working Paper No. 32579). National Bureau of Economic Research. https://doi.org/10.3386/w32579

Kimmerer, R. W. (2013). Braiding sweetgrass: Indigenous wisdom, scientific knowledge and the teachings of plants. Milkweed Editions.

Kirsch, S. (2023). California's Rural North: Exploring the Roots of Health Disparities. California Center for Rural Policy at Cal Poly Humboldt. https://ccrp.humboldt.edu/sites/default/files/californias_rural_north_exploring_the_roots_of_health_disparities_final_0.pdf

Kirwan, M. L., Temmerman, S., Skeehan, E. E., Guntenspergen, G. R., & Fagherazzi, S. (2016). Overestimation of marsh vulnerability to sea level rise. Nature Climate Change, 6, 253–260. https://doi.org/10.1038/nclimate2909

Klamath Basin Monitoring Program. (2024). Blue-green algae tracker. https://kbmp.net/maps-data/blue-green-algae-tracker

Klein, E. (2025). Abundance. Avid Reader Press.

Knapp, R.A., Boiano, D.M. & Vredenburg, V.T. (2007). Removal of nonnative fish results in population expansion of a declining amphibian (mountain yellow-legged frog, Rana muscosa). Biological Conservation, 135(1), 11-20.

Knapp, E.E., Lydersen, J.M., North, M.P., Collins, B.M., 2017. Efficacy of variable density thinning and prescribed fire for restoring forest heterogeneity to mixed-conifer forest in the central Sierra Nevada, CA. Forest Ecology and Management 406, 228–241. https://doi.org/10.1016/j.foreco.2017.08.028

Knapp, E.E., Bernal, A.A., Kane, J.M., Fettig, C.J., North, M.P., 2021. Variable thinning and prescribed fire influence tree mortality and growth T during and after a severe drought. Forest Ecology and Management 479, 118595.

Kneitel, J. M., Samiylenko, N., & Alyssa, L. R. (2017). California vernal pool endemic responses to hydroperiod, plant thatch, and nutrients. Hydrobiologia, 801, 129–140. https://doi.org/10.1007/s10750-017-3174-7

Knight, C.A., Cogbill, C.V., Potts, M.D., Wanket, J.A. & Battles, J.J. (2020). Settlement-era forest structure and composition in the Klamath Mountains: reconstructing a historical baseline. Ecosphere, 11, e03250.

Koman, P. (2019). Mapping modeled exposure of wildland fire smoke for human health studies in California. *Atmosphere, 10*(6), 308. https://doi.org/10.3390/atmos10060308

Kopp, R. E., Horton, R.M., Little, C.M., Mitrovica, J.X., Oppenheimer, M., Rasmussen, D.J., Strauss, B. and Tebaldi, C. (2014). Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future, 2(8), 383-406.Koteen, L. E., Baldocchi, D. D., & Harte, J. (2011). Invasion of non-native grasses causes a drop in soil carbon storage in California grasslands. Environmental Research Letters, 6(4), 044001. https://doi.org/10.1088/1748-9326/6/4/044001

Kousky, C., & Kunreuther, H. (2014). Addressing affordability in the National Flood Insurance Program. Journal of Extreme Events, 1(01), 1450001. https://doi.org/10.1142/S2345737614500018

Kreider, M.R., Higuera, P.E., Parks, S.A., Rice, W.L., White, N. & Larson, A.J. (2024). Fire suppression makes wildfires more severe and accentuates impacts of climate change and fuel accumulation. Nature Communications, 15, 2412.

Krochta, M., Anlauf-Dunn, K., Bugni, D., & Chang, H. (2025). Effects of climate change on stream temperature and salmonid habitats in a Cascades river basin. Journal of Environmental Management, 387, 125843.

Krupnik, A. (2025). Wildfire smoke, the Clean Air Act, and the Exceptional Events Rule: Implications and policy alternatives. *Environmental Science & Technology, 59*(6), 3124–3132. https://doi.org/10.1021/acs.est.4c08946

Kundzewicz, Z. W., Kanae, S., Seneviratne, S. I., Handmer, J., Nicholls, N., Peduzzi, P., Mechler, R., Bouwer, L.M., Arnell, N., Mach, K. Muir-Wood, R., Brakenridge, G.R., Kron, W., Benito, G., Honda, Y., Takahashi, K. & Sherstyukov, B. (2013). Flood risk and climate change: global and regional perspectives. Hydrological Sciences Journal, 59(1), 1–28. https://doi.org/10.1080/02626667.2013.857411

Laird, A. (2018). Humboldt County Humboldt Bay Area Plan, communities at risk sea level rise vulnerability assessment. https://digitalcommons.humboldt.edu/hsuslri_local/28/

Laird, A. (2019). Humboldt County Humboldt Bay Area Plan, communities at risk strategic sea level rise adaptation planning report. https://digitalcommons.humboldt.edu/hsuslri_local/29/

Lake, F. K., Wright, V., Morgan, P., McFadzen, M., McWethy, D., & Stevens-Rumann, C. (2017). Returning fire to the land: celebrating traditional knowledge and fire. Journal of Forestry, 115, 343-353.

Lake, F. K., Marks-Block, T., Bliege Bird, R., & Curran, L. M. (2021). Revitalized Karuk and Yurok cultural burning to enhance California hazelnut for basketweaving in northwestern California, USA. Fire Ecology, 17, Article 6.

Lake, F. (2022). Chapter 1: First peoples. In M. K. Skinner, J. H. Baldwin, & K. A. Sawyer (Eds.), The Klamath Mountains: A natural history (pp. 22–43). Backcountry Press.

Lake County. (2024a). Public Safety Power Shutoff (PSPS). https://www.lakecountyca.gov/591/Public-Safety-Power-Shutoff-PSPS

Lake County. (2024b). Wildfire impact assessment: County land area affected 2015-2024. Lake County Office of Emergency Services. [As cited in The Press Democrat, August 2025]

Lake County Board of Supervisors. (2022, May 3). Proclamation of local emergency due to pervasive tree mortality. County of Lake, California. https://www.lakecountyca.gov/1748/Tree-Mortality-Program

Lake County Economic Development Corporation. (2024). Comprehensive Economic Development Strategy (CEDS). https://lakecountycaedc.org/ceds/

Lake County News. (2022). U.S. Forest Service report shows tree mortality is worsening in Lake County. Lake County News. https://www.lakeconews.com/news/74970-u-s-forest-service-report-shows-tree-mortality-is-worsening-in-lake-county

Lakhoo, D. P., Brink, N., Radebe, L., Craig, M. H., Pham, M. D., Haghighi, M. M., Wise, A., Solarin, I., Luchters, S., Maimela, G., Chersich, M. F., Chikandiwa, A., Nakstad, B., Wright, C. Y., Brimicombe, C., Technau, K.-G., Harden, L., Boeckmann, M., Strehlau, R., … HIGH Horizons Study Group. (2025). A systematic review and meta-analysis of heat exposure impacts on maternal, fetal and neonatal health. *Nature Medicine, 31*(2), 684–694. https://doi.org/10.1038/s41591-024-03395-8

Lalemand, L. B., van Mantgem, P. J., Sherriff, R. L., & Kane, J. M. (2024). Sequoia sempervirens and Pseudotsuga menziesii tree growth and drought resistance following restoration thinning in secondary northern coastal redwood forests of California. Forest Ecology and Management 569, https://doi.org/10.1016/j.foreco.2024.122149.

Largier, J. L., Magnell, B. A., & Winant, C. D. (1993). Subtidal circulation over the northern California shelf. Journal of Geophysical Research: Oceans, 98(C10), 18147-18179.

Larson, E. (2023). Atmospheric rivers and Lake County flood trends. Clear Lake News. https://lakeconews.com/news/75186-clear-lake-reaches-full-level-county-health-services-issues-health-advisory-due-to-flood-waters

Last Chance Grade Project. (2024). About the project. https://lastchancegrade.com/app_pages/view/292

Le, K. (2025). The impacts of extreme heat days on the prevalence of domestic abuse. *SAGE Open, 15*(1). https://doi.org/10.1177/21582440251317797

Lee, S. Y., Ryan, M. E., Hamlet, A. F., Palen, W. J., Lawler, J. J., & Halabisky, M. (2015). Projecting the hydrologic impacts of climate change on montane wetlands. Plos one, 10(9), p.e0136385.

Lemmo, S.L.B., Kerhoulas, L.P., Sherriff, R.L. & Beckmann, J.J. (2024). Drought effects on tree mortality and regeneration in northern California. Forest Ecology and Management, 563, 121969.

Lempert, R. J., Groves, D. G., Popper, S. W., & Bankes, S. C. (2006). A general, analytic method for generating robust strategies and narrative scenarios. *Management Science, 52*(4), 514–528. https://doi.org/10.1287/mnsc.1050.0472

Lesage, J. C., Hayes, G. F., & Holl, K. D. (2022). Native annual forbs decline in California coastal prairies over 15 years despite grazing. PLOS One, 1–15. https://doi.org/10.1371/journal.pone.0278608

Levine, J.I., Collins, B.M., Steel, Z.L., De Valpine, P. & Stephens, S.L. (2022). Higher incidence of high-severity fire in and near industrially managed forests. Frontiers in Ecology & the Environment, 20, 397–404.

Lewis, T.E., D.W. Lamphear, D.R. McCanne, A.S. Webb, J.P. Krieter, and W. D. Conroy. 2000. Regional Assessment of Stream Temperatures Across Northern California and Their Relationship to Various Landscape-Level and Site-Specific Attributes. Forest Science Project. Humboldt State University Foundation, Arcata, CA. 420 pp.

Lezama-Ochoa, N., Brodie, S., Welch, H., Jacox, M. G., Pozo Buil, M., Fiechter, J., Cimino, M., Muhling, B., Dewar, H., Becker, E., Forney, K.A., Costa, D., Benson, S.R., Farchadi, N., Braun, C., Lewison, R., Bograd, S, & Hazen, E. L. (2024). Divergent responses of highly migratory species to climate change in the California Current. Diversity and Distributions, 30(2), e13800.

Liu, D., Xu, Y., Guo, S., Xiong, L., Liu, P. and Zhao, Q., 2018. Stream temperature response to climate change and water diversion activities. Stochastic Environmental Research and Risk Assessment, 32(5), pp.1397-1413.

Liu J.C., Wilson A., Mickley L.J., Dominici F., Ebisu K., Wang Y., Sulprizio M.P., Peng R.D., Yue X., Son J.Y., Anderson G.B., Bell M.L. (2017). Wildfire-specific fine particulate matter and risk of hospital admissions in urban and rural counties. *Epidemiology, 28*(1), 77–85. https://doi.org/10.1097/EDE.0000000000000556

Liu, J., Varghese, B. M., Hansen, A., Zhang, Y., Driscoll, T., Morgan, G., Dear, K., Gourley, M., Capon, A. & Bi, P. (2022). Heat exposure and cardiovascular health outcomes: a systematic review and meta-analysis. The Lancet Planetary Health, 6(6), e484-e495.

Liu, H., Jin, Y., Roche, L. M., O'Geen, A. T., & Dahlgren, R. A. (2023). Regional differences in the response of California's rangeland production to climate and future projection. Environmental Research Letters, 18, 014011. https://doi.org/10.1088/1748-9326/aca689

Londe, D. W., Davis, C. A., Loss, S. R., Robertson, E. P., Haukos, D. A., & Hovick, T. J. (2024). Climate change causes declines and greater extremes in wetland inundation in a region important for wetland birds. Ecological Applications, 34, e2930. https://doi.org/10.1002/eap.2930

Long, J. W., Goode, R. W., Gutteriez, R. J., Lackey, J. J., & Anderson, M. K. (2017). Managing California Black Oak for Tribal Ecocultural Restoration. Journal of Forestry, 115(5), 426–434.

Lopez, A. M., Pacheco, J. L., & Fendorf, S. (2023). Metal toxin threat in wildland fires determined by geology and fire severity. *Nature Communications, 14,* 8007. https://doi.org/10.1038/s41467-023-43101-9

Lost Coast Outpost. (2024, November 19-23). 'Bomb cyclone' prompts flood watch for North Coast communities. Lost Coast Outpost. https://lostcoastoutpost.com/2024/nov/19/big-ass-storm/

Lost Coast Outpost. (2025, October 7). Trump Administration appears to claw back $88 million grant for local Tribal energy resilience project. *Lost Coast Outpost.* https://lostcoastoutpost.com/2025/oct/7/trump-administration-appears-claw-back-88-million/

Luković, J., Chiang, J. C. H., Blagojević, D., & Sekulić, A. (2021). A later onset of the rainy season in California. Geophysical Research Letters 48, doi.org/10.1029/2020GL090350.

Luong, J. C., Holl, K. D., & Loik, M. E. (2021). Leaf traits and phylogeny explain plant survival and community dynamics in response to extreme drought in a restored coastal grassland. Journal of Applied Ecology, 58(8), 1670–1680. https://doi.org/10.1111/1365-2664.13909

Luong, J. C., Press, D. M., & Holl, K. D. (2023). Lessons learned from an interdisciplinary evaluation of long-term restoration outcomes on 37 restored coastal grasslands in California. Biological Conservation, 280, 109956. https://doi.org/https://doi.org/10.1016/j.biocon.2023.109956

Lusardi, R. A., Dahlgren, R., Van Nieuwenhuyse, E., Whitman, G., Jeffres, C., & Johnson, R. (2023). Does fine-scale habitat diversity promote meaningful phenotypic diversity within a watershed network? Ecology, 104(8), 1–5. https://www.jstor.org/stable/27256236

Madej, M. A., Currens, C., Ozaki, V., Yee, J., & Anderson, D. G. (2006). Assessing possible thermal rearing restrictions for juvenile coho salmon (Oncorhynchus kisutch) through thermal infrared imaging and in-stream monitoring, Redwood Creek, California. Canadian Journal of Fisheries and Aquatic Sciences, 63(6), 1384-1396.

Madley, B. (2016). *An American genocide: The United States and the California Indian catastrophe, 1846–1873.* Yale University Press.

Maestas, J., Pellant, M., Okeson, L., Tilley, D., Havlina, D., Cracroft, T., Brazee, B., Williams, M., & Messmer, D. (2016). Fuel breaks to reduce large wildfire impacts in sagebrush ecosystems. Plant Materials Technical Note No. 66, Boise, ID, USA, pp. USDA–NRCS.

Mallek, C., Safford, H., Viers, J. & Miller, J. (2013). Modern departures in fire severity and area vary by forest type, Sierra Nevada and southern Cascades, California, USA. Ecosphere, 4, art153.

Manning, M., Rose, B., & Reed, K. (2019). Returning the Yurok forest to the Yurok Tribe: California's first Tribal carbon credit project. Stanford Environmental Law Journal, 38(1).

Marks-Block, T., & Tripp, W. (2021). Facilitating prescribed fire in Northern California through Indigenous governance and interagency partnerships. Fire, 4(37), 1–23.

Marks-Block, T., Lake, F. K., Bliege Bird, R., & Curran, L. M. (2021). Revitalized Karuk and Yurok cultural burning to enhance California hazelnut for basketweaving in northwestern California, USA. Fire Ecology, 17, 6. https://doi.org/10.1186/s42408-021-00092-6.

Martin, J. V., Dillis, C., Starrs, G., Schell, D., Grantham, T. E., & Butsic, V. (2025). Wildfire impacts and mitigation strategies among California cannabis producers. PLoS ONE, 20(4), e0321476.

Marty, J. T. (2005). Effects of Cattle Grazing on Diversity in Ephemeral Wetlands. Conservation Biology, 19(5), 1626–1632. https://doi.org/10.1111/j.1523-1739.2005.00198.x

Mastrocicco, M., Colombani, N., Soana, E., Vincenzi, F., & Castaldelli, G. (2019). Intense rainfalls trigger nitrite leaching in agricultural soils depleted in organic matter. Science of the Total Environment, 665, 80–90. https://doi.org/10.1016/j.scitotenv.2019.01.306

McKinleyville Community Services District. (2004). Constructed wetland treatment system: Design and construction report. McKinleyville CSD.

McKinleyville Community Services District. (2024). News and project updates. https://mckinleyvillecsd.ca.gov/news-and-project-updates

McKinney, S.T., Abrahamson, I., Jain, T., Anderson, N., 2022. A systematic review of empirical evidence for landscape-level fuel treatment effectiveness. Fire Ecology 18, 21. https://doi.org/10.1186/s42408-022-00146-3

Mendocino County. (2025, May 9). Mendocino County awarded $39.9 million state grant for Redemeyer Road Extension project. https://www.mendocinocounty.gov/Home/Components/News/News/7370/18?npage=48

Mendocino County Department of Transportation. (2025). Road closures and delays. Retrieved from https://www.mendocinocounty.gov/departments/transportation/road-closures-and-delays

Mendocino Voice. (2025, November 20). Fort Bragg to test the state's first wave-powered desalination system. https://mendovoice.com/2025/11/fort-bragg-to-test-the-states-first-wave-powered-desalination-system/

MendoFever. (2025, January 7). Redwood Valley's water system transition: What's next?

Meo-Filho, P., Ramirez-Agudelo, J. F., & Kebreab, E. (2024). Mitigating methane emissions in grazing beef cattle with a seaweed-based feed additive: Implications for climate-smart agriculture. Proceedings of the National Academy of Sciences, 121(50), e2410863121. https://doi.org/10.1073/pnas.2410863121

Meyers, D., Bohorquez, J., Cumming, T., Emerton, L., van den Heuvel, O., Riva, M., & Victurine, R. (2020). Conservation finance: A framework. Conservation Finance Alliance. https://static1.squarespace.com/static/57e1f17b37c58156a98f1ee4/t/5e728a4e1e6cc747e7cdbdc2/1584564815888/Conservation+Finance+Framework+March+2020.pdf

Michaels, J., Batzer, E., Harrison, S., & Eviner, V. T. (2021). Grazing affects vegetation diversity and heterogeneity in California vernal pools. Ecology, 102(4), 1–10. https://doi.org/10.1002/ecy.3295

Microgrid Knowledge. (2024). For 3 outage-prone tribes, 3 nested microgrids spanning 26 miles. https://www.microgridknowledge.com/reliability-resilience/article/55132376/

Middleton, B. A., & Kleinebecker, T. (2012). The Effects of Climate-Change-Induced Drought and Freshwater Wetlands. In B. A. Middleton (Ed.), Global Change and the Function and Distribution of Wetlands (pp. 117–147). Springer, Dordrecht. https://doi.org/10.1007/978-94-007-4494-3_4

Milana, C., & Ashta, A. (2012). Developing microfinance: A survey of the literature. Strategic Change, 21(7–8), 299–330.

Milazzo, F., Francksen, R. M., Zavattaro, L., Abdalla, M., Hejduk, S., Ravetto, S., Pittarello, M., Newell, P., Schils, L. M., Smith, P., & Vanwalleghem, T. (2023). The role of grassland for erosion and flood mitigation in Europe: A meta-analysis. Agriculture, Ecosystems and Environment, 348, 108443. https://doi.org/10.1016/j.agee.2023.108443

Millar, C. I., Stephenson, N. L., & Stephens, S. L. (2007). Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications, 17, https://doi.org/10.1890/06-1715.1

Miller, J.D., Skinner, C.N., Safford, H.D., Knapp, E.E. & Ramirez, C.M. (2012). Trends and causes of severity, size, and number of fires in northwestern California, USA. Ecological Applications, 22, 184–203.

Miller, R. K., Field, C. B., & Mach, K. J. (2020). Barriers and enablers for prescribed burns for wildfire management in California. Nature Sustainability, 3(2), 101–109. https://doi.org/10.1038/s41893-019-0451-7

Mills, E. (2012). The greening of insurance. Science, 338(6113), 1424–1425. https://doi.org/10.1126/science.1229351

Mills, E. (2022). Contrary to conventional methods, best practices for cannabis cultivation result in less intensive land and water use for outdoor than for indoor farming. https://drive.google.com/file/d/1Ym7UnxfjOA1veyuk2wtv-Bv3Y84TSOSt/view

Mills, E. (2025a). The emergence of indoor agriculture as a driver of global energy demand. npj Sustainable Agriculture, 3, 52. https://doi.org/10.1038/s44264-025-00091-z

Mills, E. (2025b). Harmonizing cannabis and environmental policy. International Journal of Drug Policy. https://doi.org/10.1016/j.drugpo.2025.104923

Mills, E. (2025c). Energy-intensive indoor cultivation drives the cannabis industry's expanding carbon footprint. One Earth, 8, 101179. https://doi.org/10.1016/j.oneear.2025.101179

Mola, J. M., & Williams, N. M. (2018). Fire-induced change in floral abundance, density, and phenology benefits bumble bee foragers. Ecosphere, 9(1), e02056. https://doi.org/10.1002/ecs2.2056

Montillet, J.P, Melbourne, T.I. & Szeliga, W.M. (2018). GPS Vertical Land Motion Corrections to Sea-Level Rise Estimates in the Pacific Northwest. Journal of Geophysical Research: Oceans, 123(2), 1196-1212. https://doi.org/10.1002/2017JC013257

Montrone, A., Saito, L., Weisberg, P. J., Gosejohan, M., Merriam, K., & Mejia, J. F. (2019). Climate change impacts on vernal pool hydrology and vegetation in northern California. Journal of Hydrology, 574(October 2017), 1003–1013. https://doi.org/10.1016/j.jhydrol.2019.04.076

Moody's RMS. (2025, December 3). Why does the U.S. flood insurance gap persist, and how can private insurance transform the market? https://www.moodys.com/web/en/us/insights/insurance/us-flood-insurance-gap-how-private-insurers-can-transform-the-market.html

Moore, S. K., Trainer, V. L., Mantua, N. J., Parker, M. S., Laws, E. A., Backer, L. C., & Fleming, L. E. (2008). Impacts of climate variability and future climate change on harmful algal blooms and human health. Environmental Health, 7(Suppl 2), S4.

Moore, S. R. (2010). Energy efficiency in small-scale biointensive organic onion production in Pennsylvania, USA. Renewable Agriculture and Food Systems, 25, 181–188.

Morelli, T.L., Daly, C., Dobrowski, S.Z., Dulen, D.M., Ebersole, J.L., Jackson, S.T., Lundquist, J.D., Millar, C.I., Maher, S.P., Monahan, W.B. & Nydick, K.R. (2016). Managing climate change refugia for climate adaptation. PloS one, 11(8), p.e0159909.

Morris, J. T., Sundareshwar, P. V., Nietch, C. T., Kjerfve, B., & Cahoon, D. R. (2002). Responses of coastal wetlands to rising sea level. Ecology, 83(10), 2869–2877.

Mote, P. W., Li, S., Lettenmaier, D. P., Xiao, M., & Engel, R. (2018). Dramatic declines in snowpack in the western US. Npj Climate and Atmospheric Science, 1(1), 2.

Munden-Dixon, K., Tate, K., Cutts, B., & Roche, L. (2018). An uncertain future: Climate resilience of first-generation ranchers. The Rangeland Journal, 41(3). https://doi.org/10.1071/RJ18023

Mutoti, M. I., Edokpayi, J. N., Mutileni, N., Durowoju, O. S., & Munyai, F. L. (2023). Cyanotoxins in groundwater; occurrence, potential sources, health impacts and knowledge gap for public health. *Toxicon, 226,* 107077. https://doi.org/10.1016/j.toxicon.2023.107077

Naiman, R. J., Johnston, C. A., & Kelley, C. A. (1988). Alteration of North American streams by beaver. Bioscience 38, 753–761.

NARUC/NASEO Microgrids State Working Group. (2021). Private, state, and federal funding and financing options to enable resilient, affordable, and clean microgrids. National Association of Regulatory Utility Commissioners & National Association of State Energy Officials. https://www.naseo.org/data/sites/1/documents/publications/v2_NASEO_MicroGrid.pdf

National Academies of Medicine. (n.d.). *Climate Communities Network.* https://nam.edu/our-work/programs/climate-and-health/climate-communities-network/

Nature, 622(7982), 761–766. https://doi.org/10.1038/s41586-023-06522-6.

National Institute of Building Sciences (2020). Mitigation Saves: Mitigation Saves up to $13 per $1 Invested. https://nibs.org/wp-content/uploads/2025/04/ms_v4_overview.pdf

NOAA. (n.d.). *Climate at a glance: County time series.* National Centers for Environmental Information. https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance

NOAA. (2022). Sea level trends - North Spit, Humboldt Bay. https://tidesandcurrents.noaa.gov/sltrends/

NOAA California Nevada River Forecast Center. (2023). December 2022 - January 2023 heavy precipitation events storm summary. National Oceanic and Atmospheric Administration. https://www.cnrfc.noaa.gov/storm_summaries/dec2022Jan2023storms.php

Norgaard, K. M. (2005, November). The effects of altered diet on the health of the Karuk people (White paper submitted to the Federal Energy Regulatory Commission, Docket No. P-2082, on behalf of the Karuk Tribe of California). Kari Marie Norgaard. Retrieved from https://pages.uoregon.edu/norgaard/pdf/Effects-Altered-Diet-Karuk-Norgaard-2005.pdf

North Coast Climate Summit. (2024). Meeting proceedings and breakout session notes. California Natural Resources Agency. [Unpublished meeting notes]

North Coast Resource Partnership. (2024). *Dashboard of outcomes.* https://northcoastresourcepartnership.org/site/assets/uploads/2024/05/NCRP-dash-board-draft-11x17-1.pdf

North Coast Resource Partnership. (n.d.). Workforce development. North Coast Resource Partnership Regional Resilience Plan. https://northcoastresourcepartnership.org/resilience-plan/solution/workforce-development/

Northern Hydrology and Engineering & Anderson, J. (2014). Estimates of local or relative sea level rise for Humboldt Bay region. Prepared for the California State Coastal Conservancy and Coastal Ecosystems Institute of Northern California.

Norton, J. (1979). When our worlds cried: Genocide in northwestern California. The Indian Historian Press.

Nunes, A. M., & Byrne, K. M. (2022). Drought and shrub cover differentially affect seed bank composition within two sagebrush steppe communities. Journal of Arid Environments, 202, 104752. https://doi.org/https://doi.org/10.1016/j.jaridenv.2022.104752

Nussbaum, R.A., Brodie, E.D., & R.M. Storm. (1983). Amphibians and reptiles of the Pacific Northwest. Caxton Press.

Obedzinski, M., Nossaman Pierce, S., Horton, G. E., & Deitch, M. J. (2018). Effects of flow-related variables on oversummer survival of juvenile Coho salmon in intermittent streams. Transactions of the American Fisheries Society, 147(3), 588-605.

Odion, D.C., Moritz, M.A. & DellaSala, D.A. (2010). Alternative community states maintained by fire in the Klamath Mountains, USA. Journal of Ecology, 98, 96–105.

Office of Environmental Health Hazard Assessment (OEHHA, 2022). Indicators of Climate Change in California, Fourth Edition. California Environmental Protection Agency.

Office of Environmental Health Hazard Assessment. (2024). *Wildfire smoke.* https://oehha.ca.gov/climate-change/epic-2022/impacts-human-health/wildfire-smoke

Olive, W. W., Chleborad, A. F., Frahme, C. W., Schlocker, J., Schneider, R. R., & Schuster, R. L. (1989). *Swelling clays map of the conterminous United States* (Map I-1940). U.S. Geological Survey. https://pubs.usgs.gov/imap/i-1940/

Olson, D., DellaSala, D.A., Noss, R.F., Strittholt, J.R., Kass, J., Koopman, M.E., & Allnutt, T.F. (2012). Climate change refugia for biodiversity in the Klamath-Siskiyou Ecoregion. Natural Areas Journal, 32: 65–74.

OPC (2024). State of California Sea Level Rise Guidance: 2024 Science & Policy Update. California Sea Level Rise Science Task Force, California Ocean Protection Council, and California Ocean Scient Trust. https://opc.ca.gov/wp-content/uploads/2024/05/California-Sea-Level-Rise-Guidance-2024-508.pdf

Orona, Brittani. 2013. *Stories of the River, Stories of the People.* Video in exhibit. Seven 30 Seconds. https://www.nativewomenscollective.org/storiesoftheriver.html

Ostoja, S. M., Choe, H., Thorne, J. H., Alvarez, P., Kerr, A., Balachowski, J., & Reyes, J. (2023). The Impact of Climate Change on California Rangelands and Livestock Management. In Agriculture (Vol. 13, Issue 11). https://doi.org/10.3390/agriculture13112095

Ott, J.E., Kilkenny, F.F., Jain, T.B., 2023. Fuel treatment effectiveness at the landscape scale: a systematic review of simulation studies comparing treatment scenarios in North America. Fire Ecology 19, 10. https://doi.org/10.1186/s42408-022-00163-2

Paci, J., Newman, M., & Gage, T. (2023). The economic, fiscal, and environmental costs of wildfires in California. Gordon and Betty Moore Foundation. https://www.moore.org/docs/default-source/default-document-library/the-economic-fiscal-and-environmental-costs-of-wildfires-in-ca.pdf

Pacific Gas & Electric. (2021, May 7). Safety issue notification: Cellon-treated poles. California Public Utilities Commission. https://www.cpuc.ca.gov/-/media/cpuc-website/industries-and-topics/documents/pge/oversight-and-enforcement/pges-selfreport-on-cellontreated-poles-572021.pdf

Pacific Gas & Electric. (2023). 2023 Annual electric reliability report.

Parker, L. E., Zhang, N., Abatzoglou, J. T., Kisekka, I., McElrone, A. J., & Ostoja, S. M. (2024). A variety-specific analysis of climate change effects on California winegrapes. International Journal of Biometeorology, 68, 1559–1571. https://doi.org/10.1007/s00484-024-02684-8

Parker-Shames, P., Choi, C., Butsic, V., Green, D., Barry, B., Moriarty, K., Levi, T., & Brashares, J. S. (2022). The spatial overlap of small-scale cannabis farms with aquatic and terrestrial biodiversity. Conservation Science and Practice, 4(2), e602.

Parks, S.A. & Abatzoglou, J.T. (2020). Warmer and drier fire seasons contribute to increases in area burned at high severity in western US forests from 1985 to 2017. Geophysical Research Letters, 47, e2020GL089858.

Parks, S. A., Guiterman, C. H., Margolis, E. Q., Lonergan, M., Whitman, E., Abatzoglou, J. T., Falk, D. A., Johnston, J. D., Daniels, L. D., Lafon, C. W., Loehman, R. A., Kipfmueller, K. F., Naficy, C. E., Parisien, M.-A., Portier, J., Stambaugh, M. C., Williams, A. P., Wion, A. P., & Yocom, L. L. (2025). A fire deficit persists across diverse North American forests despite recent increases in area burned. Nature Communications, 16, Article 1493. https://doi.org/10.1038/s41467-025-56333-8

Patterson, N. K., Lane, B. A., Sandoval-Solis, S., Persad, G. G., & Ortiz-Partida, J. P. (2022). Projected effects of temperature and precipitation variability change on streamflow patterns using a functional flows approach. Earth's Future, 10(7), e2021EF002631.

Patton, J. R., Williams, T. B., Anderson, J. K., & Leroy, T. H. (2017). Tectonic land level changes and their contribution to sea-level rise, Humboldt Bay region, Northern California: 2017 final report. Cascadia GeoSciences. https://digitalcommons.humboldt.edu/hsuslri_local/23/

Patton, J.R, Williams, T.B, Anderson, J.K, Hemphill-Haley, M., Burgette, R.J, Weldon, R., McPherson, R.C. & Leroy, T.H. (2023). 20th to 21st Century Relative Sea and Land Level Changes in Northern California: Tectonic Land Level Changes and their Contribution to Sea-Level Rise, Humboldt Bay Region, Northern California. tektonika, 1(1), 1–17. https://doi.org/10.55575/tektonika2023.1.1.6

Patton, Jason R., Patrick J. Lynett, Nicholas A. Graehl, Doug Bausch, Ashley Hoke, Troy Schmidt, Todd Becker, Willington Renteria. California Geological Survey. 2026. Influence of Future Sea-Level Rise on Tsunami Hazards in California. California's Fifth Climate Change Assessment, California Natural Resources Agency. Publication number: CNRA-CCC5A-2026-XXX.

Peltier, D. M. P., Carbone, M. S., Enright, M., Marshall, M. C., Trowbridge, A. M., LeMoine, J., Koch, G., & Richardson, A. D. (2023). Old reserves and ancient buds fuel regrowth of coast redwood after catastrophic fire. Nature Plants, 9, 1978–1985. https://doi.org/10.1038/s41477-023-01581-z

Petersen-Rockney, M. (2022). Social risk perceptions of climate change: A case study of farmers and agricultural advisors in northern California. Global Environmental Change, 75, 102557. https://doi.org/10.1016/j.gloenvcha.2022.102557

Petranka, J.W. (1998). Salamanders of the United States and Canada. Smithsonian Institution Press, Washington, D.C.

Pierce, D. W., Cayan, D. R., Feldman, D. R., & Risser, M. D. (2023). Future increases in North American extreme precipitation in CMIP6 downscaled with LOCA. Journal of Hydrometeorology, 24(5), 951–975.

Pierce, E. and Schnetzer, A. (2023) Microcystin Concentrations, Partitioning, and Structural Composition during Active Growth and Decline: A Laboratory Study. Toxins 15(12):684. https://doi.org/10.3390/toxins15120684

Pierotti, R. & Wildcat, D. (2000). Traditional Ecological Knowledge: the third alternative (commentary). Ecological Applications, 10(5), 1333-1340.

Pilliod, D.S., & Peterson, C.R. (2001). Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. Ecosystems, 4(4), 322-333.

Pinstrup-Andersen, P. (2018). Is it time to take vertical indoor farming seriously? Global Food Security, 17, 233–235.

Pister, E.P. (2001). Wilderness fish stocking: history and perspective. Ecosystems, 4(4), 279-286.

Pollock, M. M., Heim, M., & Naiman, R. J. (2003). Hydrologic and geomorphic effects of beaver dams and their influence on fishes. Pages 213–234 in Gregory, S.V., Boyer, K. & Gurnell, A., editors. The ecology and management of wood in world rivers. American Fisheries Society, Bethesda, Maryland.

Power, M. E., Chandra, S., Gleick, P., & Dietrich, W. E. (2024). Anticipating responses to climate change and planning for resilience in California's freshwater ecosystems. Proceedings of the National Academy of Sciences of the United States of America. Advance online publication. https://doi.org/10.1073/pnas.2310075121

Preisler, H.K., Grulke, N.E., Heath, Z. & Smith, S.L. (2017). Analysis and out-year forecast of beetle, borer, and drought-induced tree mortality in California. Forest Ecology and Management, 399, 166–178.

Prigge, J. L., Bisangwa, E., Richwine, J. D., Sykes, V. R., Ivey, J. L. Z., & Keyser, P. D. (2024). Native forbs provide pollinator resources and improve forage nutrient composition, animal performance, and pasture productivity. Agronomy, 14(10), 2184. https://doi.org/10.3390/agronomy14102184

Priestley, M. D. K., & Catto, J. L. (2022). Improved representation of extratropical cyclone structure in HighResMIP models. Geophysical Research Letters, 49, e2021GL096708. https://doi.org/10.1029/2021GL096708

Prugh, L. R., Deguines, N., Grinath, J. B., Suding, K. N., Bean, W. T., Stafford, R., & Brashares, J. S. (2018). Ecological winners and losers of extreme drought in California. Nature Climate Change, 8, 819–827. https://doi.org/10.1038/s41558-018-0255-1

PSE Healthy Energy. (2021). Preventing wildfires with power outages: The growing impacts of California's Public Safety Power Shutoffs. https://www.psehealthyenergy.org/our-work/publications/archive/psps-impacts/

Rachowicz, L.J., Knapp, R.A., Morgan, J.A., Stice, M.J., Vredenburg, V.T., Parker, J.M. & Briggs, C.J. (2006). Emerging infectious disease as a proximate cause of amphibian mass mortality. Ecology, 87(7), 1671-1683.

Ratajczak, Z., Nippert, J. B., & Collins, S. L. (2012). Woody species decrease diversity across North American grasslands and savannas. Ecology, 93(4), 697–703. https://doi.org/10.1890/11-1199.1

Ratcliff, F., Rao, D., Barry, S., Dewees, S., Macaulay, L., Larsen, R., Shapero, M., Peterson, R., Moritz, M., & Forero, L. (2022). Cattle grazing reduces fuel and leads to more manageable fire behavior. California Agriculture, 76(2), 60–69. https://doi.org/10.3733/ca.2022a0011

Ray, S. J. (2020). A field guide to climate anxiety: How to keep your cool on a warming planet. University of California Press.

Raymond, C.L., Peterson, D.L., 2005. Fuel treatments alter the effects of wildfire in a mixed-evergreen forest, Oregon, USA. Can. J. For. Res. 35, 2981–2995. https://doi.org/10.1139/x05-206

Redheaded Blackbelt. (2022, December 27). Winter storm leaves thousands of Humboldt and Mendocino PG&E customers in the dark. https://kymkemp.com/2022/12/27/winter-storm-leaves-thousands-of-humboldt-and-mendocino-pge-customers-in-the-dark/

Reed, K. (2022, Fall). Creating a PolyTEK. Humboldt: The Magazine of Cal Poly Humboldt. https://now.humboldt.edu/magazine/fall2022/2-2_creating-polytek.html

Reed, K. (2023). Settler cannabis: From gold rush to green rush in Indigenous Northern California. University of Washington Press.

Reeves, M., Moreno, A., Bagne, K., & Running, S. W. (2014). Estimating the effects of climate change on net primary production of US rangelands. Climate Change, 126(3-4), 429-442.

Reguero, B. G., Bresch, D. N., Beck, M. W., Calil, J., & Meliane, I. (2020). Financing coastal resilience by combining nature-based risk reduction with insurance. Ecological Economics, 169, 106487. https://doi.org/10.1016/j.ecolecon.2019.106487

Reilly, M.J., McCord, M.G., Brandt, S.M., Linowksi, K.P., Butz, R.J. & Jules, E.S. (2020). Repeated, high-severity wildfire catalyzes invasion of non-native plant species in forests of the Klamath Mountains, northern California, USA. Biological Invasions, 22, 1821–1828.

Reyes, A. (2025). Truth demands: A memoir of murder, oil wars, and the rise of climate justice. North Atlantic Books.

Richmond, L., Anderson, J., Archibald, J., Brown, A., Canter, A., Cashman, E., Chang, J., De Smet, C., Everett, Y., Graham, J., Herrera, N., Jansen, B., Kalt, J., Laird, A., Landry, L., Lipe, D., Ludka, B., Jarrín, J.R.M., Marlow, J., Orth-Gordinier, K., Patton, J.R., Shaughnessy, F., Suarez, A., Toyofuku, A., de Dios, A.R.V., & Wilkinson, H. (2023). Transformative Sea-Level Rise Research and Planning: Establishing a University, Tribal, and Community Partnership for a Resilient California North Coast. Humboldt Journal of Social Relations (45), p. 67-93. https://www.jstor.org/stable/48725120

Risling Baldy, Cutcha, and Carrie Tully. 2019. "Working for and toward Land Return of Goukdi'n (Jacoby Creek Forest)." https://www.cutcharislingbaldy.com/uploads/2/8/7/3/2873888/working_for_and_toward_land_return_of_goukdi%E2%80%99n___jacoby_creek_forest___1_.pdf

Robinson, W., Kerhoulas, L.P., Sherriff, R.L., Roletti, G. & van Mantgem, P.J. (2023). Drought survival strategies differ between coastal and montane conifers in northern California. Ecosphere, 14, e4480.

Roche, L. (2016). Adaptive rangeland decision-making and coping with drought. Sustainability, 8(12), 1334. https://doi.org/10.3390/su8121334

Rockweit, J.T., Franklin, A.B. & Carlson, P.C. (2017). Differential impacts of wildfire on the population dynamics of an old-forest species. Ecology, 98, 1574–1582.

Rogers-Bennett, L., & Catton, C. A. (2019). Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens. Scientific Reports, 9, 15050. https://doi.org/10.1038/s41598-019-51114-y

Rojanasakul, M. & Flavelle, C. (2024) Find Out How Your Home Insurance Costs Compare in Our Interactive Map. New York Times. https://www.nytimes.com/interactive/2024/07/08/climate/home-insurance-cost-county.html

Rosenstock, S. S., Ballard, W. B., & Devos, J. C. (1999). Viewpoint: Benefits and impacts of wildlife water developments. Journal of Range Management, 52(4), 302–311. https://doi.org/10.2307/4003538

Round Valley Indian Tribes. (2024). Tribal water system governance ordinances and management protocols. Round Valley Indian Tribes Utility Board.

Round Valley Indian Tribes. (n.d.). Water Association. https://www.rvit.org/program-directory/water-association

Rowe, K. C., Rowe, K. M. C., Tingley, M. W., Koo, M. S., Patton, J. L., Conroy, C. J., Perrine, J. D., Beissinger, S. R., & Moritz, C. (2015). Spatially heterogeneous impact of climate change on small mammals of montane California. Proceedings of the Royal Society B: Biological Sciences, 282(1799), 20141857. https://doi.org/10.1098/rspb.2014.1857

Royston, S., Watson, C.S., Legrésy, B., King, M.A., Church, J.A. & Bos, M.S. (2018). Sea-Level Trend Uncertainty With Pacific Climatic Variability and Temporally-Correlated Noise. Journal of Geophysical Research: Oceans, 123(3). https://doi.org/10.1002/2017JC013655

Rural Community Assistance Corporation. (2024). Environmental Services. https://www.rcac.org/

Rural County Representatives of California. (2022, September 26). Rural County Representatives of California says PG&E reports over 1,400 fast trip power outages so far in 2022. Sierra Sun Times. https://www.goldrushcam.com/sierrasuntimes/index.php/news/local-news/41035-rural-county-representatives-of-california-says-pg-e-reports-over-1-400-fast-trip-power-outages-so-far-in-2022-fast-trip-safety-settings-deenergize-circuits-when-an-object-comes-into-contact-with-a-powerline-or-there-is-an-equipment-issue

Ryan, M.E., Palen, W.J., Adams, M.J. & Rochefort, R.M. (2014). Amphibians in the climate vise: loss and restoration of resilience of montane wetland ecosystems in the western US. Frontiers in Ecology and the Environment, 12(4), 232-240.

Roddam, M., & Ward, D. M. (2017). Life-history differences of juvenile Chinook salmon Oncorhynchus tshawytscha across rearing locations in the Shasta River, California. Ecology of Freshwater Fish, 26(1), 150-159.

Saitone, T. L., Forero, L. C., Nader, G. A., & Forero, L. E. (2016). Calf and yearling prices in California and the western United States. California Agriculture, 70(4), 179–186. https://doi.org/10.3733/ca.2016a0019

Saler, J. L., & Jules, E. S. (2021). Woody vegetation encroachment: a driver of herbaceous species diversity loss in a coastal fen. Madroño, 68(1), 9–19. https://doi.org/10.3120/0024-9637-68.1.9

Samuelson, H., Baniassadi, A., Lin, A., Izaga González, P., Brawley, T., & Narula, T. (2020). Housing as a critical determinant of heat vulnerability and health. Science of The Total Environment, 720, 137296. https://doi.org/10.1016/j.scitotenv.2020.137296

Sanchez, G. M., Lawrimore, M. A., Petrasova, A., Vogler, J. B., Collins, E. L., Petras, V., Harper, T., Butzler, E. J., & Meentemeyer, R. K. (2024). The safe development paradox of the United States regulatory floodplain. PLoS ONE, 19(12), e0311718.

Sandel, B., & Dangremond, E.M. (2012). Climate change and the invasion of California by grasses. Glob Change Biol, 18: 277-289. https://doi.org/10.1111/j.1365-2486.2011.02480.x

Sanford, E., Sones, J. L., García-Reyes, M., Goddard, J. H. R., & Largier, J. L. (2019). Widespread shifts in the coastal biota of northern California during the 2014–2016 marine heatwaves. Scientific Reports, 9, Article 4216. https://doi.org/10.1038/s41598-019-40784-3

Santora, J. A., Mantua, N. J., Schroeder, I. D., Field, J. C., Hazen, E. L., Bograd, S. J., Sydeman, W.J., Wells, B.K., Calambokidis, J., Saez, L., Lawson, D. & Forney, K. A. (2020). Habitat compression and ecosystem shifts as potential links between marine heatwave and record whale entanglements. Nature communications, 11(1), 536.

Save California Salmon. (n.d.). Tribes along the rivers. Save California Salmon. Retrieved September 15, 2025, from https://www.californiasalmon.org/copy-of-learn-about-our-rivers

Sawyer, J. O., Keeler-Wolf, T., & Evens, J. M. (2009). A Manual of California Vegetation, 2nd edition. California Native Plant Society. 1300 pp.

Sawyer, J. O., Thornburgh, D.A. (1977). Montane and subalpine vegetation of the Klamath Mountains. Pages 699-732 in M.G. Barbour and J. Majors, editors. Terrestrial Vegetation of California. John Wiley and Sons, New York, USA.

SB 310: Prescribed fire: civil liability: cultural burns, Pub. L. No. SB310 (2024).

Schatz Energy Research Center. (2024, August 6). DOE funding enables a transformative energy solution for rural Northern California tribes. Cal Poly Humboldt. https://schatzcenter.org/2024/08/teras/

Schickedanz, H., Jennings, L., & Schickedanz, A. (2022). The association between adverse childhood experiences and positive dementia screen in American older adults. *Journal of General Internal Medicine, 37,* 1406–1412. https://doi.org/10.1007/s11606-021-07192-8

Schimelpfenig, G., Smith, D., Dilli, C., & Butsic, V. (2021). Cannabis H2O: Water use & sustainability in cultivation. U.C. Berkeley Cannabis Research Center & New Frontier Data.

Schriver, M., Sherriff, R. L., Varner, J. M., Quinn-Davidson, L., & Valachovic, Y. (2018). Age and stand structure of oak woodlands along a gradient of conifer encroachment in northwestern California. Ecosphere, 9(10), e02446. https://doi.org/https://doi.org/10.1002/ecs2.2446

Schroeder, I. D., Santora, J. A., Mantua, N., Field, J. C., Wells, B. K., Hazen, E. L., Jacox, M. & Bograd, S. J. (2022). Habitat compression indices for monitoring ocean conditions and ecosystem impacts within coastal upwelling systems. Ecological Indicators, 144, 109520.

Sherriff, R. L., Garwood, J. & Kauffmann, M. (2022). Climate. In Kauffmann, M. & Garwood, J. (Eds.), The Klamath Mountains: A Natural History (pp. 98-117). Backcountry Press.

Shi, L., Chu, E., Anguelovski, I., Aylett, A., Debats, J., Goh, K., Schenk, T., Seto, K. C., Dodman, D., Roberts, D., Roberts, J. T., & VanDeveer, S. D. (2016). Roadmap towards justice in urban climate adaptation research. Nature Climate Change, 6(2), 131–137. https://doi.org/10.1038/nclimate2841

Shi, B., Xu, W., Zhu, Y., Wang, C., Loik, M. E., & Sun, W. (2019). Heterogeneity of grassland soil respiration: Antagonistic effects of grazing and nitrogen addition. Agricultural and Forest Meteorology, 268, 215–223. https://doi.org/10.1016/j.agrformet.2019.01.028

Siegel, K. J., Macaulay, L., Shapero, M., Becchetti, T., Larson, S., Mashiri, F. E., Waks, L., Larsen, L., & Butsic, V. (2022). Impacts of livestock grazing on the probability of burning in wildfires vary by region and vegetation type in California. Journal of Environmental Management, 322, 116092. https://doi.org/10.1016/j.jenvman.2022.116092

Sillett, S.C., Van Pelt, R., Carroll, A.L., Campbell-Spickler, J. & Antoine, M.E. (2020). Aboveground biomass dynamics and growth efficiency of Sequoia sempervirens forests. Forest Ecology and Management, 458, 117740.

Silverberg, D. (2025, February 21). How climate change can hurt cannabis crops. Cannabis Business Times. https://www.cannabisbusinesstimes.com/climate-environment-control/news/15737975/how-climate-change-can-hurt-cannabis-crops-bottom-lines

Sims, H. (2018, February 28). Yurok Tribe acquires thousands of acres of Blue Creek watershed from Green Diamond; will manage land to restore ecosystem. Lost Coast Outpost. https://lostcoastoutpost.com/2018/feb/28/yurok-tribe-acquires-thousands-acres-blue-creek-wa/

Siskiyou County Department of Agriculture. (2023). Siskiyou County 2022 Annual Crop and Livestock Report. https://www.co.siskiyou.ca.us/sites/default/files/fileattachments/agriculture/page/4581/agd_20231228_2022_crop_report.pdf

Six Rivers National Forest. (1990-2024). Forest road decommissioning and storm-proofing program: Cumulative watershed improvements. U.S. Forest Service.

Soland, K. R., Kerhoulas, L. P., Kerhoulas, N. J., & Teraoka, J. R. (2021). Second-growth redwood forest responses to restoration treatments. Forest Ecology and Management 496, 119370.

Solar Power World. (2017, April 20). JLM Energy and Hoopa Valley Tribe install solar-plus-storage system to offset diesel generation. Solar Power World. https://www.solarpowerworldonline.com/2017/04/jlm-energy-hoopa-valley-tribe-solar/

Solazzi, M. F., Nickelson, T. E., Johnson, S. L., & Rodgers, J. D. (2000). Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Canadian Journal of Fisheries and Aquatic Sciences, 57(5), 906-914.

Solomon, G. M., Stanton, B., Ryan, S., Little, A., Carpenter, C., & Paulukonis, S. (2022). Notes from the field: Harmful algal bloom affecting private drinking water intakes—Clear Lake, California, June–November 2021. MMWR Morbidity and Mortality Weekly Report, 71(41), 1306–1307. https://doi.org/10.15585/mmwr.mm7141a3

Sorel, M. (2022). Informing salmon conservation with population models that account for individual heterogeneity. University of Washington.

Stapleton, J. J., & Orloff, S.B. (2017). Dyer's Woad. Pest Notes. Publication 74175, ANR Publications, Oakland, CA. http://ipm.ucanr.edu/PMG/PESTNOTES/pn17475.html

Stephens, S.L., Kane, J.M. & Stuart, J.D. (2018). North Coast Bioregion. In: Fire in California's Ecosystems (eds. van Wagtendonk, J. & Sugihara, N.). University of California Press, Berkeley, California, pp. 146–169.

Stephens, J. L., Gillespie, C. R., & Alexander, J. D. (2020). Restoration treatments reduce threats to oak ecosystems and provide immediate subtle benefits for oak-associated birds. Restoration Ecology, 29(1), 1–11. https://doi.org/10.1111/rec.13298

Stromberg, M. R., Corbin, J. D., & D'Antonio, C. M. (Eds.). (2007). California Grasslands Ecology and Management. University of California Press.

Sturrock, A. M., Carlson, S. M., Wikert, J. D., Heyne, T., Nusslé, S., Merz, J. E., ... & Johnson, R. C. (2020). Unnatural selection of salmon life histories in a modified riverscape. Global Change Biology, 26(3), 1235-1247.

Sullivan, R. M., A. Laird, B. Powell, and J. K. Anderson. 2022. Sea level rise vulnerability assessment for State wildlife areas surrounding Humboldt Bay, northern California. California Fish and Wildlife Journal 108:e24, doi.org/10.51492/cfwj.108.24

Swain, D. L., Langenbrunner, B., Neelin, J. D., & Hall, A. (2018). Increasing precipitation volatility in twenty-first-century California. Nature Climate Change, 8(5), 427–433. https://doi.org/10.1038/s41558-018-0140-y

Swain, D. L. (2021). A shorter, sharper rainy season amplifies California wildfire risk. Geophysical Research Letters, 48(5), 1–5. https://doi.org/10.1029/2021GL092843

Swain, D.L., Abatzoglou, J.T., Albano, C.M., Brunner, M.I., Diffenbaugh, N.S., Kolden, C., Prein, A.F., Singh, D., Skinner, C.B., Swetnam, T.W. & Touma, D. (2025). Increasing hydroclimatic whiplash can amplify wildfire risk in a warming climate. Global Change Biology, 31(2), https://doi.org/10.1111/gcb.70075

Sweet, W. V., Hamlington, B. D., Kopp, R. E., Weaver, C. P., Barnard, P. L., Bekaert, D., Brooks, W., Craghan, M., Dusek, G., Frederikse, T., Garner, G., Genz, A. S., Krasting, J. P., Larour, E., Marcy, D., Marra, J. J., Obeysekera, J., Osler, M., Pendleton, M., & Roman, D. (2022). Global and regional sea level rise scenarios for the United States: Updated mean projections and extreme water level probabilities along U.S. coastlines (NOAA Technical Report NOS 01). National Oceanic and Atmospheric Administration, National Ocean Service. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf

Swieca, K., Sponaugle, S., Schmid, M. S., Ivory, J., & Cowen, R. K. (2025). Oceanographic and trophodynamic underpinnings of anchovy success in the northern California Current. Frontiers in Marine Science, 12, 1558793.

Sydeman, W. J., García-Reyes, M., Schoeman, D. S., Rykaczewski, R. R., Thompson, S. A., Black, B. A., & Bograd, S. J. (2014). Climate change and wind intensification in coastal upwelling ecosystems. Science, 345(6192), 77-80.

Tang, J., Nolan, M., Antonio, C. D., Cooper, S. D., & Stratton, L. (2023). Reinvasion of restored California vernal pools reveals the importance of long-term restoration planning. Restoration Ecology, 31(7), 1–12. https://doi.org/10.1111/rec.13991

Taylor, A.H., Harris, L.B. & Drury, S.A. (2021). Drivers of fire severity shift as landscapes transition to an active fire regime, Klamath Mountains, USA. Ecosphere, 12, e03734.

Taylor, A., Dronova, I., Sigona, A., & Kelly, M. (2024). Using Sentinel-2 Imagery to Measure Spatiotemporal Changes and Recovery across Three Adjacent Grasslands with Different Fire Histories. Remote Sensing, 16, 2232. https://doi.org/10.3390/rs16122232

Taylor, A., Sigona, A., & Kelly, M. (2024). Centering Amah Mutsun voices in the analysis of a culturally important, fire-managed coastal grassland. Ecological Applications, 34(6), e3014. https://doi.org/10.1002/eap.3014

Technical Advisory Board. (2024). Meeting notes from North Coast 5th Climate Assessment technical advisory board meetings. California Natural Resources Agency. [Unpublished meeting notes]

Temin, D. M. (2023). Remapping sovereignty: Decolonization and self-determination in North American Indigenous political thought. University of Chicago Press.

Termeer, C., Dewulf, A., Lieshout, M., 2010. Disentangling scale approaches in governance research: comparing monocentric, multilevel, and adaptive governance. Ecol. Soc. 15 (4), 29. http://www.ecologyandsociety.org/vol15/iss4/art29/.

Thibaut, J. W., & Walker, L. (1975). *Procedural justice: A psychological analysis.* Lawrence Erlbaum Associates.

Thompson, L. (1916). To the American Indian: Reminiscences of a Yurok woman. Heyday Books.

Thompson, A. R., Swalethorp, R., Alksne, M., Santora, J. A., Hazen, E. L., Leising, A., ... & Wells, B. (2024). State of the California Current Ecosystem report in 2022: a tale of two La Niñas. Frontiers in Marine Science, 11, 1294011.

Tiberti, R., Buchaca, T., Boiano, D., Knapp, R.A., Pou Rovira, Q., Tavecchia, G., Ventura, M. & Tenan, S. (2021). Alien fish eradication from high mountain lakes by multiple removal methods: Estimating residual abundance and eradication probability in open populations. Journal of Applied Ecology, 58(5), 1055-1068.

Times-Standard. (2022, October 17). Humboldt County plans to use living shoreline to mitigate sea level rise between Brainard, Bracut. Republished by Humboldt Waterkeeper. https://humboldtwaterkeeper.org/climate-change-impacts-sea-level-rise/1619-humboldt-county-plans-to-use-living-shoreline-to-mitigate-sea-level-rise-between-brainard-bracut-2

Times-Standard. (2024, November 21). Eel River expected to flood Thursday and Friday. Times-Standard. https://www.times-standard.com/2024/11/21/eel-river-expected-to-flood-thursday-and-friday/

To, P., Eboreime, E., & Agyapong, V. I. O. (2021). The impact of wildfires on mental health: A scoping review. Behavioral Sciences, 11(9), 126. https://doi.org/10.3390/bs11090126

Tortorelli, C. M., Krawchuck, M. A., & Kerns, B. K. (2020). Expanding the invasion footprint: Ventenata dubia and relationships to wildfire, environment, and plant communities in the Blue Mountains of the Inland Northwest, USA. Applied Vegetation Science, 23, https://doi.org/10.1111/avsc.12511.

Trainer, V. L., Kudela, R. M., Hunter, M. V., Adams, N. G., & McCabe, R. M. (2020). Climate extreme seeds a new domoic acid hotspot on the US west coast. Frontiers in Climate, 2, 571836.

Trinity County Department of Transportation. (2024). Road maintenance & snow plow policy. Trinity County. https://www.trinitycounty.org/540/Road-Maintenance-Snow-Plow-Policy

Trinity Journal. (2025, January). End of Garrett Road gone. Trinity Journal. https://www.trinityjournal.com/news/local/article_5d93cadc-d2d0-11ef-a480-9f99b3c9b4af.html

Tripp, B. (2020, September 16). Our land was taken, but we still hold the knowledge of how to stop mega-fires. The Guardian. https://www.theguardian.com/commentisfree/2020/sep/16/california-wildfires-cultural-burns-indigenous-people

Trivedi, S., & Srivastava, S. (2023, May 4). 200 and counting: Global financial institutions are exiting coal [Report]. Institute for Energy Economics and Financial Analysis. https://ieefa.org/resources/200-and-counting-global-financial-institutions-are-exiting-coal

U.S. Census Bureau. (2020). 2020 Census demographic and housing characteristics file (DHC), Table P2: Urban and rural. https://data.census.gov/

U.S. Census Bureau. (2023). American Community Survey 5-year estimates subject tables: Table S1701, poverty status in the past 12 months. https://data.census.gov/

U.S. Environmental Protection Agency. (2019). *Exceptional events guidance: Prescribed fire* (Memorandum). https://www.epa.gov/sites/default/files/2019-08/documents/ee_prescribed_fire_final_guidance_-_august_2019.pdf

U.S. Energy Information Administration. (2020). Residential Energy Consumption Survey (RECS). https://www.eia.gov/consumption/residential/

U.S. Chamber of Commerce (2024). Preparing for climate-related catastrophes beats focusing on recovery alone. The Economic Benefits of Investing in Climate Resilience | U.S. Chamber of Commerce.

U.S. Department of Energy. (2024, August 6). DOE announces $2.2 billion to strengthen America's power grid through eight projects across 18 states [Press release]. https://www.energy.gov/articles/doe-announces-22-billion-strengthen-americas-power-grid

U.S. Department of Interior. (2024). During visit to Klamath River, Secretary Haaland announces four tribal water projects.

U.S. Environmental Protection Agency. (2019). Exceptional events guidance: Prescribed fire (Memorandum). https://www.epa.gov/sites/default/files/2019-08/documents/ee_prescribed_fire_final_guidance_-_august_2019.pdf

U.S. Geological Survey. (2024). Water quality monitoring following Klamath River dam removal. USGS Water Resources.

U.S. Government Accountability Office. (2024, December). Federal grants: Agencies should enhance efforts to identify and assist applicants with limited resources (GAO-25-107674). https://www.gao.gov/assets/gao-25-107674.pdf

U.S. Senate Committee on the Budget. (2024, December 18). New data reveal climate change–driven insurance crisis is spreading. https://www.budget.senate.gov/chairman/newsroom/press/new-data-reveal-climate-change-driven-insurance-crisis-is-spreading

U.S. Senate Committee on the Budget (2024) Senate Budget Committee Staff Report. Next to Fall: the Climate-Driven Insurance Crisis is Here-and Getting Worse https://www.budget.senate.gov/imo/media/doc/next_to_fall.pdf

U.S. Forest Service. (n.d.). Watershed and fisheries ecological restoration on the Six Rivers National Forest. Six Rivers National Forest. https://www.fs.usda.gov/detailfull/srnf/home/?cid=STELPRDB5445190

USDA National Ag Statistics Service. (2025). Land Values 2025 Summary. ISSN: 1949-1867. https://downloads.usda.library.cornell.edu/usda-esmis/files/pn89d6567/2n49w148w/m039n441h/land0825.pdf

Vander Vorste, R., Obedzinski, M., Nossaman Pierce, S., Carlson, S. M., & Grantham, T. E. (2020). Refuges and ecological traps: Extreme drought threatens persistence of an endangered fish in intermittent streams. Global Change Biology, 26(7), 3834-3845.

van Leeuwen, C., Sgubin, G., Bois, B., Ollat, N., Swingedouw, D., Zito, S., & Gambetta, G. A. (2024). Climate change impacts and adaptations of wine production. Nature Reviews Earth & Environment, 5, 258–275. https://doi.org/10.1038/s43017-024-00521-5

van Mantgem, P.J., Lalemand, L.B., Keifer, M., Kane, J.M., 2016. Duration of fuels reduction following prescribed fire in coniferous forests of U.S. national parks in California and the Colorado Plateau. Forest Ecology and Management 379, 265–272. https://doi.org/10.1016/j.foreco.2016.07.028

Van Pelt, R., Sillett, S.C., Kruse, W.A., Freund, J.A., Kramer, R.D., 2016. Emergent crowns and light-use complementarity lead to global maximum biomass and leaf area in Sequoia sempervirens forests. Forest Ecology and Management 375, 279-308, https://doi.org/10.1016/j.foreco.2016.05.018.

van Wagtendonk, J.W., Sugihara, N.G., Stephens, S.L., Thode, A.E., Shaffer, K.E. & Fites-Kaufman, J.A. (Eds.), 2018. Fire in California's Ecosystems, Second. ed. University of California Press, Berkeley, California, USA.

Varfalameyeva, K., Solís, P., Phillips, L., Charley, E., Hondula, D. & Kear, M. (2021). Heat Mitigation Solutions Guide for Mobile Homes. Knowledge Exchange for Resilience Solutions Series. Tempe: Arizona State University. https://keep.lib.asu.edu/items/162992

Veissier, I., Van, E., Palme, R., Moons, C. P. H., Ampe, B., Sonck, B., Andanson, S., & Tuyttens, F. A.M. (2018). Heat stress in cows at pasture and benefit of shade in a temperate climate region. International Journal of Biometerology, 62, 585–595. https://doi.org/10.1007/s00484-017-1468-0

Vernon, M., Sherriff, R.L., van Mantgem, P., & Kane, J. (2018). Thinning, tree growth, and resistance to multi-year drought in a mixed-conifer forest of northern California. Forest Ecology and Management 422, https://doi.org/10.1016/j.foreco.2018.03.043

Vitousek, S., Vos, K., Splinter, K., O'Neill, A.C., Foxgrover, A.C., Hayden, M.K., Barnard, P.L., & Erikson, L.H. (2023). Projections of shoreline change for California due to 21st century sea-level rise. U.S. Geological Survey data release, https://doi.org/10.5066/P9CJMB2H

Walker, W. E., Haasnoot, M., & Kwakkel, J. H. (2013). Adapt or perish: A review of planning approaches for adaptation under deep uncertainty. *Sustainability, 5*(3), 955–979. https://doi.org/10.3390/su5030955

Wang, B., Eum, K.-D., Kazemiparkouhi, F., Li, C., Manjourides, J., Pavlu, V., & Suh, H. (2020). The impact of long-term PM2.5 exposure on specific causes of death: Exposure-response curves and effect modification among 53 million U.S. Medicare beneficiaries. Environmental Health, 19, Article 20. https://doi.org/10.1186/s12940-020-00575-0

Wang, J., Church, J.A., Zhang, X. & Chen, X. (2021). Reconciling global mean and regional sea level change in projections and observations. Nat Commun 12, 990. https://doi.org/10.1038/s41467-021-21265-6

Warren, G. S. (2023). The chronic growing problem: Environmental and social justice concerns with indoor cannabis grows. Cardozo Law Review, 45, 1901. https://cardozolawreview.com/the-chronic-grow%cb%99ing-problem-environmental-and-social-justice-concerns-with-indoor-cannabis-grows/

Wartenberg, A. C., Holden, P. A., Bodwitch, H., Parker-Shames, P., Novotny, T., Harmon, T. C., Hart, S. C., Beutel, M., Gilmore, M., Hoh, E., & Butsic, V. (2021). Cannabis and the environment: What science tells us and what we still need to know. Environmental Science & Technology Letters, 8(2), 98–107. https://doi.org/10.1021/acs.estlett.0c00844

WaterWorld. (2021, October 13). Fort Bragg, CA to launch desalination system [Press release]. https://www.waterworld.com/drinking-water/infrastructure-funding/press-release/14212100/fort-bragg-ca-to-launch-desalination-system

Weinreb, E. (2021, August 5). 'Witnessing the Collapse': Officials warn of cascading crises facing Pacific salmon. North Coast Journal. https://www.northcoastjournal.com/news/witnessing-the-collapse-21162729

Weisberg, D. (2025). Effects of natural disasters on intimate partner violence. Domestic Violence Report, 30(4), 57–72.

Welsh Jr, H.H. (1990). Relictual amphibians and old-growth forests. Conservation Biology, 4(3), 309-319.

Welsh Jr., H., K. Pope, & Boiano, D. (2006). Sub-alpine amphibian distributions related to species palatability to non-native salmonids in the Klamath Mountains of northern California, Diversity and Distributions, 12, 298-309.

Welsh Jr., H.H. & G.L. Hodgson. (2013). Woodland salamanders as metrics of forest ecosystem recovery: a case study from California's redwoods. Ecosphere, 4, 1-25.

Westerling, A.L. (2016). Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. Philosophical Transactions of the Royal Society B: Biological Sciences, 371, 20150178.

Whyte, K. (2017). Indigenous climate change studies: Indigenizing futures, decolonizing the Anthropocene. English Language Notes 55, no. 1 (2017): 153-162. https://kylewhyte.marcom.cal.msu.edu/wpcontent/uploads/sites/12/2018/07/IndigenousClimateChangeStudies.pdf

Whyte, K. P., Talley, J. L., & Gibson, J. D. (2019). Indigenous mobility traditions, colonialism, and the Anthropocene. Mobilities, 14(3), 319–335. https://doi.org/10.1080/17450101.2019.1611015

Wild Rivers Outpost. (2021, May 18). Crescent City Harbor's solar panels beginning to pay off, commissioner, consultant says. https://wildrivers.lostcoastoutpost.com/2021/may/18/crescent-city-harbors-solar-panels-beginning-pay-c/

Wilder, B.A. (2020). Runoff prediction and ecohydrological recovery for small watersheds after fire southern California. Master's thesis. San Diego, CA: San Diego State University.

Williams-Jara, M., G., Espinoza-Tenorio, A., Monzón-Alvarado, C., Posada-Vanegas, G., & Infante-Mata, D. (2022). Fires in coastal wetlands: a review of research trends and management opportunities. Coastal Wetlands, 42, 56.

Wilson, R., Lile, D., Drake, D., Orloff, S., Lancaster, D., George, H., Delmas, R., & Bower, A. (2006). Dryland pastures: Establishment and management in the intermountain region of Northern California (Publication 8163). University of California Agriculture and Natural Resources. https://anrcatalog.ucanr.edu/pdf/8163.pdf

Wilson, B., Tate, E., & Emrich, C. T. (2021). Flood recovery outcomes and disaster assistance barriers for vulnerable populations. Frontiers in Water, 3. https://doi.org/10.3389/frwa.2021.752307

Winnacott, B. M. (2021). Response of coastal ichthyoplankton assemblages off northern California to seasonal oceanographic and climate variability [Master's thesis, Cal Poly Humboldt]. Digital Commons. https://digitalcommons.humboldt.edu/etd/531

Wolff, A. S. (2024). Characterizing the beneficial uses of the Arcata Marsh constructed wetland treatment system and wildlife sanctuary (Master's thesis, Cal Poly Humboldt). Digital Commons. https://digitalcommons.humboldt.edu/etd/793/

Woodmansee, G., Macon, D., Schohr, T., & Roche, L. M. (2021). On-ranch adaptation to California's historic 2012-2016 drought. Rangelands, 43(6), 222–230. https://doi.org/10.1016/j.rala.2021.10.003

Woodmansee, G., & Doran, M. (2025). Diverse rancher insights into the direct-to-consumer marketing of meat products in Northern California: Experiences and lessons learned in a post-COVID consumer environment [Manuscript in preparation].

Woodmansee, G., Macon, D., Schohr, T., & Roche, L. (2025). Building ranch resilience to drought: Management capacity, planning, and adaptive learning during California's 2012–2016 drought. Rangeland Ecology & Management, 98, 63–72. https://doi.org/10.1016/j.rama.2024.07.009

Woodward, B.D., Romme, W.H. & Evangelista, P.H. (2020). Early postfire response of a northern range margin coast redwood forest community. Forest Ecology and Management, 462, 117966.

Woolway, R. I., & Merchant, C. J. (2019). Worldwide alteration of lake mixing regimes in response to climate change. Nature Geoscience, 12(4), 271-276.

Woolway, R. I., Sharma, S., Weyhenmeyer, G. A., Debolskiy, A., Golub, M., Mercado-Bettín, D., ... & Jennings, E. (2021). Phenological shifts in lake stratification under climate change. Nature communications, 12(1), 2318.

Writer, J. H., Hohner, A., Oropeza, J., Schmidt, A., Cawley, K., & Rosario-Ortiz, F. L. (2014). Water treatment implications after the High Park Wildfire, Colorado. Journal American Water Works Association, 106(4), E189-E199.

Wrubel, E., & Parker, V. T. (2018). Local patterns of diversity in California northern coastal scrub. Ecology and Evolution, 8(15), 7250–7260. https://doi.org/10.1002/ece3.4104

Yang, Z., Dominguez, F., Zeng, X., Hu, H., Gupta, H., & Yang, B. (2017). Impact of irrigation over the California Central Valley on regional climate. Journal of Hydrometeorology, 18(5), 1341-1357.

Yarnell, S. M., & Thoms, M. (2022). Enhancing the functionality of environmental flows through an understanding of biophysical processes in the riverine landscape. Frontiers in Environmental Science, 10, 787216.

Yates, D., Galbraith, H., Purkey, D., Huber-Lee, A., Sieber, J., West, J., ... & Joyce, B. (2008). Climate warming, water storage, and Chinook salmon in California's Sacramento Valley. *Climatic Change*, 91(3), 335-350.

Young, D. J. N., Porensky, L. M., Wolf, K. M., Fick, S. E., & Young, T. P. (2015). Burning reveals cryptic plant diversity and promotes coexistence in a California prairie restoration experiment. Ecosphere, 6(5), 81.

Yu, Y., Zou, W., Jerrett, M., & Meng, Y.-Y. (2023). Acute health impact of wildfire-related and conventional PM2.5 in the United States: A narrative review. Environmental Advances, 12, 100179. https://doi.org/10.1016/j.envadv.2022.100179

Zakowski, E., Parker, L. E., Johnson, D., Aguirre, J., & Ostoja, S. M. (2023). California wine grape growers need support to manage risks from wildfire and smoke. California Agriculture, 77(2), 40–48. https://doi.org/10.3733/ca.2023a0006

Zald, H.S.J. & Dunn, C.J. (2018). Severe fire weather and intensive forest management increase fire severity in a multi-ownership landscape. Ecological Applications, 28, 1068–1080.

Zanon, T., Komainda, M., Ammer, S., Isselstein, J., & Gauly, M. (2022). Diverse feed, diverse benefits - the multiple roles of feed diversity at pasture on ruminant livestock production - a review. Journal of Veterinary Science & Animal Husbandry, 10(1), 1–20.

Zhu, K., Song, Y., Lesage, J. C., Luong, J. C., Bartolome, J. W., Chiariello, N. R., Dudney, J., Field, C. B., Hallett, L. M., Hammond, M., Harrison, S. P., Hayes, G. F., Hobbs, R. J., Holl, K. D., Hopkinson, P., Larios, L., Loik, M. E., & Prugh, L. R. (2024). Rapid shifts in grassland communities driven by climate change. Nature Ecology and Evolution, 8, 2252–2264. https://doi.org/10.1038/s41559-024-02552-z



CALIFORNIA'S FIFTH
CLIMATE CHANGE
ASSESSMENT