ECOSYSTEMS OF CALIFORNIA: THREATS & RESPONSES

Supplement for Decision-Making

EDITED BY HAROLD MOONEY AND ERIKA ZAVALETA

ECOSYSTEMS OF CALIFORNIA: THREATS & RESPONSES

Supplement for Decision-Making

EDITED BY HAROLD MOONEY AND ERIKA ZAVALETA

Additional writing and editing provided by

ROB JORDAN
TERRY NAGEL
DEVON RYAN
JENNIFER WITHERSPOON

Graphics edited by Melissa C. Chapin
Design by Studio Em Graphic Design

This compilation of summaries, threats, and responses are presented as a supplement to the book *Ecosystems of California*, printed in 2016 by the University of California Press

© 2016 The Regents of the University of California

For more information about *Ecosystems of California* or the content presented in this supplement, contact editors Harold Mooney or Erika Zavaleta via the Stanford Woods Institute for the Environment at: environment@stanford.edu

Contents

Contributors

JOHN T. ABATZOGLOU
University of Idaho
Moscow, Idaho

DAVID D. ACKERLY
University of California
Berkeley, California

PETER S. ALAGONA
University of California
Santa Barbara, California

EDITH B. ALLEN
University of California
Riverside, California

PETER ALPERT
University of Massachusetts
Amherst, Massachusetts

TANYA ATWATER
University of California
Santa Barbara, California

HELEN BAILEY
University of Maryland
Solomons, Maryland

DENNIS D. BALDOCCHI
University of California
Berkeley, California

MICHAEL G. BARBOUR
University of California
Davis, California

PATRICK L. BARNARD
U.S. Geological Survey
Santa Cruz, California

JAMES BARTOLOME
University of California
Berkeley, California

ERIN BELLER
San Francisco Estuary Institute
Richmond, California

JAYNE BELNAP
U.S. Geological Survey
Moab, Utah

ERIC P. BJORKSTEDT
NOAA Southwest Fisheries
Science Center
Trinidad, California

CAROL A. BLANCHETTE
University of California
Santa Barbara, California

STEVEN J. BOGRAD
NOAA Southwest Fisheries
Science Center
Monterey, California

ABRAHAM BORKER
University of California
Santa Cruz, California

RICHARD D. BRODEUR
NOAA Northwest Fisheries
Science Center
Newport, Oregon

MATTHEW L. BROOKS
U.S. Geological Survey
Oakhurst, California

ANDRZEJ BYTNEROWICZ
USDA Forest Service
Riverside, California

JOHN CALLAWAY
University of San Francisco
San Francisco, California

MARK H. CARR
University of California
Santa Cruz, California

DANIEL R. CAYAN
Scripps Institution of
Oceanography / USGS
La Jolla, California

REBECCA CHAPLIN-KRAMER
Stanford University
Stanford, California

NONA R. CHIARIELLO
Stanford University
Stanford, California

RICARDO CISNEROS
University of California
Merced, California

ELSA E. CLELAND
University of California
San Diego, California

JAMES E. CLOERN
U.S. Geological Survey
Menlo Park, California

BRANDON COLLINS
USDA Forest Service
Davis, California

PAUL W. COLLINS
Santa Barbara Museum of
Natural History
Santa Barbara, California

SCOTT D. COOPER
University of California
Santa Barbara, California

TARA CORNELISSE
Canisius College
Buffalo, New York

DONALD CROLL
University of California
Santa Cruz, California

FRANK W. DAVIS
University of California
Santa Barbara, California

TODD E. DAWSON
University of California
Berkeley, California

MICHAEL L. DEAS
Watercourse Engineering, Inc.
Davis, California

LESLEY A. DEFALCO
U.S. Geological Survey
Henderson, Nevada

MARK W. DENNY
Stanford University
Pacific Grove, California

FLAVIA C. DE OLIVEIRA
University of California
Santa Cruz, California

NOAH DIFFENBAUGH
Stanford University
Stanford, California

LOWELL DILLER
Green Diamond Resources
Korbel, California

CHRISTOPHER R. DOLANC
Mercyhurst University
Erie, Pennsylvania

WALTER G. DUFFY
U.S. Geological Survey
Arcata, California

JENIFER E. DUGAN
University of California
Santa Barbara, California

JOHN M. ENGLE
University of California
Santa Barbara, California

KATHERINE K. ENNIS
University of California
Santa Cruz, California

LA'SHAYE ERVIN
University of Utah
Salt Lake City, Utah

ANDREW B. ESCH
University of California
Santa Barbara, California

TODD C. ESQUE
U.S. Geological Survey
Henderson, Nevada

VALERIE T. EVINER
University of California
Davis, California

KATE FAULKNER
Channel Islands National Park
Ventura, California

MARK FENN
USDA Forest Service
Riverside, California

ROBERT S. FERANEC
New York State Museum
Albany, New York

MARIA JOÃO FERREIRA
DOS SANTOS
Utrecht University
Utrecht, The Netherlands

CHRISTOPHER B. FIELD
Carnegie Institution for Science
Stanford, California

JOHN C. FIELD
NOAA Southwest Fisheries
Science Center
Santa Cruz, California

JOSEPH FLESKES
U.S. Geological Survey
Dixon, California

JENNIFER L. FUNK
Chapman University
Orange, California

PHILIP GARONE
California State University
Turlock, California

ROBERT C. GRAHAM
University of California
Riverside, California

J. LETITIA GRENIER
San Francisco Estuary Institute
Richmond, California

BRENDA J. GREWELL
University of California
Davis, California

EDWARD D. GROSHOLZ
University of California
Davis, California

ROBIN GROSSINGER
San Francisco Estuary Institute
Richmond, California

KACEY HADICK
Far Western Anthropological
Research Group
Davis, California

ELIZABETH A. HADLY
Stanford University
Stanford, California

NADIA HAMEY
Hamey Woods
Santa Cruz, California

SUSAN HARRISON
University of California
Davis, California

ELLIOTT L. HAZEN
NOAA Southwest Fisheries
Science Center
Monterey, California

BRENT HELM
DBA Helm Biological Consulting
Sheridan, California

BRIAN HELMUTH
Northeastern University
Boston, Massachusetts

KATHRYN HIEB
California Department of Fish
and Wildlife
Stockton, California

JAMES T. HOLLIBAUGH
University of Georgia
Athens, Georgia

PETER HOPKINSON
University of California
Berkeley, California

RICHARD E. HOWITT
University of California
Davis, California

DAVID M. HUBBARD
University of California
Santa Barbara, California

LYNN HUNTSINGER
University of California
Berkeley, California

SAM F. IACOBELLIS
University of California
La Jolla, California

G. DARREL JENERETTE
University of California
Riverside, California

TERRY L. JONES
California Polytechnic State University
San Luis Obispo, California

SHARON KAHARA
Humboldt State University
Arcata, California

TODD KEELER-WOLF
California Department of Fish and Wildlife
Sacramento, California

JON E. KEELEY
U.S. Geological Survey
Three Rivers, California

NOAH KNOWLES
U.S. Geological Survey
Menlo Park, California

SARAH J. KUPFERBERG
University of California
Berkeley, California

SUZANNE LANGRIDGE
University of California
Santa Cruz, California

ANDREW W. LEISING
NOAA Southwest Fisheries Science Center
Monterey, California

CHENG LI
Stanford University
Stanford, California

MILTON LOVE
University of California
Santa Barbara, California

JAMES A. MACMAHON
Utah State University
Logan, Utah

LISA MANDLE
Stanford University
Stanford, California

JESSICA MARTER-KENYON
University of California
Santa Barbara, California

SARA M. MAXWELL
Old Dominion University
Norfolk, Virginia

ALEX MCCALLA
University of California
Davis, California

KATHYRN MCEACHERN
U.S. Geological Survey
Ventura, California

JOHN MELACK
University of California
Santa Barbara, California

ADINA M. MERENLENDER
University of California
Berkeley, California

CONSTANCE I. MILLAR
USDA Forest Service
Albany, California

LUKE P. MILLER
Hopkins Marine Station
Pacific Grove, California

HAROLD MOONEY
Stanford University
Stanford, California

PETER MOYLE
University of California
Davis, California

KARINA J. NIELSEN
San Francisco State University
Tiburon, California

MALCOLM NORTH
USDA Forest Service
Davis, California

A. TOBY O’GEEN
University of California
Davis, California

ELISSA M. OLIMPI
University of California
Santa Cruz, California

V. THOMAS PARKER
San Francisco State University
San Francisco, California

JAE R. PASARI
Pacific Collegiate School
Santa Cruz, California

DIANE E. PATAKI
University of Utah
Salt Lake City, Utah

TIM PAULSON
University of California
Santa Barbara, California

STEPHANIE PINCETL
University of California
Los Angeles, California

ROGER POWELL
North Carolina State University
Raleigh, North Carolina

MARY E. POWER
University of California
Berkeley, California

R. BRANDON PRATT
California State University
Bakersfield, California

PAULO QUADRI BARBA
University of California
Santa Cruz, California

ELIZABETH RAUER
Khaled bin Sultan Living Oceans Foundation
Landover, Maryland

ROSEMARY RECORDS
Colorado State University
Fort Collins, Colorado

DANIEL C. REED
University of California
Santa Barbara, California

DANIEL V. RICHARDS
Channel Islands National Park
Ventura, California

LAURA ROGERS-BENNETT
California Department Fish and Wildlife
Bodega Bay, California

PHILIP W. RUNDEL
University of California
Los Angeles, California

HUGH D. SAFFORD
USDA Forest Service
Vallejo, California

S. GEOFFREY SCHLADOW
University of California
Davis, California

BENKTESH SHARMA
University of California
Berkeley, California

M. REBECCA SHAW
Environmental Defense Fund
San Francisco, California

JOSEPH SILVEIRA
U.S. Fish and Wildlife Service
Willows, California

BARRY SINERVO
University of California
Santa Cruz, California

SARAH A. SKIKNE
University of California
Santa Cruz, California

JAYSON R. SMITH
California State Polytechnic University
Pomona, California

DENA SPATZ
University of California
Santa Cruz, California

SHERI SPIEGAL
University of California
Berkeley, California

BRONWEN STANFORD
University of California
Santa Cruz, California

RICK STARR
University of California
San Diego, California

NATHAN L. STEPHENSON
U.S. Geological Survey
Three Rivers, California

WILLIAM STEWART
University of California
Berkeley, California

KATHARINE N. SUDING
University of Colorado
Boulder, Colorado

MARTHA SUTULA
Southern California Coastal Water Research Project
Costa Mesa, California

ROBERT SWIERS
North Carolina State University
Raleigh, North Carolina

BERNIE TERSHY
University of California
Santa Cruz, California

TARA L. E. TRAMMELL
University of Delaware
Newark, Delaware

CLAUDIA M. TYLER
University of California
Santa Barbara, California

SAMUEL VELOZ
Point Blue Conservation Science
Petaluma, California

KERSTIN WASSON
Elkhorn Slough National Estuarine Research Reserve
Royal Oaks, California

TERRELL WATT
Terrell Watt Planning Consultants
San Francisco, California

ROBERT H. WEBB
University of Arizona
Tucson, Arizona

ALISON WHIPPLE
San Francisco Estuary Institute
Richmond, California

AMELIA A. WOLF
University of California
Santa Cruz, California

WALLACE B. WOOLFENDEN
USDA Forest Service, retired
Swall Meadows, California

ROB YORK
University of California
Berkeley, California

ERIKA ZAVALETA
University of California
Santa Cruz, California

The individuals listed were contributors to *Ecosystems of California,* University of California Press, 2016, the book on which this supplement is based.

Introduction

This overview of California's natural ecosystems, the threats they face, and available policy responses was compiled as a supplement to *Ecosystems of California*, a comprehensive guide published by the University of California Press in 2016. The book and this supplement cover the major ecosystems of the state, including marine, freshwater and terrestrial systems, both natural and managed. They look at each system as it was in the past, present, and as projected in the future. In this booklet, we summarize the key findings from each chapter of the book, and add new material on threats that each system faces and proposed policy responses to these threats.

We hope the booklet serves a useful guide to nongovernmental organizations and government bodies, both federal and state, that share the mission of protecting the extraordinary natural richness of California. This complex and interconnected "natural infrastructure" provides an exceptional wealth of nature's goods and services to California's residents and visitors, as well as to those in many other regions who benefit from the state's diverse exports.

We are indebted to the Stephen Bechtel Fund, the California Academy of Sciences, The David and Lucile Packard Foundation and the Stanford Woods Institute for the Environment for their generous support for the production of this supplement, as well as to the *Ecosystems of California* book from which it is derived. We also thank the University of California Press for permission to use material from the book for this booklet.

Stanford Woods Institute for the Environment

S. D. Bechtel, Jr. Foundation
Stephen Bechtel Fund

the David & Lucile Packard Foundation

Fire as an Ecosystem Process

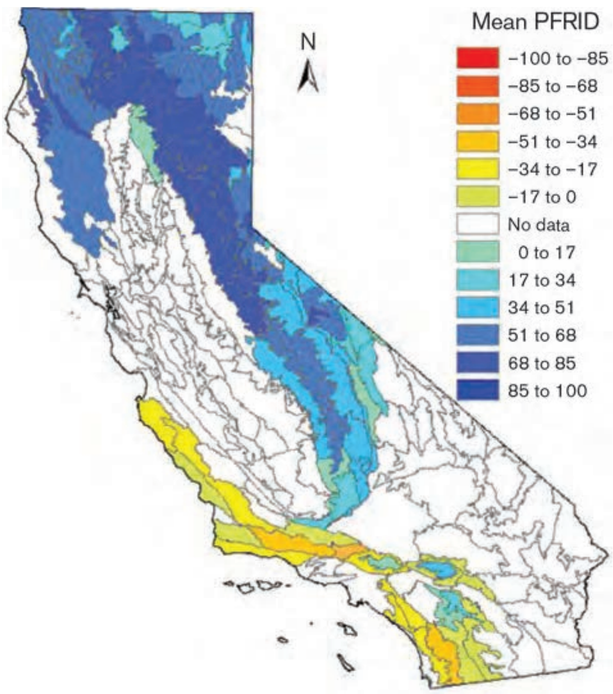
JON E. KEELEY AND HUGH D. SAFFORD

California's Mediterranean-type climate makes the landscape particularly predisposed to fires. Rains occur during winter, and because of the ocean's influence, temperatures are relatively mild, leading to abundant plant growth that can produce densely vegetated landscapes of potential fuels. The hot, annual summer drought makes this vegetation highly flammable. In combination, these factors contribute to frequent wildfires that burn extensive parts of the landscape.

Fire is a natural ecosystem process throughout much of California. Historically, humans have played a substantial role in perturbing natural fire regimes. These impacts have differed substantially between montane, coniferous forests and lower-elevation, nonforested environments. Although humans today are responsible for more than half of all fires ignited in forested landscapes, lightning has historically been an abundant source of ignition. Many California forests have had a long history of frequent, low-, and moderate-intensity surface fires, and the primary human impact has been suppression of the natural fire regime. These surface fires have been amenable to fire attack, rendering the history of fire suppression largely equivalent to fire exclusion. One consequence has been an anomalous accumulation of surface fuels and ingrowth of young trees, both of which have contributed to the potential for a fire regime shift to high-intensity crown fires.

Shrublands and other nonforested landscapes in the state have historically burned in high-intensity crown fires. As a result, fire suppression activities have been unable to exclude fire as in conifer forests. These landscapes have historically low lightning frequency; since human occupation, people have been the dominant source of ignitions. With increasing population growth, fire suppression efforts have worked hard to keep up with increasing numbers of fires. However, twentieth-century fires have been more abundant in central and southern coastal California than historically was the case. This increase in fire frequency has had negative ecosystem impacts by type-converting native shrublands to nonnative grasslands throughout many parts of the region. Future global changes are likely to have very different impacts on these two landscapes, with global warming playing a significant role in forests, and demographic growth and urban development playing larger roles in coastal plains and foothill chaparral.

Because of the prevalence of fires in California and mounting losses of resources, property, and lives, fire management has unavoidably become a central focus of federal, state, and local agencies across California. Together, these agencies spend more than three billion dollars annually in wildfire prevention and suppression, and the costs of fighting fire are rising rapidly.



Deviation of twentieth-century burning frequency from the historical regime, illustrated by mean percentage fire return interval departure index (mean PFRID), one measure of FRID. Negative values (warm colors) indicate areas where fire frequencies since 1910 are higher than under presettlement conditions; positive values (cool colors) are areas where fire frequencies over the past century are lower than under presettlement conditions (based on Safford and Van de Water 2014). Values are generalized to the Forest Service's ecological subsection map (Miles and Goudey 1997) from Forest Service and National Park Service lands in each subsection; subsections with negligible USFS or NPS lands are left blank (Safford and Van de Water 2014). By convention, areas within approximately 33 percent of zero change (-33 to +33) are considered minimally or not departed; and areas with greater than 67 percent departure (either positive or negative) are considered substantially departed (Safford and Van de Water 2014).

THREATS AND RESPONSES

THREATS	RESPONSES
California has two distinctly different fire regimes: crown fire and surface fire.	Decision-makers need to not rely on a single model of how management activities have altered historical fire regimes. Specifically, there is a need to recognize that more northern and higher elevation landscapes have experienced fire suppression impacts and may require fire restoration. On many other landscapes, fire suppression policy has not eliminated fire and, in fact, human ignitions have increased fire frequency. On these landscapes there is a need for reducing fire disturbance in order to limit unwanted type conversion from native shrublands to exotic grasslands.
Plant and animal communities respond very differently to different fire behaviors.	When considering issues of fire size, fire frequency, fire intensity, etc., it is important that decision-makers understand that each of these parameters has different effects on plant and animal communities. For example, large fire events have minimal impact on plant communities but profound impacts on recovery of some animal populations.
A significant component of the firefighting arsenal is use of prefire vegetation treatments such as prescribed burning or mechanical alteration of vegetation. In many forests, such fire hazard reduction treatments are compatible with resource protection. However, in chaparral shrublands, such treatments may cause ecosystem damage such as increasing invasive species. Fire management policy has had an inordinate focus on trying to restore historical patterns of fire in the state.	There is a need for consideration of how to balance fire hazard reduction with resource protection. On many shrubland landscapes there is a need for in-depth studies on the efficacy of landscape scale fuel treatments when conducted away from the wildland-urban interface. Alternative models of fire management should be considered, such as trying to minimize extinctions of endangered species, or invasion of nonnative species.

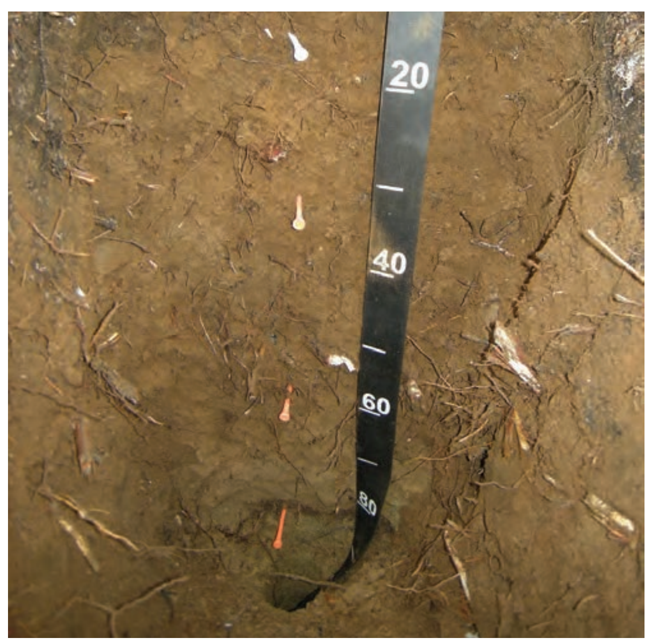
Geomorphology and Soils

ROBERT C. GRAHAM AND A. TOBY O'GEEN

Tectonic activity has endowed California with a plethora of rock types and terrains that have been further shaped by climate. The resulting landscapes, with their distinct geochemical foundations and climatic influences, support a diverse array of ecosystems and coevolved soils. The characteristics of these soils reflect the environmental influences they experienced during their formation, be that a few hundred years on a landslide scarp or a million years of stability on an ancient river terrace. The soil properties that coevolved with landscapes and ecosystems took thousands of years to form but can be disrupted by humans in days. The future of soil conditions in the state is in the hands of humans.

The equilibrium between soils and their natural environments was largely undisturbed by humans until the massive influx of immigrants began in the mid-nineteenth century. Placer and hydraulic mining destroyed thousands of hectares of soils. Early agricultural operations had modest effects on soils, but as land modification increased in the form of land leveling and deep ripping, the long-evolved characteristics of the soils were lost forever, traded for enhanced agricultural production. Virtually all agriculture in California relies on irrigation, and the altered water budget changes the soils themselves. Certain timber management practices, such as scalping to control brush and promote reestablishment of conifers after logging, physically disrupt the native soils. Forest and chaparral fires, made larger and more severe by a century of suppression, expose bare soil to erosion. Fire suppression activities themselves, such as firebreaks and access roads, cause soil erosion. Currently, the construction of solar and wind power facilities is physically disturbing huge expanses of native soils in the deserts. We are rapidly reaching a point where native, undisturbed soils are rare. The extent to which the loss of native soils is justified by resource production is open to interpretation, but once soils are altered from their native state, the ecosystems they support will no longer be truly natural.

Giant sequoia grove on a broad glacial moraine in Giant Forest, Sequoia National Park. Photo: Chris Savastio.



Excavated soil profile in the giant sequoia grove shown above. Photo: Chris Savastio.

THREATS AND RESPONSES

THREATS	RESPONSES
Native soils, unmodified by human activity, provide a record of previous environmental conditions and give insights into natural ecosystem processes. Such native soils are becoming rare, and we are losing the valuable interpretive power they provide.	Public and private land management organizations need to ensure that representative tracts of native soils are preserved in the varied environments of the state, particularly those most subject to intensive management practices, such as agriculture or urbanization. These native soils need to be maintained for baseline comparative research purposes.
Irrigation in the west side of the San Joaquin Valley is causing salinization of agricultural lands. Agricultural runoff and deep percolation from these areas threaten water quality.	Irrigated agriculture inevitably leads to soil salinization unless surplus water is available to leach the salts from the land, and ultimately to the sea. Until surplus water and a disposal path become apparent, systems are needed to segregate salts into some areas while maintaining low salinity in other areas for agricultural productivity.
Development of solar power facilities, and other activities in California deserts, are disturbing fragile surface soils that will release huge amounts of dust via wind erosion. This dust pollutes the air and even distant water bodies. Some dust may contain natural asbestos fibers and other toxic substances.	Land management agencies should work with the National Cooperative Soil Survey to identify sensitive areas susceptible to dust generation so development can be avoided there. Placement of solar facilities on surfaces that are already developed, such as parking facilities and warehouse roofs, will avoid disruption of sensitive lands.
Increased fire frequency and severity will increase soil erosion, depleting nutrients from the soil and polluting the surface waters that receive the runoff.	Forest thinning reduces fire risk and increases soil water storage, resulting in less erosion, healthier forests, higher stream base flows, and improved water quality.
Soils in the Delta continue to subside, increasing the risk of levee failure and saltwater intrusion.	Delta growers are implementing carbon-friendly farming systems and practices that more closely mimic the natural state of these soils, such as growing more rice and allowing soils to naturally flood when fallow.
Groundwater pumping is collapsing aquifers and causing land subsidence in the San Joaquin Valley.	Growers, irrigation districts, and water management agencies are evaluating agricultural groundwater banking. This practice would introduce controlled flooding of agricultural land on suitable soils as a way to capture floodwaters on the land and recharge groundwater.
Urban development has expanded into vast acreages of prime farmland in California, diminishing our capacity to sustainably produce food and fiber.	The California Land Conservation Act (Williamson Act) preserves agricultural and open-space land, providing property tax relief to growers and ranchers in exchange for a ten-year agreement that the land will not be converted to urban uses.

Atmospheric Chemistry

ANDRZEJ BYTNEROWICZ, MARK FENN, EDITH B. ALLEN, AND RICARDO CISNEROS

Air quality issues have a long history in California. In precolonial times, long before the modern-day smog problem emerged in the 1940s, air quality was almost certainly poor at times, due to emissions from lightning-caused fires and those set by Native Americans. The summer of 1943 marked the beginning of smog in Los Angeles, or at least of public awareness of the approaching air pollution tidal wave.

Since the mid-1940s, air quality in California, in its southern part, has been among the worst in the nation. We now know that the infamous Los Angeles photochemical smog is a result of uncontrolled emissions of volatile organic compounds (VOCs), carbon monoxide (CO), and nitrogen oxides (NOx) from millions of motor vehicles and other pollution sources. These compounds undergo photochemical reactions under conditions of high temperatures, light intensity, and thermal inversions typical in summer in the Los Angeles Basin, bounded by several mountain ranges. Thousands of secondary chemical compounds are formed during such reactions, including highly toxic ozone (O_3), nitric acid vapor (HNO_3), peroxyacetyl nitrate (PAN), and many other compounds toxic to vegetation and humans.

Generally, ozone air pollution in California has been improving significantly since the 1970s; however, it still causes serious ecological and human health effects. At present, it is mainly elevated levels of ozone and nitrogen deposition that cause negative impacts of air pollution on California ecosystems. The most serious ecological effects occur in mixed conifer forests of southern California and on the southwestern slopes of the Sierra Nevada. Ozone can be transported long distances, affecting remote areas such as Joshua Tree National Park in the Mojave Desert or the eastern Sierra Nevada.

Effects of nitrogen deposition on other ecosystems have been intensively studied in California for the past two decades. Nitrogen deposition to California ecosystems is dominated by dry deposition of ammonia and nitric acid vapor, although nitrogen deposition in fog water can also be important in montane regions. Movement of ammonia and nitric acid vapor in complex terrain, and therefore nitrogen deposition, is much more spatially restricted than ozone distribution due to the high deposition velocity of these pollutants. Consequently, steep landscape gradients of nitrogen deposition occur in California mountain ranges, with the highest potential for adverse effects near emission source areas (such as the western side of the Sierra Nevada and near population centers), while remote areas remain relatively unaffected.

The most sensitive indicators of harmful nitrogen deposition effects on California ecosystems include shifts in epiphytic lichen communities and elevated lichen-tissue nitrogen in mixed conifer forests, oak woodlands, or chaparral ecosystems; and enhanced biomass of exotic grasses to levels capable of causing biodiversity changes and sustaining wildland fires in desert scrub, pinyon-juniper, and coastal sage scrub ecosystems. Increased nitrate concentrations in stream water and groundwater from montane catchments can also result from nitrogen deposition, but the land area thus affected in California is much less than that experiencing biodiversity reduction. Approximately 35 percent of California's land area exceeds critical loads of nitrogen deposition for these impacts in seven major vegetation types in California. Urgent need exists for large-scale evaluation of California forest health in light of the interactive effects of elevated ozone concentrations, nitrogen deposition, climate change, insects, and diseases.

Finally, particulate matter pollution is a serious health threat in California, especially in urban areas affected by emissions from mobile sources such as the Los Angeles Basin, San Francisco Bay Area, and California Central Valley. The Central Valley is also affected by particulate matter emissions from intensive agricultural activities, while vast arid areas, such as the Owens Valley, suffer from suspended dust during high wind events. Potential exceedances of the national and California particulate matter air quality standards can hinder the use of prescribed fire as a management tool in forests.

Photochemical smog.
A Over the Los Angeles Basin, view from the San Bernardino Mountains. Photo: Andrzej Bytnerowicz.
B Over the San Joaquin Valley, view from Moro Rock. Photo: Andrzej Bytnerowicz.

THREATS AND RESPONSES

THREATS	RESPONSES
Increasing background ozone concentrations from pollution source areas in California and from long-range transport of polluted air masses from Southeast Asia, potentially resulting in ozone injury to sensitive plants in forests and other ecosystems. This problem will be exacerbated in coming years because higher temperatures, caused by global warming, are expected to increase the rates of photochemical reactions leading to ozone generation.	Reduction of emissions of ozone precursors (nitrogen oxides, volatile organic compounds) in California. Lowering the ozone thresholds for federal and state ambient air quality standards. Implementation of a secondary standard for ozone aimed at protection of ecological resources (sensitive vegetation). Increased international cooperation in reducing air pollutant emissions.
Increased atmospheric nitrogen deposition leads to undesirable ecological changes: shifts in biodiversity, expansion of invasive plants, soil and water contamination, increased drought stress, and susceptibility to pest outbreaks in forests and other ecosystems.	Comprehensive monitoring and evaluation of potential ecological risks caused by elevated nitrogen deposition. Implement new regulations or standards that control the impacts of atmospheric nitrogen deposition (the Critical Loads approach for nutrient nitrogen). Establish more effective control of individual drivers of elevated nitrogen deposition (nitrogen oxides, nitric acid, ammonia, particulate ammonium, and nitrate).
Elevated ambient concentrations of ammonia, mainly caused by emissions from agriculture and motor vehicles equipped with three-way catalytic converters. Ammonia contributes to elevated atmospheric nitrogen deposition, leading to ecological consequences.	Reduction of emissions from agriculture by more efficient use of synthetic and organic fertilizers, control of emissions from dairy farms and other concentrated animal feeding operations, etc. Development and implementation of state and federal regulations controlling emissions of chemically reduced nitrogenous compounds.

Ecosystems Past: Vegetation Prehistory

CONSTANCE I. MILLAR AND WALLACE B. WOOLFENDEN

In the same way that learning details of one's family history—the environments, traditions, and lifeways of our ancestors—helps us understand the modern human condition, the historical context of landscapes helps us understand modern flora and fauna. Regional and global geologic dynamics interacted with, and influenced, the climate of the California region. Together, sequences of geologic and climatic variability influenced the rise of modern flora.

Included among the lessons in the historical context of landscapes is the important role of past climatic change in shaping California's vegetation, including both individual species and community associations. Past climate changes have been continuous and included many interacting quasi-cyclic patterns with nested time scales (decadal to multi-millennial). Because California's native flora developed in the presence of dramatic climate change, many adaptations have evolved within species to cope with these pressures. Conservation and management efforts can be most successful when they work in concert with these natural adaptive mechanisms.

At top, paleogeography of North and South America, circa 90 million years ago. Above, an oblique Western Hemisphere view showing the Cretaceous Western Interior Seaway of midcontinent and the extensive mountain regions of western North America. Source: Blakey 2008.

THREATS AND RESPONSES

THREATS	RESPONSES
Climate change has been ongoing naturally prior to contemporary anthropogenic influences on the climate system. Native species have been exposed to climate changes in their evolutionary history, as well as to similar influences driven by anthropogenic influences, and have adapted to respond to such changes.	Policies informed by historic species' responses to natural climate change are likely to be more effective in adapting current populations for future climates (i.e., by mimicking lessons from history).
Historic responses to natural climate change often involved changes in species' distribution ranges, as individuals moved to more favorable new environments.	Recognize that native species' ranges are fluid, and under changing climates migration is likely in some locations, whereas population extirpations are likely elsewhere. These are natural and often adaptive adjustments. Where species are not able to migrate due to land fragmentation or other barriers, consider creating migration corridors or (after thorough review and evaluation) assisted migration.
Historic responses to natural climate change often involved genetic adaptations in situ.	Maintain and promote within-population genetic diversity, and maintain connectivity among populations that foster gene flow.
Historic responses to natural climate change often involved individualistic species-by-species responses, with the result that community assemblages (plants or animals) changed adaptively as climate changed.	Recognize that maintenance of historic (e.g., twentieth century) species diversities might not be the most adaptive condition under future climates. New assemblages of adapted species are likely to form and/or can be assisted by management intervention.

Biodiversity

BERNIE TERSHY, SUSAN HARRISON, ABRAHAM BORKER, BARRY SINERVO, TARA CORNELISSE, CHENG LI, DENA SPATZ, DONALD CROLL, AND ERIKA ZAVALETA

By almost all measures, California is the most biodiverse state in the U.S. and one of the most biodiverse regions of the world outside the tropics. California's high levels of endemism and species richness are related to its physical diversity, its Mediterranean climate, and perhaps its unique evolutionary history.

More than 30 percent of California's species are threatened with extinction. However, less than 0.3 percent of California's native species have been driven to global extinction in the past two hundred years. This is remarkable, considering the sheer scale and magnitude of California's agricultural development, suburban sprawl, water diversion, resource extraction, and pollution, combined with the intentional and unintentional introduction of more than fifteen hundred species and a history of overhunting and overfishing.

Somehow, to paraphrase Aldo Leopold, we have managed to save almost all the pieces and, remarkably, now have a second chance to move into the future with thriving populations of nearly the full complement of California's flora and fauna.

California is a wealthy state with a long history of environmental leadership and one of the world's most innovative societies. More than any high-biodiversity region in the world, California has the economic, cultural, and intellectual resources needed to have both thriving human communities and thriving ecosystems with their full diversity of species.

Although imperfect and heavily concentrated in desert and high mountain areas, the state's systems of protected areas cover 46 percent of its land area, offering the raw material for habitats in which species can persist and recover. With increasingly effective environmental regulation of wildlife harvest and pollution, and the creation of new protected areas and smarter development, overharvest, pollution, and even habitat loss could become less significant drivers of new declines and extinctions. If this happens, then the most acute remaining challenges will be the damaging impacts of invasive species within natural and protected areas and the inability of protected areas to meet the needs of all their current species as California's climate changes.

In California the days of government agencies casually introducing new species are long gone, and smarter policies govern invasive species prevention and management. Climate change will stress existing reserves and wildlife populations but may also provide new conservation opportunities. Just as California has been a national and global leader in a range of other social and economic areas, California can be a global leader in biodiversity conservation.

THREATS AND RESPONSES

THREATS	RESPONSES
Habitat modification: California's network of terrestrial protected areas covers 46 percent of the state, but many areas critical for threatened species remain unprotected.	Climate change will drive land use changes that will create opportunities to create new protected areas. Protected area design and management is steadily improving, and tools are available to identify and prioritize lands, as are innovative approaches to protecting them. Analysis of protection gaps for California's threatened species will help guide the formation of new protected areas. Realistic financial incentives for private landowners to increase numbers of threatened species on their land can be a cost-effective complement to protected areas and significantly decrease habitat modification.
Pollution	California's global leadership in environmental protection strategies has significantly reduced pollution in the last twenty-five years. Although damaging toxins continue to be identified (e.g., atrazine, brodifacoum), a 2013 ban on lead ammunition to help protect critically endangered species demonstrates California's continued leadership in effective environmental regulation. California should continue to pursue aggressive reduction in greenhouse gas emissions. California's Environmental Protection Agency (EPA) should prioritize federal EPA permitted substances that should be aggressively evaluated for use changes or outright bans.
Overexploitation	With increasingly effective environmental regulation of wildlife harvest, overexploitation is no longer a significant threat to California's biodiversity. California's game management should be subject to ongoing evaluation and improvement, not only to protect wildlife populations, but also to improve the experience of wildlife harvesting. Wildlife harvest of all types creates a critical constituency for conservation actions.
Threatened species	Once habitats are protected or restored, threatened species as well as species that provide important ecosystem system services and functions can be introduced or reestablished. The successful reintroduction of locally extinct marsh sandwort (Arenaria paludicola), Owens pupfish (Cyprinodon radiosus), Roosevelt elk (Cervus canadensis roosevelti) and Tule elk (Cervus canadensis nannodes), bald eagles (Haliaeetus leucocephalus), island fox (Urocyon littoralis), and California condors (Gymnogyps califonianus) to the wild demonstrates that even the most endangered of California's species can be saved.

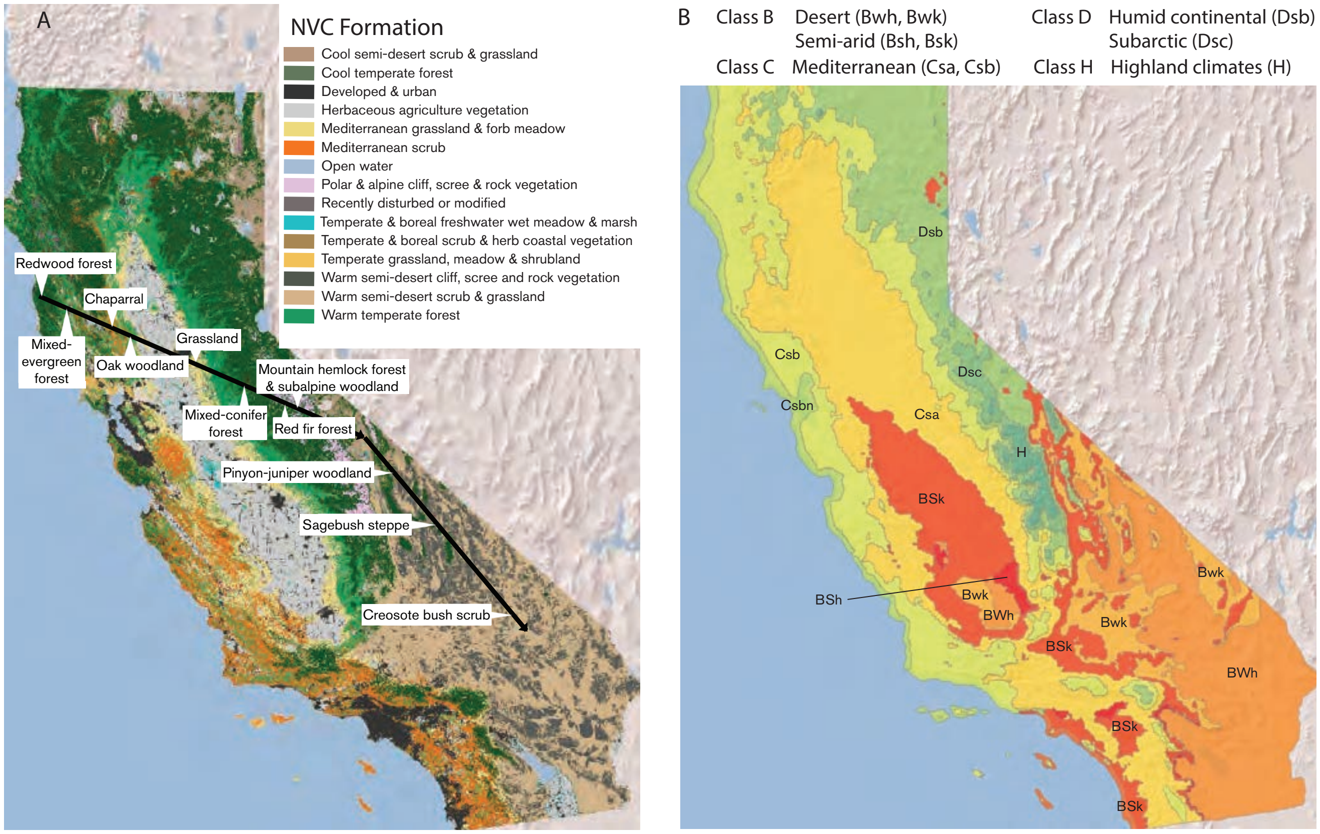
Vegetation

CHRISTOPHER R. DOLANC, TODD KEELER-WOLF, AND MICHAEL G. BARBOUR

Vegetation comprises all plant species of a region and their pattern across the landscape. Wide gradients of climate and topography drive tremendous diversity of vegetation types in California, ranging from tall redwood forests with more than 2,000 millimeters per year of rain to warm desert scrub with less than 50 millimeters per year. Soil and microclimate heterogeneity across the state further increase vegetation diversity. The classification of vegetation is the arrangement of plant communities into categories that share common characteristics. The National Vegetation Classification system relates vegetation to climatic data and helps demonstrate how California vegetation types are related to other vegetation types around North America and the world. California has examples of most of the major vegetation types found on the earth, lacking only tropical, polar, and boreal types. Forested vegetation types can be found in the northwest and mountainous parts of the state, where annual precipitation is high. Scrub and grassland types predominate where annual precipitation is low and where evaporative demand is higher and/or soils and thinner. This chapter reviews twelve of the most abundant vegetation types of California by running a virtual transect from the northwestern corner of the state, east across the Central Valley and Sierra Nevada, and down through the deserts into the southeastern part of the state.

THREAT AND RESPONSES

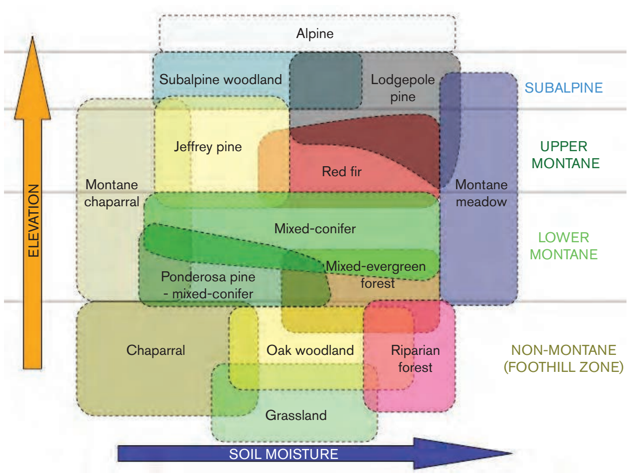
THREAT	RESPONSE
Because California's vegetation is so tightly linked to climate, it is hard to imagine a greater threat than climate change. Even minute changes in climate have the potential to change every vegetation type in California, their distributions, composition, and driving factors. Some studies predict the greatest reductions in ecosystem area will be higher elevation systems, but much is still unknown about how increasing temperatures will disproportionately impact wetter vs. drier systems, and higher vs. lower elevations. There is increasing evidence that drought is causing increased mortality of large trees, and possibly all trees. Wildfires appear to be growing longer and more numerous, as a result of warmer, longer growing seasons in combination with decades of fire suppression and the difficulty of reversing its impacts. Meanwhile, urbanization will make it more difficult for species to migrate, or track climate, in response to change.	Reducing greenhouse gas emissions is going to continue to be one of the greatest challenges of our generation, and California needs to continue to be out front on that endeavor. In the meantime, we need to continue researching how the different ecosystems (vegetation types) in California are interconnected, and map out potential shifts in distribution and composition. A better understanding of the connection between the physiological response and biogeographic response is critical. California has certainly seen changes in climate before, but not at the predicted pace of our current change, on top of a matrix of other kinds of disturbances.



A Distribution of vegetation types in California using the National Vegetation Classification (NVC) system at the level of "formation," which is analogous to many of California's well-known vegetation types (highlighted by boxes on the map). Note the presence of forest types in the mountains and northwest part of the state, where precipitation is high, and dominance by scrub types in the southern, drier part of the state. The black line represents the northwest to southeast virtual transect used to "sample" major vegetation types throughout much of the chapter, including labels of many of the types described. Ecosystem types as defined in this booklet often coincide with boundaries of vegetation types. They sometimes encompass more than one (as in deserts, which includes desert steppe, scrub, and grassland) or only part of one (as in redwood forests, which make up a subset of the Warm Temperate Forest (NVC category).

B Climate zones of California. Note the similarity between the distribution of climate in this figure and the vegetation types in (A).

Map is based on the Köppen 1936 system of climate zones.



Hypothetical distribution of common vegetation types of the central Sierra Nevada arrayed on gradients of elevation (Y-axis) and soil moisture (x-axis). The x-axis could be considered a gradient from xeric to mesic sites, caused by such factors as aspect, steepness, soil type, and bedrock depth. This diagram does not consider disturbance, which also affects the position of most vegetation types. For example, frequent disturbance of chaparral causes it to convert to grassland. Source: Dolanc, unpublished data.

Biological Invasions

ERIKA ZAVALETA, ELISSA M. OLIMPI, AMELIA A. WOLF, BRONWEN STANFORD, JAE R. PASARI, SARAH A. SKIKNE, PAULO QUADRI BARBA, KATHERINE K. ENNIS, AND FLAVIA C. DE OLIVEIRA

Invasive species have had tremendous impacts on the ecosystems and economy of California. Both ecological and human factors govern the dynamics of invasions in the state. California's equable Mediterranean climate, diversity of geologic and climatic conditions, and widespread natural disturbances such as fires and floods contribute to surplus resources and favorable habitats for potential invaders. But patterns of invasions in California are most strongly dictated by both historical and modern human impacts on the introduction, establishment, and spread of invasive species.

Major phases of terrestrial biological invasions in California have been defined by shifts in human land use following the first European settlements and exacerbated by an increasing human population and improvements in transportation infrastructure. California's unique human history has driven patterns of both intentional introductions for food, pets, sports, and horticulture, as well as unintentional (though preventable) introductions via high international and interstate trade and traffic. Humans have also increased the process of establishment and spread for invasive species by altering existing disturbance regimes, patterns of connectivity, and abiotic conditions.

In general, densely populated areas of California, especially along the coast, harbor the highest numbers and associated impacts of introduced species. California's open ocean, alpine, and forest ecosystems tend to have fewer invaders, while its freshwater, grassland, and estuarine ecosystems are generally highly invaded. Documented impacts of invasive species on native species in California include genetic impacts, local or species-level extinctions via disease and displacement, changes in community composition and native species diversity, and altered ecosystem processes such as nutrient cycling and disturbance regimes. Economic costs include direct losses to crops or managed resources and investments in management and control efforts. Costs also accrue from decreased ecosystem services, such as decreased climate and flood regulation and reduced water resources.

A great many successful eradication and control efforts illustrate that invaded areas can be restored, while a great many invasions have also become irreversible parts of California's diversity and ecological dynamics. Successful eradication of damaging invasive mammals from California's islands is a globally significant conservation victory that protected many of the state's most vulnerable terrestrial species. Successful eradication of pike (Esox lucius) from Lake Davis and invasive trout (Salmonidae) from many high Sierra lakes shows that invasive species eradication is also an effective tool for the conservation of California's freshwater systems.

The future of invasions in California will be shaped by increases in international trade and transport, the state's population, and climate change and disturbances, along with innovations and investments in management. The days of government agencies casually introducing new species are long gone, and increasingly smart policies govern invasive species prevention and management. Invasive species management involves prevention, early detection, eradication, and control.

THREATS AND RESPONSES

THREATS	RESPONSES
New invasive species	Preventing introductions of potentially invasive species in the first place is the most successful and cost-effective management strategy. The cost of preventing new invasions is a small fraction of the typical cost of control and impacts associated with established invasive species. A white list of safe species that are allowed for importation—rather than a blacklist of species that should not be imported—will better protect against new invasive species getting established in California. A process to rapidly identify, permit, fund, and initiate eradication and control actions for all likely invasive species will decrease establishment of new invasive species.
Established invasives	For species that establish populations in California, management options include eradication targeted at high-priority, early-stage invaders; long-term control efforts such as weeding, hunting, timed grazing, and mating disruption; and biological control, which has been used to manage invasive agricultural pests and noxious weeds. Control should use an Integrated Pest Management framework and the goals (containment, reduction, or decreased impact within current range) should be clearly defined. Standardized early detection programs that search for the presence of the most damaging and likely to establish invasive species will help detect new invasive species while they can still be easily eradicated. Automated DNA, acoustic, and visual sensors can decrease the cost and increase the scale of early detection. A prioritization of established invasive species for control would focus efforts on the most damaging invasive species and those where control can be most effective, or where new research on control techniques is needed, or new techniques field-tested, such as the use of bacteria to control invasive cheatgrass (Bromus tectorum) in eastern California. Invasive species eradications from islands and freshwater systems should be prioritized and conducted at increasingly larger scales and for a greater variety of invasive species. Opportunities to eradicate invasive species from mainland terrestrial habitats should be prioritized and implemented as experiments. Pre-authorization, a dedicated emergency eradication fund, and a list of preselected implementers would greatly facilitate effective action.

Climate Change Impacts

CHRISTOPHER B. FIELD, NONA R. CHIARIELLO, AND NOAH DIFFENBAUGH

Climate change has already had a wide range of direct and indirect effects on California's diverse ecosystems. Future impacts cannot be specified with precision, for two main reasons. First, the magnitude of warming will depend on the trajectory of future emissions. Second, climate change effects will unfold in a multi-stressor context, with impacts emerging from interacting consequences of changes in land use, composition of the atmosphere, water pollution, and biological invasions, in addition to changes in climate.

California has warmed by about 0.9°C since the beginning of the twentieth century, close to the global average. Many ecological responses to this past warming are well documented. They involve changes in species ranges, abundances, and the timing of activities like migration or flowering. Few studies to date address the important issues of responses to climate change in the context of multiple stressors and effects of climate extremes. This is partly because scientific and public perceptions of climate change emphasized a need for studies where a climate-change signal could be empirically isolated, and other contributing drivers of ecological change could be ruled out. Such cases are the exception, not the norm. Future research must address interactions between climate change and other stressors to identify ecological consequences that are outside the realm of current predictions, both quantitatively and qualitatively.

Even with ambitious mitigation, the world at the end of the twenty-first century will be about 2°C warmer than preindustrial levels. This change will lead to widespread ecological impacts. Continuing high emissions could yield a 4°C future for California by the end of the century, with rapid warming continuing thereafter. At this level, impacts will be severe and pervasive, but also difficult to predict. By 2100, the world of continued high emissions is so different from the present that all bets are off as to how ecological systems will respond. With rates of change one to two orders of magnitude higher than in past periods of climate change, there is little information on prospects for persistence or relocation of individual species or entire ecosystems.

California's strong topographic relief and climate gradients from coast to inland mean that species could, in principle, shift relatively short distances to stay in a zone of constant climate. However, varying abilities to move, long lags to maturity in many plants, limited available area and soil as species approach mountain peaks, and literally shifting off the tops of the mountains will all constrain the ability of plants and animals to relocate to suitable new habitats. Other limits to gradual relocation will come from the extensive footprint of human activities. Moreover, many of the species that are best at relocating rapidly are weedy or invasive. Weeds could be the big winners in an era of climate change, at the expense of native biodiversity.

Biodiversity changes in California in response to climate change are difficult to predict, but climate change will be an increasingly strong threat multiplier for species already under pressure from land use change, biological invasions, and other stressors. The highest priority for managing risks to California's ecosystems in the long term is to reduce emissions and avoid a 4°C future.

THREATS AND RESPONSES

THREATS	RESPONSES
Even with 1°C warming, the occurrence of hot extremes is projected to increase over much of California, along with earlier melting of snowpack and less snowmelt available during the hot season. By the end of the twenty-first century, choices about emissions pathways, especially over the next one to two decades, will lead to dramatically different worlds. A world of ambitious mitigation will stabilize at about 2°C above preindustrial levels, while a world of continued high emissions will still be warming rapidly, passing 4°C or more by 2100.	With ambitious mitigation, we can stabilize warming in the range of 2°C above preindustrial levels. At this level, there is a good chance that biome boundaries, biodiversity, and ecosystem function will change gradually and incrementally, avoiding a dramatic worst-case scenario for California ecosystems.
Many of California's ecological treasures, including pockets of exceptional biodiversity, and iconic as well as rare or endangered species, are limited to small areas or unusual soils. Others are now in islands surrounded by a sea of human development. These species and ecosystems tend to be especially vulnerable and have limited prospects for relocation.	Limiting warming is a key component of managing and reducing risks from a changing climate. Investments in managing other stresses can help provide time and space for ecosystem responses. Increasing the size, habitat quality, and connectedness of protected areas can increase the probability of including suitable future habitats. Facilitated migration and gene-bank protection may be useful components of a multi-pronged strategy for protection.
Climate change poses grave risks for California's biodiversity, potentially playing a major role in driving a global mass extinction.	Ambitious mitigation to limit warming is essential. So is continued research to understand the requirements for survival. Investments in reducing interacting stressors and providing room for nature are critical components of the portfolio of strategies to manage and reduce risk.
In a warming world, alpine species and habitats tend to disappear, as they are literally pushed off the tops of the mountain peaks. As a consequence, alpine species and habitats are among the state's and the world's most endangered.	Limiting warming is the most powerful tool for managing impacts to alpine habitats. Habitat protection, facilitated migration, and gene-bank protection also can be helpful.
Climate change acts as a threat multiplier. Risks for ecosystems already stressed by land use change, invasive species, nitrogen deposition, and other factors will be amplified, in ways and to levels that are difficult to predict, by changes in temperature and atmospheric CO_2.	Limiting warming with ambitious mitigation is key to managing and reducing risks. Reducing pressure from other stressors can play a critical role in providing time and options for species and ecosystems.

Introduction to Concepts of Biodiversity, Ecosystem Functioning, Ecosystem Services, and Natural Capital

REBECCA CHAPLIN-KRAMER, LISA MANDLE, ELIZABETH RAUER, AND SUZANNE LANGRIDGE

Biological diversity—or biodiversity—is the variety of life across all ecological levels, from genes to species to ecosystems. Biodiversity includes everything from the vast array of life on land and in the seas to the foods we eat and the landscapes in which we live and visit.

Ecosystems, the diversity of life within them, and their basic ecological processes, support and enhance human life and therefore have implications for societal decisions. Both natural and human-modified ecosystems provide benefits to society, and these benefits have been termed "ecosystem services."

The value of ecosystem services can be considered a flow of benefits from nature to people and has been termed "natural capital."

The difference between ecosystem services and natural capital is akin to the difference between income and wealth. They are often positively correlated, and while poor management of a capital asset may produce short-term gains in income, long-term degradation of that asset will ultimately erode the benefits it can provide to people. However, recent polling has determined that the terms "ecosystem services" and "natural capital" are unfamiliar to the U.S. populace, especially in comparison to more straightforward terms like "nature's benefits" or "nature's value" (Fairbank et al. 2010).

Ecosystem functions support ecosystem services, and in common parlance these two terms are often used interchangeably, but they are not the same thing. The Millennium Ecosystem Assessment framework defines different types of services as provisioning (such as food, fuel, and fiber), regulating (such as air and water purification, climate stabilization, and hazard mitigation), and cultural (such as spiritual, aesthetic, and educational enjoyment of nature). Additionally, there are supporting functions that deliver ecosystem services such as soil formation, primary production, and nutrient cycling.

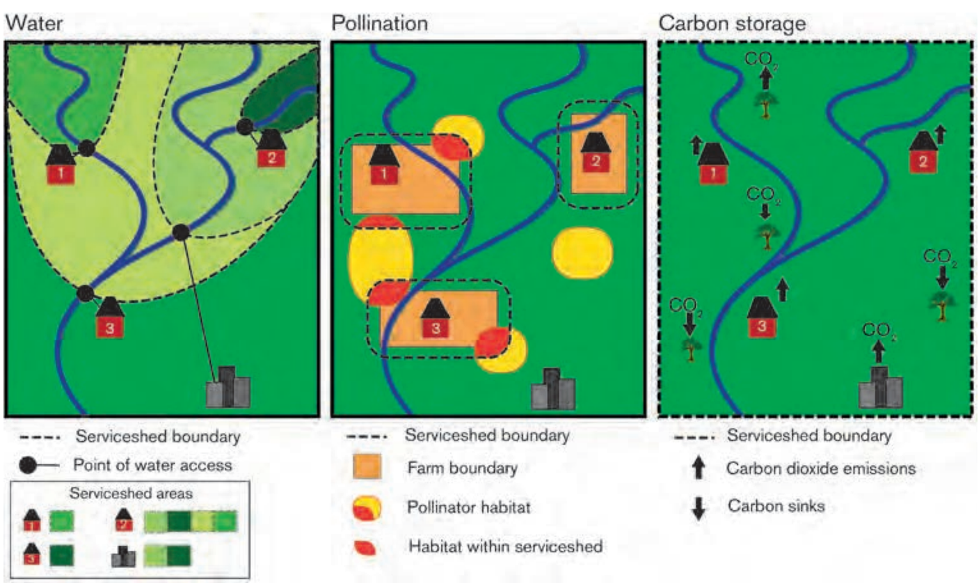
Examples from California illustrate a diverse set of ecosystem services provided by managed and unmanaged ecosystems. These include agricultural production, pest control, pollination, forage production for livestock, timber and non-timber forest products, fisheries and aquaculture, water production and regulation, water purification, carbon sequestration, hazard mitigation (from coastal and inland flooding), and recreation. Tracing ecosystem services along the chain of supply, service, and value helps clearly delineate the ecological and social processes that intersect in human experience of and dependence on nature.

Information about biodiversity, ecosystem functioning, and ecosystem services can help inform decisions in different ways and for different policy contexts, such as conservation planning, climate adaptation, and permitting and mitigation. These three contexts give a brief but diverse view of the many ways to value nature, and of how using science to reveal these values can translate into actionable policy.

THREATS AND RESPONSES

THREATS	RESPONSES
Biodiversity has intrinsic value, and many conservation efforts do not require a broader approach to consider ecosystem function or ecosystem services to successfully preserve biodiversity. However, ecosystem functions are both affected by and can affect biodiversity, and therefore the functions underpinning ecosystem services can be correlated with biodiversity.	An integrated framework for biodiversity and ecosystem services allows for scientific measurement of nature's diverse benefits to assist policy-makers in defining goals. It also provides managers tools to track progress toward these goals, with improved outcomes for humans and the ecosystems upon which they rely.
Although there is growing interest from governments, businesses, and multilateral organizations in including ecosystem services in impact assessments and mitigation requirements, the development of standardized approaches to determining suitable offsets for ecosystem services lags behind those developed for wetlands and for particular species.	A holistic impact assessment and mitigation framework that simultaneously assesses impacts on biodiversity, ecosystem function, and ecosystem services would better guide development and mitigation decisions in the diverse decision contexts facing California.
Certain policies aimed at benefiting one type of ecosystem service may in fact threaten other ecosystem services. For example, eliminating riparian buffers on the margins of farm fields, in response to pathogen transmission, can result in the loss of water quality regulating and pollination and pest control services. Another example is new road or housing developments placed in natural areas, as increased access to open space enhances recreational and aesthetic benefits and raises the value of those nearby properties, but can degrade the quality of habitat and biodiversity and some other services (such as potential carbon sequestration or water regulating services if soil is compacted).	Consider the different intended uses or demands placed upon a group of "bundled" ecosystem services to assess how some ecosystem services may be put under threat by some policies. Create policies that assess various ecosystem services provided in an area and that respond to the values provided from the bundled ecosystem services.

Servicesheds



Ecosystem services are produced in different places and at different scales, or "servicesheds," depending on the biophysical processes that determine their supply as well as on the ability of people to access those benefits. For water provisioning services, the serviceshed is the area upstream of a beneficiary's point of water access, as the quantity and quality of water will depend on the state of upstream ecosystems. Some servicesheds overlap (e.g., those for Farms 1 and 2 with Farm 3) and some are located distant from the beneficiaries (if, for instance, the city pipes water from afar). For crop pollination, servicesheds depend on pollinators' flight ranges and the location of pollinator-dependent crops. In the case of carbon storage, all beneficiaries share a global serviceshed, in which everyone is affected by carbon sequestration and carbon emissions that occur anywhere else in the world. As different servicesheds for different services intersect on the same landscapes, trade-offs and synergies between different services will likely vary across space and time.

The Offshore Ecosystem

STEVEN J. BOGRAD, ELLIOTT L. HAZEN, SARA M. MAXWELL, ANDREW W. LEISING, HELEN BAILEY, AND RICHARD D. BRODEUR

The California Current System (CCS) is one of the world's four eastern boundary upwelling systems, which are among the most productive ecosystems in the ocean. The offshore ecosystem is driven by seasonal coastal upwelling that transports nutrients into the photic zone, fueling phytoplankton blooms that support a diverse food web from zooplankton and forage fish to top predators. Copepods, euphausiids, and forage fish (e.g., sardines, anchovies) serve as critical prey resources for a suite of predators ranging from seabirds to large whales. Intermittent gelatinous zooplankton blooms can alter the energy flow through the food web, although the causes and trophic impact of these blooms are not well understood. Many mobile species migrate seasonally to the CCS, and latitudinally within the CCS, following patterns of recurrent productivity. Mesoscale features such as eddies, fronts, and upwelling shadows often result in marine hot spots having high trophic exchange (predation hot spots) and increased ecosystem importance (biodiversity hot spots).

Historically, forage fish provided livelihood for coastal communities throughout the region, although population collapses have resulted in increased economic importance from bottom fish, salmon, highly migratory fish, and squid fisheries, to name a few. Population centers along the California coast use the offshore ecosystem for fishing, oil exploration, military activities, ecotourism, and shipping, and increased use results in increased risk to resident species, including pollution, oil spills, ship strikes, gear entanglements, bycatch, and ocean noise. Given the strong bottom-up forcing of the CCS, the impacts of climate-driven changes in the system could be profound. These impacts include changes in the timing and strength of upwelling, which may lead to mismatches between prey availability and predator distribution, and increased hypoxia and ocean acidification, which may reduce viable habitat for many species and alter community structure. Understanding the interplay between natural climate variability and ecosystem services is critical for effective management of the CCS into the future.

THREATS AND RESPONSES

THREATS	RESPONSES
Oil spills and pollution can have significant effects on offshore ecosystems. Seabirds exposed to even small amounts of oil can lose flight capability and experience wasting fat and muscle tissue and abnormal conditions in vital organs. Oil spills can also negatively impact deep-water corals, sea turtles, pinnipeds, and cetaceans.	Marine protected areas (MPAs) are management tools that have been utilized extensively in California waters. These areas prohibit oil and gas development, as well as pollution discharge, while still allowing fishing, among other activities.
Ship traffic, military sonar, oil and gas efforts, and other activities in the ocean can create loud noise underwater that can negatively impact marine life. Loud noise can impair animals' ability to navigate, detect prey, and communicate with each other. Noise also may increase stress and affect population rates among marine life.	Sanctuaries and MPAs can help reduce noise by limiting boat traffic and oil and gas development in critical marine habitat.
Ship strikes, when a ship collides with large marine species, are of concern, particularly for large whales such as blue, humpback, fin, and gray whales. Ships of any size can strike whales; however, those more than 80 meters long and those traveling faster than 14 knots, such as is common in the commercial shipping industry, are most likely to have lethal effects.	A joint working group in the San Francisco Bay Area has identified three management strategies to avoid ship strikes: modifying shipping lanes to avoid sensitive areas, implementation of dynamic management areas (DMAs) where vessels have to choose alternate shipping lanes or reduce speeds when concentrations of whales are present, and creating a real-time whale sighting/monitoring network with participation from the shipping industry to support the DMAs.
Climate change impacts are a serious threat to offshore ecosystems. Ocean acidification, a decrease in the pH of the ocean from increased carbon uptake, influences the ability of animals with carbonate skeletons to uptake carbonate of skeletal structure. This has affected deep-sea corals, krill, fish, mollusks, and gelatinous zooplankton.	Recognizing the connection between climate change, ocean acidification, and related impacts that create cumulative effects on offshore ecosystems will lead to improved ecosystem-based management that can adapt to changing ocean conditions.

Shallow Rocky Reefs and Kelp Forests

MARK H. CARR AND DANIEL C. REED

Kelp forests are among the most productive and species-rich ecosystems in temperate latitudes. Much like terrestrial forests, kelp forests are often layered with tall, canopy-forming kelps extending from the seafloor to the water's surface (as much as 40 meters) and a variety of shorter algal species that constitute a layered understory. Their complex physical structure creates habitat, food, and refuge for a diverse array of organisms, including a number of commercially and recreationally important fish and invertebrate species. Like terrestrial forests, kelp forests modify the physical environment by reducing light penetration to the seafloor and reducing current velocity.

The species of kelp, other algae, fishes, and invertebrates that constitute kelp forest communities vary at different latitudes, with marked differences among southern, central, and northern California. Within each of these regions, the distribution of kelp forests is patchy and determined by the availability of rocky substratum, light, water temperature, exposure to waves, and grazers. The extent and density of kelp forests varies from year to year, influenced by oceanographic conditions such as El Niños and La Niñas. The magnitude and duration of effects of these disturbances vary geographically and are most pronounced in southern California.

Complex kelp forest food webs are fueled by the great primary and detrital production of the kelps and other algae, as well as by a continuous influx of plankton. These sources of production support a phenomenal diversity of invertebrates, including herbivores, detritivores, planktivores, and carnivores. In turn, these species are consumed by a great variety of carnivorous invertebrates and fishes. In strong contrast to terrestrial forest ecosystems, the primary producers (algae) and consumers (sessile invertebrates) compete directly for limited space on the rocky substratum. The strength of these various species interactions (e.g., competition, predation, mutualisms) varies geographically with changes in the species composition of the forest community. Notably, sea urchins, important grazers of structure-forming kelps, show dramatically different patterns of abundance in southern, central, and northern California. In southern and northern California, intense grazing by large numbers of urchins can eliminate kelp from localized areas. In central California, where greater numbers of sea otters occur, these voracious predators greatly diminish urchin abundance and their impact on kelp.

The great diversity and productivity of species associated with shallow rocky reefs and kelp forests support a variety of human activities and ecosystem services. Nonconsumptive services include tourism, recreation, and spiritual and cultural values that extend back to the period of indigenous Californians. Consumptive services include economically and culturally significant recreational and commercial fisheries and, historically, the harvest of kelp for a variety of uses. Because of their close proximity to shore, kelp forest ecosystems are vulnerable to a number of anthropogenic threats, including diminished water quality (e.g., sedimentation, turbidity, contaminants, shore-based water intake and discharge), direct and indirect effects of fishing, invasive species, and a changing global atmosphere and climate. Climate change can be manifested in kelp forests in a variety of ways, including changes in the magnitude and frequency of major storm events, sea surface temperature, and the magnitude and location of coastal upwelling—all of which determine nutrient availability and the productivity of the forests. Additional climate-related impacts, hypoxia, and ocean acidification may be most pronounced in areas of coastal upwelling, which show dramatic variation in oxygen and pH levels.

While the climate-related threats to kelp forests are relatively intractable to local management, California is taking bold steps to address threats posed by fisheries and water quality. Examples include a recently established statewide network of marine protected areas and more stringent water-quality regulations. It is hoped that these management actions will protect the structural and functional integrity of kelp forest ecosystems, enhancing their resistance and resilience to the multitude of potential perturbations associated with a changing global climate.

THREATS AND RESPONSES

THREATS	RESPONSES
A changing global climate is forecasted to alter coastal oceans in several ways that can have detrimental impacts to kelp forest ecosystems. Increasing surface water temperatures can restrict nutrient availability that fuels kelp production and stresses algae, invertebrates, and fishes, while enhancing bacterial growth and the likelihood of disease outbreaks and changes in current patterns, and also altering species ranges, both native and nonnative invasive species. Declines in the frequency or intensity of upwelling will reduce coastal ocean productivity and the fisheries they support. Changes in the location of upwelling along the coast will cause shifts in associated fisheries. Forecasted increases in the intensity and frequency of El Niño events will increase the frequency and extent to which kelp forests are removed by associated storms and ocean swell. Declines in pH of ocean waters (ocean acidification) can have a variety of physiological consequences for marine organisms. Marked differences in these physiological consequences among the species that inhabit kelp forests are likely to cause changes in their relative abundances and the structure and functions of kelp forest ecosystems. For species with calcium carbonate structures (e.g., shells, skeletal structures), their ability and the rate at which they create these structures can be impaired. How these changes in abundance and productivity will impact the productivity of fisheries associated with kelp forests is unclear. Similarly, declines in oxygen levels of ocean waters (hypoxia and anoxia) will impair growth and survival of invertebrates and fishes and cause changes in their distributions. Physiological and behavioral responses to low oxygen levels can increase the vulnerability of species to their competitors and predators, including fisheries. Another emerging threat to kelp forest ecosystems is the cumulative effects of climate change and other human influences. How the separate and combined effects of these threats change the species composition, functional interactions, productivity, and resiliency of kelp forest ecosystems and their services remains to be seen.	Ensuring the functional capacity of important species (e.g., foundation, keystone, and ecosystem engineers) to contribute to a forest's resistance and resilience by protecting these species from human impacts is essential. Ensure the capacity of species to relocate to areas of tolerable conditions, including different depths or locations along the coast. Networks of marine protected areas (MPAs) simultaneously contribute to protection of ecologically important species and foster the successful movement of species, across depths and along the coast, by protecting habitat and ecosystems to which species can relocate. For these purposes, individual MPAs need to include habitats across depths, and spacing of MPAs in a network should be scaled to distances of larval dispersal and adult movement. The design of MPA networks needs to be evaluated to determine if they are achieving these management goals. Long-term integrated ecological and oceanographic monitoring is required to both identify the ecological responses and consequences of climate change on kelp forest ecosystems and to evaluate how well MPA networks are contributing to the protection of these ecosystems to cumulative human impacts, including climate change. A well-developed statewide, long-term, integrated ecological and oceanographic monitoring program is critical to determining how the different communities described in this chapter (southern, central, and northern California) respond to regional differences in changing oceanographic conditions. Strong coastal development and discharge regulations and infrastructure to support management goals are key to minimizing land-based threats to coastal marine ecosystems, including shallow rocky reefs and kelp forests.

Intertidal Summary

CAROL A. BLANCHETTE, MARK W. DENNY, JOHN M. ENGLE, BRIAN HELMUTH, LUKE P. MILLER, KARINA J. NIELSEN, AND JAYSON R. SMITH

Intertidal ecosystems exist at the interface between land and ocean and occupy a narrow band of the coast that is above water at low tide and underwater at high tide. Organisms occupying intertidal areas have evolved unique adaptations to withstand the wide variation in physical conditions, including temperature, salinity, and desiccation (drying) characteristic of these environments. Although intertidal habitats can have either soft (e.g., sand, mud) or hard (rocky) bottom substrates, we have focused on rocky intertidal ecosystems, which occur along the entire California coast. Rocky intertidal ecosystems of the Pacific coast support a high diversity of invertebrate and algal species and have served as a model ecosystem for experimental marine ecology.

The organisms inhabiting rocky intertidal ecosystems tend to occur in characteristic bands or zones determined in part by time of submergence (underwater) and emergence (above water). Species including rockweed, acorn barnacles, turban snails, and lined shore crabs exist in the high intertidal zone of California's coast, which is inundated only during high tides. The middle intertidal zone, exposed to the air at least once a day, is home to creatures such as sea lettuce, aggregating anemones, chitons, gooseneck barnacles, mussels, and ochre stars. Kelps, coralline algae, surfgrass, giant green anemones, purple sea urchins, and bat stars inhabit the low intertidal zone that is exposed only during very low tides.

Ecological processes, such as competition, predation, and recruitment, play an important role in determining the species composition of intertidal assemblages. Many invertebrate and algal species that occupy the shoreline as adults have early life history stages such as spores and larvae when they may spend days to months drifting in the ocean before settling on the shore. These early life history stages are one important connection between the benthic (rocky bottom) habitat of the intertidal and the pelagic (open ocean) realm. Intertidal organisms also depend on water movement for delivery of food and nutrients as well as reproduction and dispersal.

People use intertidal ecosystems for food and recreation; however, these ecosystems are also sensitive to anthropogenic impacts from pollution, oil spills, harvesting, and trampling. Following the California Marine Life Protection Act (1999), a statewide network of marine protected areas has been established along the California coast, and many of these reserves include significant portions of rocky intertidal habitat. Climate change likely poses the most serious threat to intertidal ecosystems, where many species are already living close to their physiological tolerance limits. Increases in temperature, coastal erosion rates, and sea level rise; decreases in ocean pH; and altered circulation patterns resulting from changing climate conditions all could significantly impact intertidal ecosystems in the coming decades.

THREATS AND RESPONSES

THREATS	RESPONSES
Climate Change: • Increasing frequency and intensity of storms • Alterations of the frequency and intensity of episodic events, such as El Niño Southern Oscillation (ENSO) • Increasing frequency and intensity of upwelling • Ocean acidification • Sea level rise • Changes in water temperature • Changes in coastal weather, including air temperature, fog, cloud cover, and wind • Changes in ocean circulation and nearshore currents, affecting larval dispersal and connectivity • Changes in salinity • Increases in UV radiation	• Support for emissions controls to reduce CO_2 • Support for marine protected areas as a tool to provide ecological resilience to climate impacts through effects on population sizes, habitat representation, and biodiversity
Harvesting: • Commercial • Recreational, subsistence harvesting • Fish bait	• Enforcement of collecting regulations • Limits on harvest • Marine protected areas
Visitation: • Trampling • Rock turning • Handling	• Education about tide pool etiquette • Regulation of numbers of visitors
Threats of Invasive Species:	• Control of invasive species through education efforts • Removal of invasive species early in the invasion period
Coastal Development, Renewable Energy: • Habitat alteration • Sedimentation • Freshwater runoff • Changes in wave climates	• Education about storm drains and runoff • Limit coastal development near rocky intertidal sites • Monitor wave climate • Regulate offshore energy development
Pollution: • Large point source oil spills • Chronic nonpoint source oil • Heavy metals, pesticides, hydrocarbons, other endocrine disrupters, etc. • Thermal • Sewage, nutrient enrichment, eutrophication • Toxic algal blooms	• Reduce coastal runoff • Regulate development by oil companies, farmers, factories, and others to reduce toxic waste

Estuaries: Life on the Edge

JAMES E. CLOERN, PATRICK L. BARNARD, ERIN BELLER, JOHN CALLOWAY, J. LETITIA GRENIER, EDWIN D. GROSHOLZ, ROBIN GROSSINGER, KATHRYN HIEB, JAMES T. HOLLIBAUGH, NOAH KNOWLES, MARTHA SUTULA, SAMUEL VELOZ, KERSTIN WASSON, AND ALISON WHIPPLE

Estuaries are transitional ecosystems at the land's edge where seawater and freshwater meet. California's estuaries are influenced by their connectivity to both the Pacific Ocean through water exchange and immigration of marine organisms, and to watersheds that deliver freshwater, sediments, nutrients, and chemicals contained in agricultural and urban runoff. Estuaries are dynamic ecosystems with physical, chemical, and biological variability caused by tidal oscillations, seasonal and annual variability of precipitation, shifts in the climate system, and human activities concentrated along the coast.

California's estuaries provide habitats supporting a unique assemblage of algae, plants, invertebrates, fish, birds, and marine mammals. Some species are "estuarine endemics," limited in their distribution mostly or entirely to estuaries; others are coastal generalists that rely on estuaries for foraging, resting, or breeding habitat. Some marine fish, crab, and shrimp use estuaries as nursery habitat, while other fishes including salmon, sturgeon, and shad migrate from ocean to rivers to spawn and return as juveniles. Many shorebirds, waterfowl, and seabirds rest and forage in California estuaries as residents or during annual migrations along the Pacific Flyway.

Commercial fishing has long ended in California's estuaries, but ocean fisheries include many estuarine-dependent species such as Dungeness crab, English sole, and California halibut. Estuaries harbor shellfish including native oysters, and support shellfish culture. Tidal marshes sequester substantial carbon, protect shorelines from storm surges and floods, and filter contaminants. Estuarine microbes assimilate human wastes and degrade many organic pollutants. The natural harbors of California provide ports for commercial transport. Coastal settings provide breathtaking beauty and many opportunities for recreation.

Degradation of estuarine ecosystems has occurred through many human activities and land uses. As a consequence, more than 90 percent of California's tidal marshes have been lost, and fifteen species of mammals, birds, and fish are at risk of extinction.

THREATS AND RESPONSES

THREATS	RESPONSES
Habitat loss and alteration: Through filling, diking, excavation, and urbanization we have substantially altered the mix of habitats within California's estuaries.	Greater effort is required to restore estuarine ecosystems, and strategic regional planning should be developed and expanded to incorporate a mix of habitat types along the gradient from subtidal areas to uplands.
Altered freshwater inflows: State and federal agencies face an enormously challenging task of finding allocations of freshwater that balance the needs of agriculture, our growing population, and protection of fish, birds, and wildlife that depend on estuaries.	Resource agencies must agree on criteria to establish the minimum freshwater inflow required to support estuarine ecosystem services upon which we rely. Keys to success are a mechanistic understanding of the linkages between freshwater inflows and ecological condition, and creative use of adaptive management.
Altered tidal flows	Adaptive management plans for water control structures, such as tide gates, can improve function of managed wetlands.
Eutrophication and hypoxia: Many estuaries receive nutrient inputs from wastewater treatment plants and urban and agricultural runoff, leading to eutrophic symptoms such as harmful algal blooms, hypoxia, and loss of seagrasses.	Greater clarity is needed on biological assessment endpoints to guide management of nutrient loads to California's estuaries.
Pollutants	Identify the risks and policy approaches for minimizing threats to estuaries from contaminants of emerging concern and from nonpoint sources such as urban and agricultural runoff.
Estuarine acidification: Low pH water affects the survival of mollusks and other invertebrates. It also alters fish foraging, predation escape, migration, and reproduction.	Reduce carbon and nutrient pollution inputs that can exacerbate ocean-driven acidification, and investigate the use of seagrass habitat to buffer acidification effects on nearshore and estuarine habitat.
Sea level rise	Consideration of strategic placement of sediment to accelerate marsh accretion and other flexible sediment management policies will be needed to maintain estuarine sediment supplies.
Invasive species	California's 2003 Marine Invasive Species Act is among the strictest U.S. regulations of ship ballast discharge to prevent or minimize the introduction of nonindigenous species from commercial vessels. However, ballast water is only one of many vectors for invasive species establishment. A more comprehensive approach to invasive species management is needed.

Sandy Beaches

JENIFER E. DUGAN AND DAVID M. HUBBARD

Composed of sand and biota constantly moving across and along the shoreline, sandy beaches are among the most dynamic ecosystems in the world. Dominating open coastlines of California, beaches are iconic assets highly prized for recreation and coastal economies.

Less appreciated is the fact that beaches are ecosystems that harbor unique biodiversity, support productive food webs, and provide irreplaceable ecosystem functions and services to society. These include filtering vast volumes of seawater and buffering the land from storm waves.

Although their characteristic, highly mobile burrowing animals are often invisible to a casual visitor, California beaches can be hot spots of intertidal biodiversity. Subsidies of kelp and phytoplankton from other marine ecosystems to beach food webs fuel intense biological productivity capable of supporting a high abundance of wildlife, rapid processing of organic inputs, and high rates of nutrient remineralization.

Ongoing disturbance and escalating threats to beach ecosystems pose formidable challenges in California and elsewhere. Groomed beaches in urban areas are subject to the most intense disturbance regime of any ecosystem in the state. Beaches are increasingly trapped in a "coastal squeeze" between urbanization and effects of sea level rise from climate change. Societal responses to beach erosion and retreat rely largely on "soft" (beach filling) or "hard" (shoreline armoring) engineering that both affect the biodiversity, food webs, and functioning of beaches as ecosystems.

The widespread but unsupported assumption that beach ecosystems recover very rapidly from all forms of disturbance is used to justify numerous management actions. Increased recognition and understanding of sandy beaches as vulnerable and threatened ecosystems are needed to conserve and protect these dynamic ecosystems on the edge of a warming and rising sea.

THREATS AND RESPONSES

THREATS	RESPONSES
The most intensive development, direct manipulations, and intense human recreational activities occur in upper shore zones of beaches. These upper shore zones are vital to nesting or nurseries of beach wildlife and support numerous endemic species with low dispersal abilities.	Recognize upper shore zones as Environmentally Sensitive Habitat Areas (ESHAs) and designate beaches as coastal wetlands to provide a policy framework to address impacts to beach ecosystems. Extend the boundaries of state marine protected areas (MPAs) inland from the mean high tide line to the extreme high water line to protect sandy beach ecosystems.
Armoring and resulting passive erosion effects have reduced beach widths and habitat extent over large stretches of the California coastline. The most intense impacts of armoring are generally to the upper shore zones and biota. As sea level rise contributes to coastal squeeze, the impacts of these structures on beaches will intensify.	New armoring projects are subject to state approval and permits. Many new and existing structures are unpermitted. A few projects have removed armoring and moved threatened infrastructure inland to allow coastal retreat, demonstrating approaches that could provide ecological and economic benefits.
Reductions in sand supply due to dams and sand mining have significant implications for the quality and quantity of beach habitat. The impoundment of sand behind dams alone is estimated to have reduced sand supply to beaches by 50 percent in southern California.	Responses include removing obsolete dams and coastal structures that are barriers to sand transport. Regulating sand mining in riverbeds, dune fields, and other source areas also could enhance sediment supply to the coast.
Beach filling projects cause mortality of wildlife and can profoundly alter sediment characteristics, inhibiting ecological recovery. Beach filling has been conducted on a massive regional scale for years in California with little to no scientific evaluation of the direct or cumulative ecological impacts on beach ecosystems or other coastal ecosystems.	Recognizing beaches as ESHAs and coastal wetlands would provide a policy framework to address these impacts. Develop beach filling that more closely emulates the natural processes of sand delivery to the coast.
Beach grooming (or raking to remove trash and drift seaweeds) results in major impacts to biodiversity and ecosystem functions. In addition, a number of the MPAs established by the state in 2012 allow beach grooming in the boundaries.	New permits for beach grooming are no longer being issued by the state and are being replaced by local voluntary programs such as modified grooming to avoid disturbing the eggs of beach nesting grunion. Educational outreach on the role of drift seaweeds in beach ecosystems, combined with the creation of no grooming zones, could help conserve beach biodiversity.
Climate change, including sea level rise and increased storms, is expected to intensify pressures on beach ecosystems by increasing rates of shoreline erosion and degrading habitat. These impacts will be most severe where coastal land uses and development constrain shoreline evolution and retreat.	Comprehensive conservation planning for coastal habitats is needed to allow scope for retreat of soft sediment shorelines like beaches. This planning should include current conditions and resources, existing uses and designations, projections for change, and the use of innovative conservation and restoration approaches.

Coastal Dunes

PETER ALPERT

Coastal sand dunes are recycled land that is washed down from inland mountains in rivers, carried alongshore by currents, washed ashore by waves, and blown in from beaches to form a moving landscape of ridges and hollows. Dunes have distinctive plants and invertebrates, some that are rare or confined to the state. Plants that colonize bare dunes stabilize them, at which point other plants appear, and the main factors controlling vegetation shift from movement of sand to availability of resources such as water, nitrogen, and light.

Coastal dunes offer the people of California recreation, scenery, and attractive sites for construction. However, the movement of sand dunes also can damage property and infrastructure. People have responded by protecting some dunes, building over many of the dunes close to cities, and stabilizing dunes with introduced plants. Dunes in northern California now are largely covered with introduced plants, dunes in southern California have been mostly built over, and most of the state's relatively intact dunes lie within public reserves.

The California Coastal Commission, created by the California Coastal Act of 1976, regulates further development of coastal dunes in most of the state. Management of remaining dunes requires a balance of human use and conservation, restoration of dunes laid bare by use or covered with introduced plants, and control of introduced plants where communities of native plants and animals persist. Restorations have been notably successful at several sites in northern California. In the long term, the future of dunes is linked to climate change. Rising sea level is expected to displace dunes inland, likely causing net loss.

THREATS AND RESPONSES

THREATS	RESPONSES
Introduced, invasive plants are cutting off the supply of sand to dunes and crowding out native species.	The three most invasive species, European beach grass, highway ice plant, and purple veldt grass, can be prevented from spreading further and even locally removed in the ten or so best remaining examples of native dune communities.
In some places, trampling and driving are denuding dunes.	Managers can balance recreation and conservation at individual sites based on potential for recreation and the level of remaining native biodiversity.
Rise in sea level and increase in intensity of storms may eventually flood and erode dunes.	Only global reductions in emissions of greenhouse gases can respond to threats of sea level rise and intensity of storms.

Coastal Sage Scrub

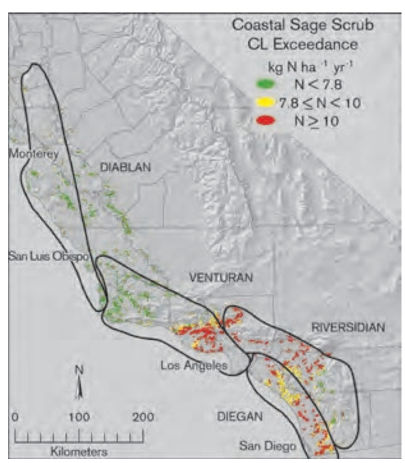
ELSA E. CLELAND, JENNIFER L. FUNK, AND EDITH B. ALLEN

From a distance, coastal sage scrub might not appear the most compelling of California ecosystems. Short in stature, it lacks the majesty of a redwood forest, but up close, coastal sage scrub is a feast for the senses. This ecosystem is known for its fragrance. Shrubs in the genera Artemisia and Salvia often dominate it, and visitors are frequently overwhelmed by the heady scent of sage in the air.

Coastal sage scrub is renowned for both its beauty and its spectacular diversity. It includes some two hundred species of forbs throughout its range and a diverse array of associated animal species of conservation concern. Coastal sage scrub, with its interspersed forblands and riparian areas, has a greater concentration of rare species than other any California ecosystem type.

Coastal sage scrub is also among the most threatened ecosystems, facing numerous challenges for land management and conservation. Its inherently coastal distribution means that this ecosystem faces some of the greatest pressures associated with anthropogenic and land use change, as well as other environmental changes associated with large human population centers—in particular, nitrogen deposition from fossil fuel production, accelerated fire regimes, and invasion by exotic species. Exotic annual grasses are especially problematic and often defy attempts at restoration. Recent research in coastal sage scrub has focused on environmental conditions that favor native shrub establishment over the growth of exotic annual grasses, opening windows into our understanding of how factors such as fire and seasonality influence species interactions in this ecosystem.

Exotic annual grasses that have senesced late in the growing season on a previously burned hillside in Orange County, surrounded by mature coastal sage scrub. Exotic grass litter is highly flammable and helps spread fire, fueled by Santa Ana winds in many parts of southern California. Photo: Jennifer Funk.



Critical loads (CL) of anthropogenic nitrogen (N) deposition in coastal sage scrub, which increase exotic grass productivity and reduce richness of native forb and arbuscular mycorrhizal species. The higher value of 10 kg N ha-1 yr-1 is based on modeled CMAQ (Congestion Monitoring and Air Quality) data; the lower level of 7.8 is based on empirical data (data from Fenn et al. 2010).

THREATS AND RESPONSES

THREATS	RESPONSES
Land use change and disturbance: Only a small fraction of the historical extent of coastal sage scrub remains today, due predominantly to urbanization and agriculture. Frequent disturbance at the urban-wildland interface has negative impacts on the iconic plants and wildlife of coastal sage scrub. Disturbances include soil disturbance, fire, invasion by exotic species, pollution, and dust from adjacent roads.	Increasing the level of protection on remaining coastal sage scrub habitat is key to the long-term persistence of coastal sage scrub species. Reducing disturbances on and adjacent to protected lands is of key importance.
Invasion by exotic species: Invasion by exotic annual species is a major threat to coastal sage scrub communities, competing with native plant species, reducing the survival of regenerating shrub seedlings, and making habitat unsuitable for some threatened and endangered animal species.	Exotic annual grass invasions are promoted by soil disturbance, fire, and nitrogen deposition, hence managing to prevent these environmental changes can aid in maintaining healthy coastal sage scrub communities. Restoration efforts following fire or disturbance can use strategies to favor native species over invaders. For instance, exotic annual species often have numerical dominance in seed banks and can competitively suppress native seedlings emerging from seeding efforts, but have less impact on larger, planted individuals. Irrigation can be detrimental to native coastal sage scrub species, favoring exotic species instead. Mowing or raking to remove exotic annual thatch in open areas can favor some native species that require high light environments to establish. Finally, timed herbivory in some areas has been shown to reduce seed output of herbaceous exotic species, especially early in the growing season before native species have flowered.
Accelerated fire regimes: In the fragmented landscapes characterizing current coastal sage scrub habitat, fires are more frequent today than they were historically. Today, fires also promote the spread of invasive species, and the combination of fire and subsequent invasion can strongly suppress coastal sage scrub regeneration.	Fire management is a complex issue, and local knowledge is important for identifying the best strategy for maintaining healthy habitats. Some wildlife characteristic of coastal sage scrub requires open areas between shrubs, which are promoted by a patchwork of controlled burning. Other wildlife find recently burned areas unsuitable habitat. Therefore, the choice of fire management strategy will depend on the species of conservation concern at a particular site. Preventing unintended fires, of course, is of paramount importance.
Nitrogen deposition: Many areas of southern California are already experiencing levels of nitrogen deposition that exceed the critical loads identified for coastal sage scrub. In these areas nitrogen deposition promotes the growth of invasive annual grasses, increasing fine fuel loads and contributing to faster-moving and larger fires.	Efforts to improve air quality and reduce tailpipe emissions will be the most effective way to reduce nitrogen deposition in the southern coastal regions of California, where levels already exceed critical loads. During restoration efforts, the addition of carbon-rich native mulch or sawdust may lower soil nitrogen levels through microbial immobilization, thus reducing invasion by exotic annual species.
Climate change: The southern half of California is expected to become warmer and drier in the coming decades. Vulnerable species will need to adapt or shift their distributions to newly suitable areas in order to persist. Species distribution models demonstrate that dispersal for many species will be limited by habitat fragmentation and lack of appropriate corridors.	In addition to state, national, and international efforts aimed at preventing further climate change, policy and management efforts can mitigate some of the potential negative impacts of climate change. In particular, protecting key natural areas that link habitats would protect corridors for dispersal and migration, enabling species persistence in a changing climate. Additional work needs to be done to identify appropriate seed mixes for restoration efforts, taking into account the potential for local adaptation to climate and other local factors, such as soil types or microbial communities.

Grasslands

VALERIE T. EVINER

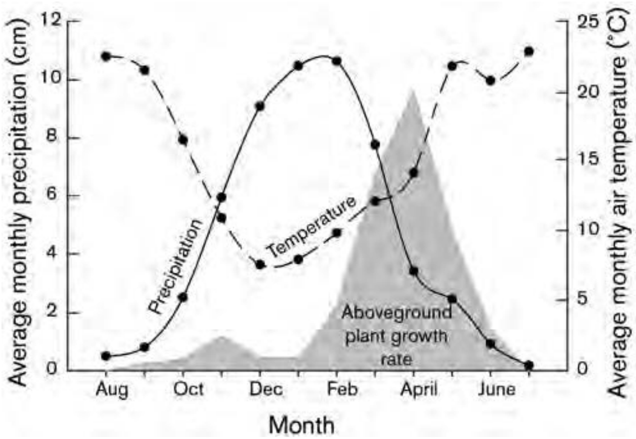
Grasslands are one of the most altered ecosystems in California, with nonnative plant species comprising more than 90 percent of plant cover in most areas. Despite this, California's grasslands are a diversity hot spot, averaging greater than fifty plant species per 30-by-30 meter area and providing habitat for nearly 90 percent of state-listed rare and endangered species and seventy-five federally listed plants and animals. They also provide 75 percent of the state's livestock forage, the main direct economic benefit from these systems. These grasslands are critical in regulating water flow (e.g., flood prevention, maintaining stream flow into the dry seasons) and water quality, and contribute significantly to regional soil carbon storage. Grasslands also support a large portion of the pollinators needed in California's cropping systems.

California's grasslands are distributed across a wide precipitation gradient, ranging from 12 to 200 centimeters per year. The drier interior grasslands tend to be dominated by nonnative annuals, while the wetter coastal grasslands tend to be dominated by a mix of native and nonnative perennials. Unique soil conditions (e.g., poor drainage, salinity, heavy metal toxicity) also define distinctive grassland types such as vernal pools, alkali sinks, and serpentine grasslands. Even within each of these grassland types, there is considerable variation in ecosystem structure and function, due to spatial and temporal variability in seasonal and annual weather patterns, topography, soil, disturbance regimes, and interactions among large herbivores, small mammals, insects, microbes, and plant communities. The predominance of annual species likely makes California's grasslands particularly sensitive to intra-annual and interannual fluctuations in abiotic and biotic controllers.

The high variability in multiple controlling factors leads to both challenges and opportunities in land management. Successful management and policy will have to shift away from a one-size-fits-all approach and embrace the reality that different techniques and guiding principles are needed from site to site, due to variations in soil, topography, and weather. In addition, at a given site, management recommendations may vary from year to year, due to high weather fluctuations (see "Range Ecosystems"). Managers and scientists will need to collaborate on adaptive management approaches to understand how multiple environmental conditions interact to impact a given goal, while exploring the synergies and trade-offs associated with suites of species and ecosystem services needed from grasslands. The dominance of annuals over large areas of grasslands will require sustained management for many different goals but also provides a relative flexibility in "resetting" the system through adaptive management approaches.

Because 88 percent of California grasslands are privately owned, conservation and restoration of these grasslands largely depends on private landowners and how they balance management for livestock production, biotic diversity, and ecosystem services.

Currently, many ranchers actively manage grasslands to improve wildlife habitat, decrease noxious weeds, and enhance water quality.



Temperature and Precipitation in Parts of California

Seasonal variations in temperature (dashed line) and precipitation (solid line) drive plant growth rate (gray shaded area), with most production occurring when both moisture and ideal growing temperatures are present. Temperature and moisture data are from the California Irrigation Management Information System (CIMIS), averaged from 1985 through 2005 and across grassland sites, including: Sierra Foothills, San Joaquin Valley, Bay Area, Sacramento Valley, North Coast Valley, South Coast Valley, and Central Coast Valley. The left-side y-axis provides the precipitation scale, while the right-side y-axis represents the temperature scale. Aboveground growth rate is not present on either y-axis, but scales from 0 to 200 g/m2/month. Growth rate data is a seasonal average across experimental sites in the Central Valley and North Coast (Eviner, unpublished data). Source: Figure updated from Biswell 1956.

THREATS AND RESPONSES

THREATS	RESPONSES
On average, over the past few decades, more than 190 square kilometers of grassland per year have been lost to vineyards, orchards, dispersed housing, and urban development, and this loss of grassland is expected to continue in the future, particularly with losses to vineyards and urban areas. Many large ranches are being subdivided, and these smaller parcels receive less management for species conservation and ecosystem services. This lack of management results in the loss of many key ecosystem services these systems provide, including pollination of adjacent crop systems and livestock forage.	Incentives to maintain these areas as rangelands (rather than being developed) are greatly needed to preserve grasslands. For all incentive programs, it will be important to foster site-specific management, rather than a uniform approach, because California's grasslands are extremely heterogeneous in climate, soil, and other environmental factors, and management for a given goal at one site may decrease that goal at another.
Many grassland areas are now experiencing a lack of fire or grazing, leading to thatch buildup, domination by noxious species such as ripgut brome, and decline in key services such as productivity, wildlife habitat, pollination, and plant diversity (particularly wildflowers).	Expanding incentive programs (e.g., water quality approaches through the Natural Resources Conservation Service) can improve ecosystem services, including wildlife habitat, pollinator habitat, carbon sequestration, invasive species control, native plant species diversity, water quality, erosion control, and fire control.
Reduced burning is causing thatch buildup, leading to lower plant diversity (particularly loss of wildflowers), and more intense fires.	Fire is a key management tool in conservation and restoration, but is nearly inaccessible to most land managers due to fire restrictions. Working with conservation managers to provide opportunities for burning can be critical for maintaining native diversity.
Nitrogen deposition is increasing the spread of invasive species on approximately 44 percent of California's grassland areas.	Of the many environmental changes California is experiencing, this may be the most straightforward to rectify by limiting nitrogen pollution from fossil fuel emissions and fertilizer.
While California's grasslands have been dominated by nonnative plants for more than 200 years, more recent invasions of harmful exotic plants (e.g., barbed goatgrass, yellow starthistle) are increasing in prevalence and range. These new invasions threaten plant diversity and livestock forage and productivity. Species like barbed goatgrass are also able to invade into previously uninvaded native refugia, such as serpentine soils, which provide hot spots for native plant diversity.	While eradication of widespread invasive species may not be feasible, it is possible to limit spread of invasive species that are not yet widespread, and to prevent new invasive species. Key policy changes to limit spread include requiring practices to clean livestock and vehicles (e.g., construction, utilities) that can become contaminated with invasive seeds and disperse them widely to new sites. Restoration of native communities that are resistant to these invaders can also be an important tool for limiting their prevalence. Early detection and eradication programs are central to minimizing the spread of new harmful invaders.

Chaparral

V. THOMAS PARKER, R. BRANDON PRATT, AND JON E. KEELEY

Chaparral shrublands are biotically diverse and the most abundant vegetation type in the state. These shrublands are dominated by evergreen species and occur in areas with hot, dry summers and cool, moist winters. The species that inhabit the chaparral have adapted to a Mediterranean-type climate. Chaparral is a dynamic ecosystem, and wildfires (see “Fire as an Ecosystem Process”) facilitated by the summer rainless period are more predictable than in many other fire-prone landscapes; this predictability is reflected in many evolutionary responses to fire. While diverse in microbes and animals, the dominant plants exhibit characteristics explicitly selected by wildfire in their development of persistent soil or canopy seed banks.

Chaparral ecosystems provide many services, such as the stabilization of steep slopes, filtration of drinking water, and myriad recreational opportunities. They also beautify the landscape for many millions of California inhabitants and visitors. Increasingly, chaparral is being managed for its intrinsic value to resource conservation and even through community restoration programs. There are many threats to chaparral ecosystems from climate change, altered fire regimes, development, nonindigenous invasive species, and poor management.

THREATS AND RESPONSES

THREATS	RESPONSES
Incomplete recognition of the difference in fire regimes, endemic species. and rare and threatened species that occupy chaparral. Because chaparral is not often perceived properly, it is quite vulnerable to human mismanagement, fragmentation, and global warming.	Chaparral has a distinct fire regime compared to other vegetation types, especially forests. Because it is geographically widespread, chaparral also varies in its fire regime among locations. This variation is not always clearly recognized in the statewide vegetation management practices of many agencies. The great biodiversity that chaparral harbors is similarly little recognized. Finally, chaparral provides considerable ecosystem services, including watershed issues such as water quality and erosion prevention that are often overlooked because of wildfire potential. Science-based management policies specific to the various types of chaparral need to be developed.

Fragmentation due to firebreaks	Policy responses to chaparral tend to focus only on fuels, and ften specify clearing or chipping chaparral in areas far from urban development. Pre-fire vegetation management needs to be recognized as a resource sacrifice when done in shrublands, and thus needs to be carried out prudently.
Fragmentation due to human development	Development adjacent to high-intensity wildfire habitat is not smart policy. County and state development policies need to consider chaparral and wildfire analogous to floodplains. Flooding is inevitable in floodplains, and fire is inevitable in chaparral. Development needs to occur in other locations and be highly regulated near chaparral.
Fragmentation due to agriculture (e.g., vineyards) and other forms of brush clearing	Fragmentation needs to be seen as a resource sacrifice and mitigation banks need to be created.
Altered fire regime is a major threat. Chaparral depends on fire in a limited range of fire regimes. Too many fires are happening in southern California and too few are occurring in other places.	Management should be focused at the Wildland Urban Interface (WUI) and leave the bulk of the landscape alone. Sources of altered fire regime include flash fuels associated with fuel breaks, urban development, agriculture and brush clearing, fire suppression, and global warming. A major source is accidental fire associated principally with development or fragmentation.
Multiple issues are involved with the threat of invasive species. One prominent one is an increase in flash fuels. Roadsides, fuel breaks, and other forms of disturbances or fragmentation increase the abundance of annuals and invasives that create easy-to-burn, flash fuels.	Stop making firebreaks that get colonized by annual grasses, keep grasses down along roadsides, and minimize clearing around homes or require homeowners to control flash fuels. Create policies that limit management and disturbance away from the WUI.
Invasive species that may displace chaparral, like invasive woody species such as French and Scotch broom and invasive annuals	Undisturbed chaparral or chaparral with natural high-intensity fire tends to maintain itself and inhibit invasion; that is not the case with altered fire regimes. Policy considerations should include limiting any activities that fragment or disturb the habitat. Also, restrictions should be placed on the horticultural trade to prevent the sale and spread of invasive plants.
Invasive species that are pathogens, such as the many species of Phytophthora	Policy should examine nursery trade introductions and methodology with respect to sources of soils and sterilization.
Climate change. Droughts are causing major mortality in southern California, fundamentally altering many of our shrublands. Droughts also are leading to an accumulation of dead fuel, inviting more intense fires to come at some point in the future. In addition, there are some signs of pathogens driving mortality of the weakened plants (e.g., Pepperdine University biologist Steve Davis is finding pathogens in Malosma laurina in the Santa Monica Mountains).	In a nutshell, we should keep our eyes open for mortality events (formal monitoring would be ideal) as a robust sign of change and come up with management strategies to cope with and figure out how to respond. Is chaparral going to convert to sage shrublands? Are chaparral stands going to convert to annual grasses? Perhaps county, state, and federal agencies could collaborate on a statewide monitoring effort.
We need to try to restore chaparral shrublands that have been degraded. This neglected ecosystem could be valuable as wildland habitat and for erosion control.	Chaparral is a diverse ecosystem with many rare and endemic species. Management plans demand science-based approaches. For example, the California Department of Forestry and Fire Protection (CalFire) management needs more science input. The California Coastal Commission needs more enforcement officers. We should set aside unprotected chaparral areas through mitigation banks. Perhaps the State of California needs a scientific advisory body.

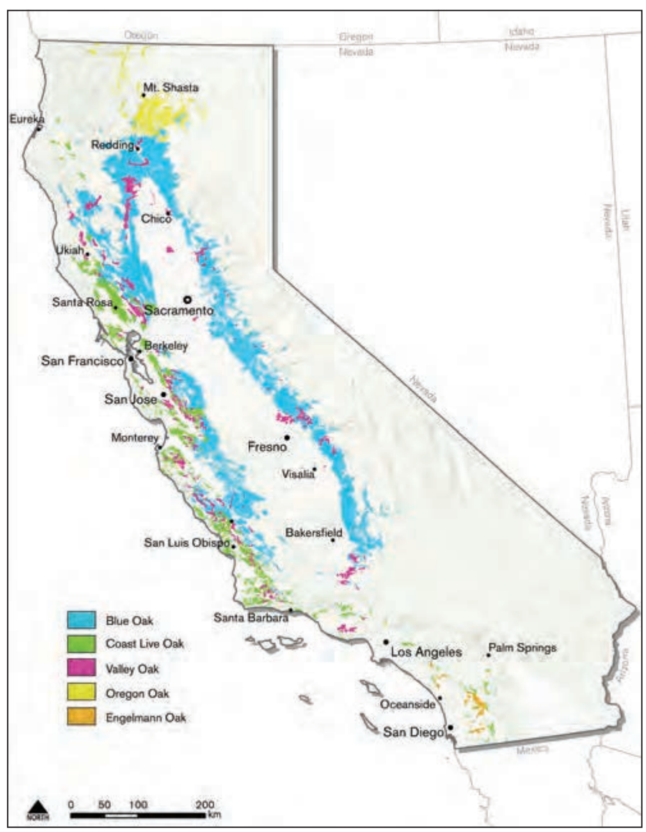
Oak Woodlands

FRANK W. DAVIS, DENNIS D. BALDOCCHI, AND CLAUDIA M. TYLER

California's oak woodlands occupy a wide range of foothill and montane environments and harbor exceptional plant and animal diversity. The open canopy of scattered trees over grass or shrub understories creates high local variation in microclimates and soils associated with tree understories and canopy gaps. The acorn crop is an important food resource for many animal species, and the trees also supply important habitat elements such as trunk cavities and downed wood. Oaks serve as foundation species in these ecosystems in that they exert inordinate control on community and ecosystem processes.

The climate of foothill oak woodlands combines high temperature seasonality, low winter and early spring rainfall, and summer and autumn drought. Both evergreen and deciduous oaks in these woodlands must cope with extreme summer heat and moisture stress. They do so by gradually reducing gas and water exchange between leaves and the atmosphere over the course of the summer and by tapping deep soil water and/or groundwater. Net primary production is largely controlled by the amount of available water, and in general uptake of carbon dioxide by photosynthesis is only slightly higher than loss of carbon dioxide through ecosystem respiration. Because oak woodlands occupy such a large area (roughly 3.5 million hectares), this small per-area carbon gain translates into significant carbon storage across the entire system. For example, blue oak woodlands are estimated to store around 8.6 teragrams of carbon annually on a statewide basis.

Oak woodlands have been significantly reduced in extent by agricultural and residential development. Ongoing suburban and rural residential development poses the greatest immediate threat to remaining oak woodlands, but climate change is also a serious concern. Both land development and climate change threaten to diminish the many ecosystem services provided by oak woodlands such as forage for livestock, important habitat for game and nongame wildlife species, and highly valued scenery. These services are mutually compatible, allowing for bundling of multiple services when designing conservation strategies such as payments for ecosystem services or purchasing of development rights.



Generalized distributions of foothill oak woodlands in California. Montane oak woodlands are not mapped. Data from U.S. Geological Survey, Gap Analysis Program (GAP). Map: Parker Welch, Center for Integrated Spatial Research (CISR).

THREATS AND RESPONSES

THREATS	RESPONSES
Oak woodland conversion to residential use, orchards, and vineyards threatens hundreds of thousands of hectares of remaining oak woodlands. Ongoing habitat loss and fragmentation jeopardizes the long-term sustainability of oak woodland ecosystems in several parts of the state.	Existing local and county ordinances have reduced tree removal rates but haven't fully conserved the biodiversity or ecosystem services of oak woodlands. Encourage landowners to retain trees, maintain native understory, and control invasive species. Mitigation of adult tree removal should adopt planting ratios (the number of planted seedlings per removed tree) that are consistent with documented seedling and sapling survival and growth rates. Sustainable livestock ranching and investments in conservation easements should be conducted over large contiguous blocks of oak woodlands.
Declining tree population size and tree densities could negatively impact oak genetic diversity and wildlife populations in areas with low regeneration rates.	Strategically use mitigation funds in woodland conservation and restoration priority areas. Regeneration can be accelerated with inexpensive seedling and sapling shelters, and with progressive livestock ranching techniques such as late-spring and summer fallowing and by fencing off riparian areas.
Sudden Oak Death (SOD) has killed millions of tanoaks, live oaks and black oaks. Spread of the disease into currently uninfected areas is a major concern.	International, federal, and state quarantine policies have been designed to reduce risk of reintroduction or spread of the disease; it is important that these policies are consistently enforced. Surveillance efforts must be maintained in vulnerable areas. Develop rapid response strategies for controlling new infestations and management plans for infested areas.
Goldspotted oak borer (GSOB) is a nonnative beetle that can kill adult coast live oaks and California black oaks. The species has invaded large areas of San Diego County and could potentially spread over a large area of California and southern Oregon.	The borer is spread mainly through GSOB-infested firewood. Public education is critical to reduce transport of infested firewood to noninfested areas. Conduct surveillance and rapid response in newly infested areas. Promulgate and enforce existing protocols for prompt removal and proper disposal of infested oaks.
Fire suppression has led to conifer encroachment, notably in black oak and Oregon white oak woodlands. The ongoing loss of oak woodlands is especially pronounced in the Oregon white oak woodlands of northwestern California.	Oak woodlands undergoing conifer encroachment can be restored using mechanical conifer removal and controlled burning to eliminate conifer seedlings. Amend the California Forest Practice Act to allow for oak woodland restoration.
Climate change is likely to disrupt oak woodlands statewide. Some areas that now support conifer and mixed hardwood-conifer forests could become more climatically suitable for oak woodland species.	Promote conservation of regional and landscape-scale habitat connectivity and maintenance of genetic diversity. Expanded protection and restoration of riparian zones and oak woodland landscapes with high topographic and soil diversity could reduce vulnerability of oak woodland biodiversity. Promote adaptive ecosystem monitoring and management based on explicit management goals and objectives.

Coastal Redwood Forests

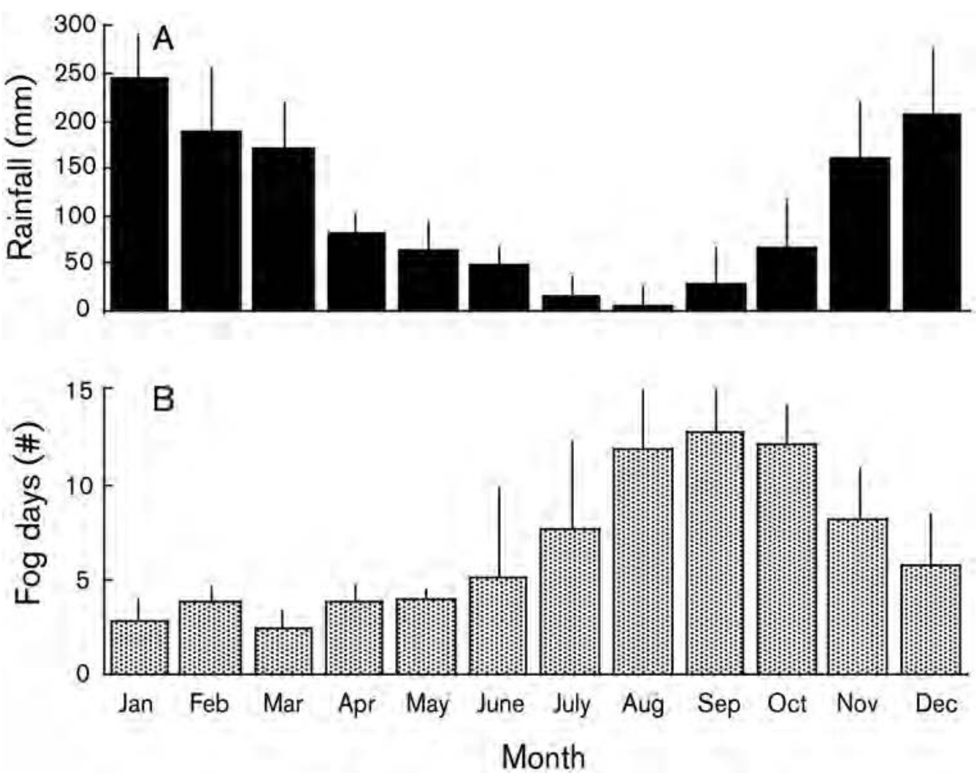
HAROLD MOONEY AND TODD E. DAWSON

The redwood forest region of California occupies the coastal plains and mountains of northwestern California. The region is rich in its diversity of ecosystem types—a feature driven mainly by topographic and substrate diversity. Northern coastal forests, which extend into Oregon and Washington, are remarkable for their diversity of conifers and for their longevity. This heavily forested region is relatively sparsely occupied by humans. The high rainfall of the area's uplands feeds a large number of rivers that flow into the Pacific, including some in a wild condition, a rarity in California. The iconic redwood forest ecosystem, located mainly on ocean-facing slopes and plains, attains world records for tree heights and biomass accumulated during the millennial lifespan of its dominants. This forest type had a vast distributional range in prehistoric times, when a summer rainfall climate existed in California. With the disappearance of summer rainfall, this ecosystem is now restricted to the cool temperatures of the northern coast, where fog occurs in the summer. Redwood trees trap fog water to support their own growth and provide moisture from drip to understory plants as well as tree roots. The future of this ecosystem under ongoing climate change will depend largely on the fate of the cold California Current, which has a marked impact on patterns of winter rainfall and generates both the summer drought and conditions leading to summer fog.

Because of the very large leaf area of redwood forests and their predominantly evergreen nature, very little light falls on the understory plants, particularly at ground level. The inhabitants of these areas have specialized capacity for capture and utilization of light energy. The relatively stable, cool, and moist conditions of the forest support a diversity of fungi that play a key role in ecosystem nutrient balance through symbiotic relationships. Furthermore, high atmospheric moisture and diversity of tree trunk surfaces, and soil development in tree crevices, provide habitat for a large number of epiphytic plants and animals. Unlike in the Sierra Nevada, where much land was put into forest reserves and parklands early in the history of the state, the vast majority of California's northern coastal forests remained unprotected until relatively recently. Only in the last several decades was Redwood National Park established, although earlier efforts provided some conservation areas elsewhere in the state. Today just 4 to 5 percent of old-growth redwood forests remain and virtually all are protected. The large area of young forest, under both public and private ownership, is now being managed in a more sustainable manner with increased attention to the dynamics of the entire redwood ecosystem.

THREATS AND RESPONSES

THREATS	RESPONSES
Historically, redwood forests have been threatened by the demand for lumber, with timber harvests increasing about 600 percent in some areas after World War II.	California's Forest Practice Act of 1973 was passed in response to these harvesting practices that led to the loss of more than 90 percent of mature redwood forests. The act has changed forestry practices on both private and public lands, with particular attention to protecting riparian areas.
The primary threat to the future of these forests is the fate of the cool, temperate climate, including foggy summers, that favors redwoods. A critical "controller" of fog production is the cold water associated with the California Current. If the current warmed, the critical elements behind fog and low cloud formation along the coast would be lost.	Scientists and environmental managers are studying the effects of global climate change on California's climate and are modeling likely shifts in forest species in response to warmer scenarios to improve future conservation planning.
Climate change also affects the frequency and severity of wildfires. Though redwoods are typically more resilient to fires than other species of trees, the increased extremes of heat and fire frequency threaten even the largest and oldest trees.	Prescribed burns, improved road infrastructure, and other forest management practices can be very useful in managing the threat of wildfires. With adaptive fire management plans, the forests' vegetation can be controlled and fuel loads can be lowered, making them less susceptible to catastrophic fires.



(A) Rainfall amount and (B) fog frequency by month in the North Coast redwood country. Source: After Dawson 1998.

Montane Forests

MALCOLM NORTH, BRANDON COLLINS, HUGH D. SAFFORD, AND NATHAN L. STEPHENSON

The strong, seasonal drought and historically frequent fire associated with a Mediterranean-type climate shape the composition and distribution of California's montane forests. Differences in fire intensity and soil moisture availability associated with small- and large-scale topographic features such as drainages, aspect, and slope position affect ecosystem productivity and processes as well as ecosystem resilience to the most common stressors: fire, drought, and bark beetles. The resulting forest is highly heterogeneous, and the range of habitats—from dry, open woodlands with understory shrubs to dense, mesic, multistory stands—supports the highest vertebrate diversity of California's forest types. Sensitive and threatened species are most associated with forest structures and habitat that have become increasingly rare after a century of logging and fire suppression.

Management of these forests on public lands tends to focus on reducing densities of trees and fuels accumulated from fire suppression and increasing frequency and extent of low-intensity burns. This type of burning has demonstrated potential to restore many ecosystem processes that have stalled in the long absence of fire. It also appears to build forest resilience to stressors likely to increase under climate change, such as drought and pests.

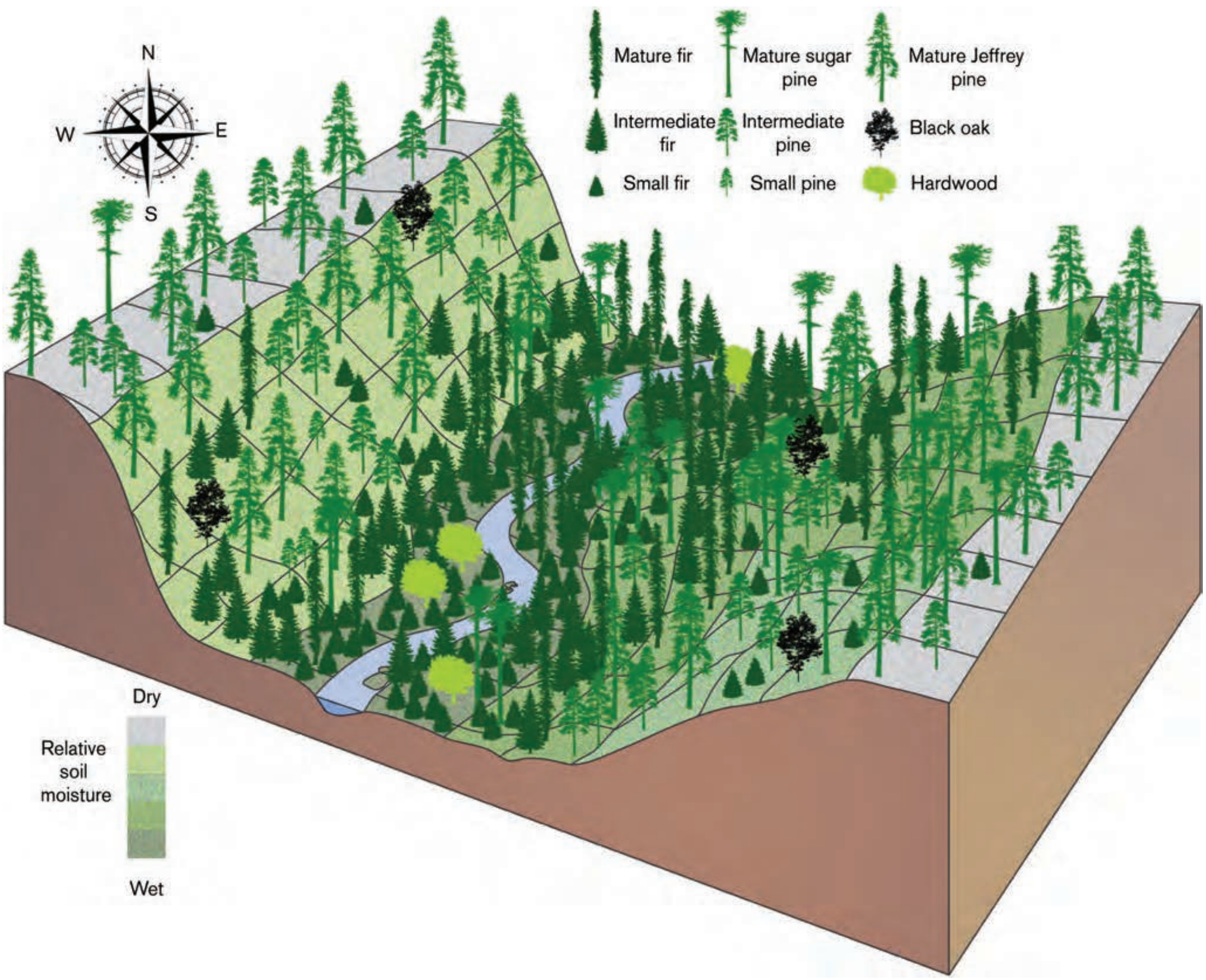
Montane forests provide important ecosystem services to the state's large and growing population, including much of its water and hydroelectric power, as well as substantial carbon storage, which can help offset human CO_2 emissions. Although many challenges confront montane forests as human population and rural home construction increase, lessons learned from past forest management and progressive use of fire provide future pathways for sustaining and improving the ecological resilience of these forests.

THREATS AND RESPONSES

THREATS	RESPONSES
Past logging has reduced the extent of old forest conditions, and decades of fire suppression have made forests susceptible to drought and uncharacteristically severe wildfires.	Protect large old trees while removing small, fire-sensitive trees with either mechanical thinning and/or prescribed fire.
Active management is needed to reduce fuels and forest density and recreate structural heterogeneity.	Management can use topography as a guide for creating different forest conditions where higher density and canopy cover for threatened rare species are associated with wetter sites and more open, pine-dominated resilient conditions are created in drier fire-prone areas.
Careful thinning can help, but ecological restoration and increased resilience require reintroduction of low-severity fire.	Make future thinning projects contingent on completing the prescribed burning of each mechanically treated stand.

National parks in the Sierra Nevada have successful prescribed burning and managed wildfire programs, showing that fire can be used in some locations to restore California's montane forests.	Zone the forest so that there are suppression areas (near homes), managed fuels reduction areas (farther from communities where fire and thinning may be used), and managed fire areas (prescribed fire and naturally ignited wildfire under favorable weather conditions). These zones should be incorporated into forest plans to ensure that suppression is not the only response to wildfire.
Social, political, liability, air quality, and safety concerns strongly favor suppression of all wildfire.	Although risk adverse, public land agencies do respond to public input and pressure. Local communities need to advocate for making their surrounding forested landscapes more fire resilient.

Landscape Schematic of Variable Mixed-Conifer Conditions Produced by an Active Fire Regime



Forest density and composition vary with topographic features such as slope, aspect, and slope position. Ridgetops, with drier soils and higher fire intensity, have lower stem density and a higher percentage of pine than more mesic riparian areas with lower-intensity fire. Midslope forest density and composition vary with aspect: density and fir abundance increase on more northern aspects (right side) and flatter slope angles. Illustration: Steve Oerding.

Subalpine Forests

CONSTANCE I. MILLAR AND PHILIP W. RUNDEL

The subalpine forests of California comprise the highest-elevation ecosystems dominated by upright trees. They are influenced primarily by abiotic controls, including persistent snowpack, desiccating winds, acute and chronic extreme temperatures, soil moisture and evapotranspiration stresses, and short growing seasons.

Bounded at the upper elevation by tree line, these forests persist under conditions of deep snows, exposure to severe winds and high solar radiation. Biotic interactions and disturbances such as fire are less important than in lower-elevation montane forests. Most subalpine forests in California are sparse woodlands, with short-statured individuals and wide spacing of young, as well as old trees interrupted by areas of exposed rock, dry upland slopes, meadows, and lakes.

Subalpine forest ecosystems extend across California in the highest mountains. In the subalpine zone, conifer forest types are diverse and characterized by iconic and charismatic species such as bristlecone pine, whitebark pine, mountain hemlock, foxtail pine, limber pine, western white pine, and Sierra juniper. Broadleaf subalpine ecosystems include those associated with high soil moisture, such as quaking aspen and water birch, as well as evergreen species on dry uplands such as mountain mahogany.

Subalpine forests have existed in California for more than twenty million years, although species diversity, ecosystem function, and mountain climates have changed drastically during that time. Unique adaptations have evolved among subalpine forest species to cope with extreme climates. These include individual longevity, long needle retention, strip-bark growth habit, and high fecundity. A remarkable coadaptation for seed dispersal and planting is exemplified by the mutual dependence of Clark's nutcracker and whitebark pine, whereby birds must open the indehiscent seed cones of the pine and birds in turn depend on seeds for food. By caching pine nuts for later harvest, the birds ensure pine regeneration in the thin and desiccating soils of the subalpine zone.

Much of the area of these forests lies in remote locations under federal administration with limited grazing uses but high recreation pressure. Subalpine forests in California face an uncertain future under changing climates. Some projections show very high losses if species move upslope and off mountain summits with warming, while others suggest that environmental heterogeneity could afford adequate refugia for long-term species persistence.

The forest-alpine ecotone at upper tree line is a zone on the landscape that can include krummholz whitebark pines, as shown here on the uplifted, metamorphic plateau of the Tamarack Crest, Sierra Nevada. Photo: Constance I. Millar.

THREATS AND RESPONSES

THREATS	RESPONSES
Air pollution impacts high-elevation ecosystems. Mountain environments upwind from industrial and vehicle emissions of atmospheric pollutants are susceptible to high levels of pollutants which negatively impact subalpine forests, reducing growth and stressing trees and making them more vulnerable to insects and disease.	Support emission regulations in urban and industrial areas.
California's subalpine forests have been relatively less affected by native insects and disease than similar forests elsewhere in western North America. This situation could change, however.	Outside of wilderness areas, forest thinning can improve resilience of conifers to native insects and disease.
California's subalpine and alpine ecosystems remain relatively free of invasive species. White pine blister rust, an exotic fungal disease, potentially could expand over larger areas of California's white pine forests as it has elsewhere in the West.	Monitor and eradicate invasive species as much as possible.

Extensive alpine fell-fields extend across the broad alpine plateaus of the White Mountains, interrupted occasionally by inselbergs, patterned ground, and other periglacial features. Photo: Constance I. Millar.

The diverse volcanic soils of the Sweetwater Mountains in the California Great Basin appear barren from a distance but support a great number of alpine herbs, including many endemics. Photo: Constance I. Millar.

Alpine Ecosystems

PHILIP W. RUNDEL AND CONSTANCE I. MILLAR

Alpine ecosystems are typically defined as those areas occurring above tree line, but alpine ecosystems at a local scale can be found below this boundary for reasons including geology, geomorphology, and microclimate. The lower limit of alpine ecosystems, the climatic tree line, varies with latitude across California, ranging from about 3,500 meters in the southern California mountains and southern Sierra Nevada to 3,200 meters in the Yosemite region, 3,000 meters near Donner Pass, 2,800 meters at Lassen Peak, and 2,700 meters on Mount Shasta. Alpine ecosystems extend beyond the typically envisioned high-elevation open slopes and summits of cold-adapted shrubs and herbs to include as well lithic environments of cliffs, talus fields, boulder fields and rock glaciers; permanent and persistent snow and ice fields, including glaciers; and various water bodies such as streams, tarns, and large lakes. Alpine ecosystems provide severe physiological stresses for both animal and plant populations. These environmental stresses in California include low winter temperatures, a short growing season, low nutrient availability, high winds, low partial pressures of CO_2, high UV irradiance, and limited water availability under summer drought.

The alpine regions of California typically experience a Mediterranean-type climate regime with dry summers and precipitation heavily centered on the winter months. This regime differs significantly from that present in most of the continental alpine habitats of the world, where summer precipitation predominates. At the upper tree line in the Sierra Nevada about 95 percent of annual precipitation falls as winter snow, with much of this accumulating during regular winter due to a very small number of storms separated by long, dry intervals. This pattern produces extreme interannual variability in precipitation and water availability. Herbaceous perennials (broad-leaved herbaceous perennials, mats and cushions, graminoids, and geophytes) dominate alpine communities and form the component of plant cover. Also present with lower species richness are low shrubs and semi-woody subshrubs. Other plant life forms such as taller woody shrubs and annuals are rare. Alpine ecosystems support a low diversity of resident mammal species, but many others use the alpine environment occasionally or seasonally. Notable are large herbivores such as mule deer and desert and Sierra Nevada bighorn sheep that forage in the alpine zone in summer. Many more small and midsized mammals occur in the alpine zone, with yellow-bellied marmots and pikas commonly seen in such habitats.

Alpine ecosystems are predicted to experience strong levels of temperature increase from global warming but will likely be most impacted by indirect effects such as declining snowpack, earlier spring runoff, and earlier growth and flowering phenology.

The American pika, a typical small mammal of the alpine zone. Photo: Andrey Shcherbina.

THREATS AND RESPONSES

THREATS	RESPONSES
Damage to wetlands, springs, and riparian communities from excessive use by feral horses, livestock (cattle and sheep), and unregulated pack stock.	Control feral horses and livestock/pack stock, fence high-priority springs and wetlands, and use salt blocks to draw animals away from sensitive areas.
Damage to wetlands, springs, and riparian communities from ATV, 4WD, and other motorized vehicles.	As much as possible, use land-management designations such as wilderness or limited use motor vehicles; control proliferation of use roads, and educate off-road vehicle user groups.
Pollution of water and damage to wetlands, springs, and riparian areas from excess and/or unregulated recreation use (backpacking/dispersed camping).	Limit backpacking use (quotas) for high-use and sensitive areas, educate recreation users about camping away from water and wetlands, and enforce regulations about camping (e.g., support more Wilderness Rangers).
Ecological conversion of wetlands to dry shrublands and conifer forest resulting from droughts and rising temperatures.	Make judicious use of beavers and meadow restoration as indicated (plug and pond) to maintain water in the uplands.
Continual stocking and self-sustaining populations of nonnative fishes into the formerly fishless high-elevation lakes of the Sierra Nevada have led to widespread losses of high-elevation endemic amphibians (specifically Sierra yellow-legged frog).	Remove nonnative fish and amphibians from select waters and reintroduce native frogs.
Chytrid fungus is a newer and exceedingly potent threat to amphibians.	No obvious management solution has been identified.
Cheatgrass is expanding into higher elevation areas, converting native range and shrublands to vast communities of exotic annual grasses.	Monitor and eradicate invasives as much as possible. Little management opportunity is available for cheatgrass control, although limiting disturbance from livestock, road building, etc., can slow the spread.
Resource managers will be increasingly faced with complex questions of adaptive management as global climate changes impact the biota of high-elevation subalpine and alpine ecosystems. Careful monitoring programs are critical to assess impacts. Species are expected to be pushed to higher elevations and potentially eliminated.	Climate change adaptation will require difficult and potentially controversial decisions related to the level of active versus passive policies of management.

Deserts

JAYNE BELNAP, ROBERT H. WEBB, TODD C. ESQUE, MATTHEW L. BROOKS, LESLEY A. DEFALCO, AND JAMES A. MACMAHON

Sparse vegetation gives the impression that there is little life in California deserts. In reality, these regions support a rich and complex web of microbes, plants, and animals that have specialized ways of coping with the extremes of temperature, light, and moisture found in desert environments. All life in these ecosystems revolves around water availability. For this reason, rain events are followed by a frenzy of activity, with everything from tiny microbes to large predators taking advantage of temporary moisture. Where permanent surface water is found, the tempo of life is more constant and less pulsed.

Desert plants have evolved many strategies for living in arid conditions, including the ability to escape, evade, endure, or resist drought. The most abundant and widespread plant in the California deserts is creosote, a classic drought resister. Plant species have many adaptive physiological features, such as thickened and reflective leaves and deep roots. Despite these adaptations, many species are still highly vulnerable to drought, as illustrated by the total shift in plant community dominance sometimes seen after extreme climate events.

In deserts invertebrates can exert strong control on plant community composition, plant distributions, soil structure and distribution of higher-trophic level animals. Invertebrates supply protein to the animals that feed on them.

Despite sparse, short vegetation, deserts support a relatively large abundance and diversity of vertebrates. Unlike plants, animals have the advantage of being able to move into shade or burrows to avoid extreme temperatures; almost no animals are seen in the heat of the day. Animals have many physiological adaptations to desert conditions, including body size, panting, color, heat exchange in blood flow, and hyperthermia.

A long history of infrastructure development associated with mineral extraction, agricultural operations, utility corridors (e.g., aqueducts, buried water pipelines, gas pipelines, and transmission lines), military training, urban/suburban/exurban development, and vehicular routes (paved and unpaved) has impacted California deserts. Unfortunately, desert regions have low resistance and resilience to disturbance. Because desert ecosystems are fragile, and their restoration is difficult if not impossible, finding ways to avoid or minimize impacts from these threats is essential. Meeting societal needs while preserving the integrity of California's deserts will be an essential challenge.

THREATS AND RESPONSES

THREATS	RESPONSES
National policies and abundant sources of sun and wind energy in the California desert have spurred the development of renewable energy. Development of infrastructure for energy capture and transmission compacts soil and reduces vegetative cover, increases soil erosion rates, changes the productivity and composition of vegetation, and impacts wildlife species. Large amounts of dust are produced from unpaved roads, even when not driven, negatively impacting roadside vegetation, human health, and water supplies when deposited on mountain snowpack. Development of infrastructure can also lead to groundwater depletion and contamination, affecting human populations and desert wildlife.	Decentralized energy generation would greatly reduce the number of new utility corridors and roads required for efficient delivery of energy. Decision support tools should be developed on where to site energy facilities, such as on soils and vegetation types with high resistance and resilience to disturbance or other locations determined to have fewer conflicts (e.g., the Desert Renewable Energy Conservation Plan).
Desert habitats and wildlife are impacted by urban development, including impervious surfaces (concrete and asphalt), groundwater pumping and contamination, dams, utility and transportation corridors, and roads and trails in desert areas. Areas surrounding cities and municipalities lead to the proliferation of intensive recreational activities (e.g., off-road vehicle use), garbage repositories, flood control basins, invasive plants, subsidized predators, and feral pets.	To maintain diversity, identify core conservation areas that are buffered from heavily used recreational areas. Incentivize conservation easements to ranchers and other landowners to steward open spaces. Through public education, discourage free-roaming pets, reduce subsidies of food and water to predators, and mitigate the impacts of off-road vehicles and water-intensive ornamental plants on desert resources. Cover canals and reduce overhead and flood watering to conserve water.
Most desert plants are not fire adapted, and the increase in fire has resulted in large-scale vegetation conversion. Plant invasions also compete with native plants and negatively affect forage and protective cover sites for native animals. Invasions of springs, seeps, and riparian areas additionally affect evapotranspiration rates and surface water abundance.	Educate the public about reducing invasive plants and preventing fires. Provide incentives to use native or sterile nonnative plant materials in ornamental horticulture and wildland revegetation projects. Reduce soil disturbance, nitrogen, and CO_2 pollution that facilitates invasive species. Establish early detection and rapid response programs to locate and eradicate encroaching nonnative species.
Climate change is forecasted to bring increased temperature and altered precipitation patterns (e.g., more frequent and deeper droughts, changes in monsoonal patterns) to most of California's desert regions. Many native plants and animals are already at thermal or water limits, forcing them to move if they are to survive.	Research is required to understand species migrations, determine those species at greatest risk, and consider management plans toward their future conservation. Regional planning efforts can provide corridors for movement of species (e.g., northward and toward higher elevation) and to expand protected areas. Assisted migration may be considered for species where corridors will not work, especially for keystone species. In restoration, use species that are compatible with predicted climate change or resistant to it. Protect community structural and functional attributes that enhance system resilience by reducing disturbance (e.g., grazing, soil disturbances). Institute long-term monitoring programs to assure that community attributes are being conserved.

Wetlands

WALTER G. DUFFY, PHILIP GARONE, BRENDA J. GREWELL, SHARON KAHARA, JOSEPH FLESKES, BRENT HELM, PETER MOYLE, ROSEMARY RECORDS, AND JOSEPH SILVEIRA

Freshwater wetlands are among the most important ecosystems in California. They can be found in all of California's ecoregions and cover about 2.3 percent of the state's area. Historically, they occupied a much greater portion of the state, but their early association with disease, and policies fostering agricultural development and flood control, led to the extensive loss of wetlands. Other human activities, such as urban development and livestock grazing, have contributed to wetland loss or diminishment of wetland ecological functioning in some areas.

California's wetlands contribute to biological diversity, support animal community diversity, and play a role in biogeochemical processes. Wetlands of the Central Valley and Klamath Basin are recognized for their global importance to waterfowl and shorebirds, as well as other birds, amphibians, and mammals. Vernal pools are valued for supporting a unique invertebrate community while also providing habitat for vertebrates. Riparian wetlands and fens in the Sierra Nevada support much of the biological diversity of that region. The biogeochemical functioning of wetlands can, under certain conditions, contribute to improving water quality by sequestering or storing nitrogen and phosphorus and by storing carbon—an increasingly important ecosystem service. Wetlands in California also store floodwater runoff and support human recreation. The latter, including hunting, fishing, wildlife viewing, and general recreation, contributes substantially to the state's economy each year.

Management of California's wetlands varies with ownership. Many wetlands under private ownership in the Central Valley and Bay-Delta regions are managed, and acquiring sufficient amounts of water to support desirable plant communities and provide bird habitat poses challenges to landowners. In these regions, flooded rice fields with relatively high wildlife value are now considered a specific type of managed wetland. Elsewhere, most wetlands are under public ownership, where management is focused on protecting habitats and, in some cases, controlling invasive species.

A changing climate will continue to influence wetland ecology in California by altering evapotranspiration and potentially changing hydroperiods and biogeochemical processes. Human population growth will strain wetlands through demand for limited water supplies as well as through encroachment and conversion. However, the services provided by wetlands to society are more widely recognized than in the past, and the restoration of converted wetlands is under way throughout the state.

THREATS AND RESPONSES

THREATS	RESPONSES
Climate change: Incomplete understanding of how climate change will affect different wetland types; no formal prioritization for wetland protection based on vulnerability; need to evaluate climate change together with other important stressors to wetlands (e.g., development and invasive species).	Assess vulnerability of wetlands, identify diverse management options, and prioritize high-value areas where adaptation or mitigation can be effective. Monitor baseline conditions to track changes over time, inform vulnerability assessment and scenario planning, and adapt management. Model hydrology, water demand and supply, and ecosystem response for high-priority areas. Explore water market approaches, adaptations to water rights, and incentive-based programs to protect environmental uses of water. Prevent fragmentation of riparian corridors from further development, protect wetlands from invasive species, and preserve groundwater recharge zones. Manage for climatic, topographic, and functional diversity; preserve refugia for native species.
Freshwater: Seasonal changes such as earlier peak stream runoff directly affect wetlands with natural hydrology, and indirectly affect wetlands with managed hydrology, by shifts in water demand and pricing. Wetlands with small drainage areas are likely to be particularly at risk.	Develop environmental flow release options from reservoirs to maintain environmental flows, reduce consumptive uses when possible, and protect recharge zones. New dams or reservoirs in some locations could moderate seasonal flow availability.
Bay-Delta: Saltwater intrusion from rising sea levels and increased risk of levee failure with aging.	Stabilize levees and evaluate effects of channelizing Sacramento River water to the central Delta.
Coastal: Sea level rise may erode wetlands if not in balance with sediment deposition. Wetlands covered by rising ocean may not be replaced by establishment at higher elevations because these areas are already developed or farmed. Salinity may change with saltwater intrusion and altered freshwater inputs, changing ecosystem composition.	Incorporate anticipated climate impacts into coastal management policy. Acquire inland buffer zones, set back coastal development to allow coastal wetlands to migrate inland, and consider adjusting sediment inputs through hydrologic management (e.g., dam removal). Where coastal areas have been diked, managers should consider adaptive capacity, resources, and values.
Managed wetlands: Obtaining adequate water supplies for wetland management will be increasingly difficult, due to climate change, rapidly expanding urban areas, agricultural needs, and in-stream demands for maintaining flows and endangered fish.	Maintain the Central Valley Project Improvement Act and fulfill the wetland water supply policies described therein. Evaluate and adjust reservoir operations as needed to adapt to changing climate, and manage flood risk and water supplies.
Rice fields as Wetlands: Reduced and unreliable water supplies to rice growers, increased opportunities for water transfers, and pressures to reduce and/or delay fall water use to maintain in-stream flows for fisheries will reduce post-harvest flooding. It also will increase plowing and other alternative rice stubble treatments that reduce rice field habitat value for waterfowl and other water birds.	Develop and implement agricultural easement and conservation programs that maintain and enhance the habitat value of rice fields and other agricultural lands within a wetland-working landscape. Investigate possible water supply management strategies that minimize conflicts among fisheries, wetlands, and other users.
Fire: Fire may have several damaging effects on seasonal wetlands.	Support programs that reduce wildland fire fuels.

Lakes

JOHN MELACK AND S. GEOFFREY SCHLADOW

Lakes occur throughout the varied landscapes of California and include large ones, such Tahoe, Mono and Clear Lakes and the Salton Sea; thousands of high-elevation lakes and ponds in the Sierra Nevada; playas in the deserts; vernal ponds; numerous water supply reservoirs; and a few natural lakes in coastal ranges. Water is essential for life, and lakes are critical sources of water and of habitat for aquatic organisms.

A common denominator influencing lakes in or near the Sierra Nevada is the annual snowfall that determines the amount and timing of runoff. As the Sierra snowpack provides the bulk of California's surface water, regional changes pose large risks to California's economy as well as to the health of its lakes and reservoirs. Likely changes include warmer temperatures due to climate change with concomitant increases in rain relative to snow and earlier timing of snowmelt. These changes will likely influence chemical conditions, seasonal mixing, and aquatic organisms. The long residence time of water in Lake Tahoe buffers the lake against annual differences in runoff, but inputs of inorganic particles and nutrients depend on the amount and timing of snowmelt as well as anthropogenic loading. Large amounts of runoff into Mono Lake after years with exceptional snowfall can alter vertical mixing, reduce nitrogen supply, and reduce algal abundance and productivity.

Lakes in California have been markedly affected by introductions of nonnative fishes, invasive pathogens, and aquatic plants. Clear Lake, a eutrophic lake in the northern coastal mountains, received large inputs of pesticides in the mid-twentieth century, which led to bioaccumulation and strong negative effects on breeding birds. Mercury mining in the lake's basin in the nineteenth century led to mercury contamination of the fishes that continues. The Salton Sea formed when an accident allowed Colorado River water to enter the basin, and its water level and salinity have varied considerably as a function of climate and runoff from agricultural and urban lands. The Salton Sea has high nutrient concentrations, algal biomass, and fish productivity, but also frequent low dissolved oxygen concentrations and fish kills.

THREATS AND RESPONSES

THREATS	RESPONSES
Inputs of excessive nutrients (eutrophication) lead to degraded ecological conditions in lakes. Increased urbanization and agricultural development in watersheds surrounding lakes lead to eutrophication.	Improved land use planning, water quality monitoring, and enforcement of existing standards to ensure that lake inflows have low levels of dissolved nutrients and particulates.
Climate change poses multiple threats to lake ecosystems: Hydrologic shifts: Decreasing snow relative to rain will likely result in higher peak streamflows and shifts in the timing of seasonal runoff. The loss of snowpack will alter the hydrologic residence time. As water resources for domestic, agricultural, and industrial needs become more limited, further diversion of water from lakes will lead to lower lake levels and increasing salinity, especially among lakes within hydrologically closed drainages. Lake warming: Lakes are warming due to climate change, producing thermal conditions that may disadvantage native species (at all trophic levels) and providing openings for aquatic invasive species. With warmer temperatures, metabolic rates will increase, as will the likelihood of decreased dissolved oxygen. Lakes that were previously ice covered may be ice free for longer periods, or not freeze at all, changing the mixing regimen of the system. Lake stratification: The length of time each year that lakes are thermally stratified is increasing. Stratification reduces vertical mixing and, as a consequence, the downward transfer of dissolved oxygen is reduced. This increases the likelihood of hypoxia and anoxia in previously well-oxygenated lakes, and the duration of such episodes will be extended. Anoxic conditions will result in the release of nutrients from the sediments (internal loading) and the release of heavy metals (mercury, iron, manganese). These can have severe human and aquatic health impacts, as well as add to the cost of water treatment for drinking purposes. Harmful algal blooms: Warming water conditions and thermal stratification, combined with higher nutrient levels, are conditions favored by bloom-forming cyanobacteria. These can release toxins in the water that are harmful to humans, wildlife, and agricultural animals.	Policies that reduce greenhouse gases by transition to non-fossil fuel-based energy production and altered management of agriculture, industry, and cities should be encouraged. Improved water policy should balance multiple uses and needs. Policies directed at reducing increased hypoxic and anoxic episodes and at increasing a lake's resilience to the impacts of increased stratification are needed. These would center on reducing the lake's oxygen demand to balance the imposed reduction in oxygen supply, and would include policies directed at reductions in nutrient inputs through improved water treatment, agricultural practices, and land use management.
Linked to climate change, the western U.S. is experiencing an increase in the number, duration, and intensity of wildfires. Burnt areas of the watershed can lead to large increases in erosion and transfer of nutrients to streams and lakes. Smokier skies due to wildfires will lead to reductions in light entering lakes that can alter primary productivity and behavior of fish and zooplankton, and create openings for aquatic invasive species.	Improved forest management and greater care by humans, who are the primary cause of many ignitions.

Rivers

MARY E. POWER, SARAH J. KUPFERBERG, SCOTT D. COOPER, AND MICHAEL L. DEAS

California's rivers are among the most dynamic, critical, altered, and vulnerable components of the state's ecosystems. These networks harbor diverse ecosystems due to their large latitudinal range and extreme topographic and geologic heterogeneity.

California's 60 major and more than a thousand smaller river drainages contrast sharply in annual precipitation. The native riverine biota has adapted behaviorally, morphologically, and physiologically to these seasonal rhythms and to "deluge or drought" year-to-year hydrologic variation, including super floods and mega droughts that have occurred over centuries and millennia. Repeatedly, human alterations have suppressed and rearranged this flow variation, creating more of a threat to the native flora and fauna of California's rivers than extreme natural variation, to which the biota has adapted.

Humans have subdued, diverted, and harnessed California's rivers, transforming them into one of the largest plumbing systems in the world. In turn, this system has been managed for flood protection, water storage, and diversion to irrigate crops, supply urban areas, and generate electricity. Although early logging, grazing, and mining damaged river watersheds and channel networks, the most massive impacts on rivers and streams came from development of water and land resources to support agricultural and urban growth.

Despite increasing demands on water supplies, encouraging cases of river restoration and improved stewardship are building on the natural resilience of some riverine landscapes and their biota. However, the future of California's rivers is inextricably linked to climate change and intensifying land use. Climate models project warming of streams and rivers, earlier peak flows, more prolonged or lower summer base flows, and autumnal and winter discharge peaks due to increased rain and rain-on-snow events, the latter associated with atmospheric rivers. Climate change will increase human demands for water, intensifying competition between interest groups and natural ecosystems for increasingly limited, variable, and compromised water supplies.

THREATS AND RESPONSES

THREATS	RESPONSES
Large dams have decapitated major rivers draining the Sierra from their headwaters. Loss of upstream habitat threatens salmonids through mechanisms like super-imposition of eggs in salmonid spawning nests. Many lowland channels, particularly in the San Joaquin Valley, have been reduced to disconnected fragments to die as pools in agricultural fields.	Prioritize migratory pathways for species dependent on riparian corridor habitats through seasonal discharge allocations that sustain channel connectivity, healthy native riparian vegetation, and edible biota.
Water management and transfers for storage, agricultural diversion, and recreation (e.g., white water rafting) can distort and even reverse the natural winter flow-summer drought Mediterranean hydrograph to which native riverine biota has adapted. Distorted timing of seasonal flows disrupts invertebrate life histories.	Schedule flow releases in managed rivers to mimic the natural winter flood and summer drought hydrograph. Reduce or eliminate pulsed (short duration) flows, particularly during the spring and summer recession and baseflow periods.
Hot low summer flow can lead to toxic algal blooms. When flow through large sunlit main stem channels decreases to critical levels, their pools and backwaters can stagnate, disconnect, and warm to temperatures that are lethal to cold water fauna such as salmonids, edible diatoms, and green algae.	Enforce winter water storage and prohibit summer water withdrawals from tributaries, springs, and larger channels supplying sunny main stem rivers during periods of severe summer low flow. Channels must be protected from loading of fertilizers and manure, particularly during these periods.
Levees, development, and water management have greatly reduced the amount and efficacy of floodplains that dissipate floodwaters over large storage areas, retain sediments, filter and assimilate pollutants and pathogens, periodically restore fertility of agricultural lands, and provide off-channel habitats during high flows that nurture fish, birds, and wildlife. Endangered species like coho would respond favorably to enhanced floodplain habitat.	Prioritize acquisition, restoration, and reconnection of coastal and lowland floodplains with lowland rivers and estuaries. Environmental flows that can restore quasi-natural inundation regimes and transport sediment will likely enable "passive" restoration in which the river and tides do the work.
Careless logging practices and road engineering have left California rivers with excessive fine sediments that leave channels wider, shallower, and often warmer, and clog water-filled pores in riverbed sediments (critical for small fish and invertebrates as refuges and for hyporheic exchange). These changes severely degrade habitat for vertebrates and invertebrates. Recently, poor road and holding pond construction, along with forest clearing for marijuana cultivation, has resumed, damaging river reaches that were on the brink of recovering 50 years after some of the most damaging logging.	Road engineering should reduce erosion of fine sediments and prevent or slow their arrival into channels. Wide forest buffers and large wood in channels should be protected to allow channels to deepen and increase in complexity. Watershed users should be required to store water in large holding tanks or other basins that will not fail and unleash small landslides into adjacent channels.
Californian rivers in some locations receive toxic inputs of mercury (often from legacy mining) and pesticides (from agriculture, including rodenticides from unregulated marijuana cultivation). In other areas, evaporation of river water from diversion storage areas has allowed toxic salts (e.g., selenium) to accumulate.	As with fine sediment loading, management should address the sources of these loadings, or in the case of salinization, the diversion and storage practices that have created the problem.
Invasive grasses, riparian trees, macrophytes, clams, snails, fishes, crayfish, frogs, and turtles are spreading through many California rivers, endangering native populations.	Exotic species, particularly from sluggish midwestern habitats, are not adapted to California hydrology. These species are often effectively managed by restoring natural seasonal hydrographs to river reaches, which favor native Californian biota and can extirpate invaders.

Island Ecosystems

KATHRYN MCEACHERN, TANYA ATWATER, PAUL W. COLLINS, KATE FAULKNER, AND DANIEL V. RICHARDS

Eighteen islands make up the California islands in the Pacific Ocean stretching from around San Francisco, California, to central Baja California, Mexico. Their geologic history of isolation, and their size, topographic complexity, and distance from other islands and the mainland lead to high endemism in flora and fauna. Because of their isolation, island plant communities tend to have fewer total plant species than the mainland and are often dominated by local endemics that evolved in these unique island environments. In turn, these habitats support both endemic animals and global travelers such as seabirds and pinnipeds. The larger islands in particular were home for at least thirteen thousand years to Native Americans who eventually established large, permanent villages; had complex interactions and trade networks with other islands and the mainland; and strongly influenced island ecosystem structure and function.

For the most part, these Native Americans practiced hunting and gathering lifestyles that did not have the widespread, devastating effects produced by later ranching activities that came with European settlement. Ecosystem collapse came quickly with the advent of ranching activities, as native scrub communities were replaced by nonnative annual grasslands, erosion and sedimentation rates increased, and water-holding capacity declined. Still, this archipelago preserves some of the last remnants of native California, now managed by federal agencies and private conservation organizations for recovery and conservation of native ecosystems. They are places of incredible biodiversity and unparalleled natural beauty. The California islands are recovering from conditions not unlike what most of southern California faces right now and will face in the future. They provide a living laboratory for recovery of native ecosystems, as well as a rare and valuable global resource.

THREATS AND RESPONSES

THREATS	RESPONSES
Nonnative plants and soil loss remain widespread and have negative ecological effects on native flora and fauna. For example, annual grasses compete with seedlings of native shrubs, slowing or preventing native vegetation recovery. Native plants cannot expand into areas that are still actively eroding. Island fauna that depend upon these native habitats are slow to rebound, as well.	Research and long-term monitoring are informing conservation efforts, such as showing which areas are slow to recover, determining the best suite of plants to use for habitat restoration, and investigating best practices for controlling erosion. Targeted restoration of ecosystem components and functions to kick-start recovery is needed within an island-wide response plan, and some hands-on management activities are already under way.
Accidental introductions of predators or invasive weeds could have devastating effects on endemic fauna and flora.	Land managers are implementing an archipelago-wide biosecurity program with the twin goals of preventing introductions and engaging in rapid response, should an introduction occur.
Overexploitation and unintended catch of marine resources continue to suppress population growth and stability in both harvested and nontargeted marine wildlife.	Marine reserves were established near the islands in the early 2000s. As the seaweeds, invertebrates, fishes, seabirds, and marine mammals they protect grow and reproduce, they can produce young that repopulate nearby areas. Continued enforcement and use of new equipment designed to reduce bycatch will allow these reserves to support local fisheries. Expansion of the marine reserve system could contribute to greater sustainability in future years.
Pollutants and nonnative plants continue to affect marine resources. These operate at different scales. The nonnative plants, like Sargassum, are changing the structure of nearshore kelp forest communities. Pollutants, like organochlorines and plastics, depress populations of wildlife and cause local extirpations. As we address some pollutants, new ones pop up as the next problem to face.	Legal restrictions have been placed on manufacturing and dumping of pollutants. Research needs to explore best practices for prevention of future pollutant effects, to detect new nonnative invaders, and develop techniques for rapid response in affected areas.
Some species that use the islands for breeding and rearing young are put at risk by fishing, hunting, habitat alterations, and climate change ranging far from the Channel Islands and beyond the jurisdictional control of island managers. For example, seabirds such as the Scripps's murrelet and Cassin's auklet breed on the Channel Islands, yet they spend most of their time at sea in other habitats.	Habitat restoration, including establishment of native shrubs for nest cover and provision of artificial nest structures, is under way on some islands. However, for such global travelers, sustainable recovery requires an international collaborative effort. In some cases, international legislation has led to recovery as habitats are protected, restored, and conserved.
Increasing sea and air temperatures, ocean acidification, less predictable and more intense storm cycles, and prolonged drought create conditions that stress individuals and limit fecundity in plants and animals. Many island endemic species cannot move to better locations and are therefore highly vulnerable to climate change.	Scientists and land managers are working to conserve endemic terrestrial wildlife, and create new populations of some of the rarest endemic plants, in diverse locations on the islands where they occur in order to spread the risk of decline as conditions shift. Careful seed collecting for deep storage at licensed facilities provides insurance against complete loss. Research and development are needed to understand where to plant and how to manage any progeny that would come from these collections. Similarly, monitoring is in place to detect declines in some endemic terrestrial and marine animals. However, whether and how to engage in assisted migration to nearby island or mainland sites is a complex endeavor requiring research and collaboration among diverse management agencies.

Marine Fisheries

ERIC P. BJORKSTEDT , JOHN C. FIELD, MILTON LOVE, LAURA ROGERS-BENNETT, AND RICK STARR

The marine ecosystems off the coast of California are among the most productive in the world, fueled by upwelling of cool, nutrient-rich waters. They are also among the most dynamic, responding dramatically to large-scale fluctuations in the winds that drive upwelling and govern the flow of the California Current.

During the last two centuries, fishers have used a diverse suite of methods and gear to harvest some 350 species from California's ocean waters. Over time, they have affected nearly every marine ecosystem through direct impacts of harvest, bycatch, and habitat damage, and through indirect effects mediated by ecological interactions and dispersal.

By emphasizing conservation as the foundation for sustainable, resilient fisheries, recent legislative mandates and policies have sought to break a pattern of rapid fleet expansion followed by collapse. Managers of marine fisheries have become more precautious and have adopted a more holistic, ecosystem-based perspective supported by a growing understanding of interactions among the ecological, economic, and social elements of fishery ecosystems. Dramatic reductions in fishing, triggered by shifts in management goals, have had profound economic and social consequences. In many cases, these decreases have also contributed to rebuilding of depleted stocks and shifts in ecosystem structure toward less disturbed states. Conservation concerns also have motivated the implementation of a network of marine protected areas (MPAs).

New techniques for assessing the status and productivity of fishery (and nonfishery) stocks, insights from comparisons of ecosystems in fished areas to those in MPAs, and increasingly sophisticated ecosystem models will enhance information available to managers. Greater emphasis on economic efficiency has spurred development and implementation of management tools such as catch shares that adjust fishers' incentives to increase profitability, reduce risk, and promote closer alignment between economic interests and ecological sustainability. Such approaches still require managers to set appropriate science-based harvest policies. Disparity in spatial scales of management and fishery effects also present an ongoing challenge.

Continued progress toward sustainable, resilient fisheries will require steadfast, yet adaptive, adherence to the hard lessons of the past, ideally supported by effective collaborations among scientists, managers, fishers, conservationists, and other stakeholders.

THREATS AND RESPONSES

THREATS	RESPONSES
Uncertainty limits our ability to foster sustainable interactions between human and natural components of fishery systems and reduces the potential to realize the economic potential of fisheries while minimizing the risk of overfishing or ecosystem disruption. Lack of information can pose especially acute risks during the development of new fisheries, and in adapting management as ecosystems respond to climate change.	Species-specific assessments (using data-poor methods where needed) should be implemented broadly in an ecosystem context. Rapid (indeed, preemptive) scientific study of emerging or potential fisheries will help avoid past mistakes. Research should target uncertainty arising from spatial variability, ecological interactions and ecosystem dynamics, the scope of direct human influence on marine ecosystems, and ecosystem responses to climate change.
Threats to fishery ecosystems include overfishing, bycatch, habitat disturbance, and illegal harvesting.	Sustainable fisheries require emphasis on precautionary approaches, limits on allowed fishing techniques, spatial management, and technological advances in fishery monitoring, as well as other efforts to limit risk of ecosystem disruption.
Increasing temperature; more intense and frequent exposures to acidification, hypoxia, and harmful algal blooms; changes in coastal circulation; and degradation of coastal habitats through eutrophication, pollution, sediment loading, shoreline alteration, and sea level rise all have substantial potential to alter the productivity and distribution of fishery stocks and the structure of the ecosystems on which fisheries depend.	Fishery managers must adopt a more holistic, ecosystem-based perspective that emphasizes precautionary approaches and limits fisheries' collective impact on ecosystem resilience. Management and governance structures should continue to implement and enhance procedures that enable rapid response to changing conditions. Ongoing support and additional resources are needed to extend our understanding of climate change and to develop robust management scenarios that span likely future conditions and incorporate social and economic elements of fishery systems.
Several economic factors present a challenge to achieving and preserving sustainable fisheries, including divergence of fishers' short-term and long-term economic incentives in open-access fisheries, the discrepancy between the windfall harvests in a developing fishery and the harvests a fishery can sustain in the long run, and the emergence of global markets that increase demand but reduce feedback from local fishers to the market. Information on social and economic drivers of fishery ecosystems is limited, which constrains managers' ability to forecast and evaluate consequences of regulatory actions.	Rights-based fisheries show great promise for enhancing long-term sustainability. Research focused on how fishers respond individually and collectively to social and economic drivers is required to better understand the dynamics (and potential for unforeseen consequences) of these fisheries. A key challenge is to develop strategies, such as innovative marketing, that enhance resilience in fishing economies fueled by lower, but hopefully more reliable, harvests from ocean fisheries.
The broader impacts of fisheries on marine ecosystems remain highly uncertain. Fishery ecosystem science will remain limited in its ability to fully inform management decisions, especially as we progress into "no-analog" futures driven by climate change.	Fisheries management should proceed from a precautionary, adaptive, flexible, and forward-looking perspective that explicitly includes ecosystem considerations in setting policy and regulations. This will require substantial and ongoing research on ecosystem responses to fishery harvests and climate; development of robust, effective indices that distill ecosystem information into products accessible to managers and stakeholders; and scenario studies that integrate human elements of fishery systems.

Forestry

WILLIAM STEWART, BENKTESH SHARMA, ROB YORK, LOWELL DILLER, NADIA HAMEY, ROGER POWELL, AND ROBERT SWIERS

Forestry is the practice of creating, managing, using, and conserving forests to sustainably meet desired social goals, needs, and values. In California, active forest management is currently limited to productive timberlands (forests that can be managed for the sustainable production of wood products) that are not in parks or preserves.

California's principal timberlands are the California mixed conifer, ponderosa pine, and Douglas fir forests of the interior and redwood forests close to the Pacific Ocean. They cover slightly less than four million of the thirteen million hectares of forests in California. Differences in timberland ownership and management, including practices on the roughly one million hectares of reserved forest lands ecologically similar to harvested areas, create a natural experiment that provides insights into how different combinations of managed disturbances (e.g., harvests, regeneration, thinning) and natural disturbances (e.g., fires, insects, diseases, droughts) affect the provision of global and local ecosystem services.

The total carbon cycle benefits derived from forest products depend on how efficiently consumers use, reuse, and recycle wood products. Private timberlands annually harvest approximately six times as much product per hectare as national forest timberlands while sustaining their inventories. The revenues from products and services are important to private timberland owners to keep them from accepting more lucrative offers to sell land for residential and recreational uses. Successful efforts to maintain and enhance biodiversity while still producing revenue have been demonstrated on some experimental forests, through habitat conservation plans, and through voluntary stewardship actions on family-owned forests.

Achieving high levels of biodiversity and resilience requires considerable investment in intensive monitoring of specific species of interest, protection of key habitat elements, and attention to disease and disturbance threats. Active management through harvesting, planned regeneration, and managed fire can increase overall resilience to unknown but changing future conditions. Our understanding of forests would benefit from more explicit experiments on both private and national forest timberlands as we move toward a more uncertain future.

Harvested Products from Private and U.S. Forest Service Timberlands in California in 2006 in (MgC)

Land ownership	Sawn wood products	Pulp	Bioenergy	Total
Private	708,633	253,083	506,166	1,467,882
National forest	105,835	36,812	115,038	257,685
Total	814,468	289,895	621,204	1,725,567
Percentage of total	47%	17%	36%	100%

Source: Morgan et al. 2012.
Note: The cubic foot harvest volumes in Morgan et al. 2012 have been converted to MgC based on Food and Agriculture Organization (FAO 1947) conversions to make them comparable to in-forest carbon stocks data in these sections.

THREATS AND RESPONSES

THREATS	RESPONSES
The loss of valuable habitat elements from natural and planned disturbances across the mosaic of forest stands negatively impacts many fish and wildlife species.	Achieving high levels of biodiversity and resilience requires considerable investment in intensive monitoring of specific species of interest, protection of key habitat elements, and attention to disease and disturbance threats.
Climate change presents unknown challenges to managers of both private and government lands, as current actions can generate a century of impacts.	Accounting for the full life cycle of climate benefits of both forests and harvested forest products will provide more accurate insights than looking at a single class of climate benefits.
Projected warmer temperatures could significantly increase tree mortality rates and reduce net growth rates in denser forest stands.	Implementing more explicit experiments on both private and government timberlands would provide better insights as we move into a more uncertain future.

Range Ecosystems

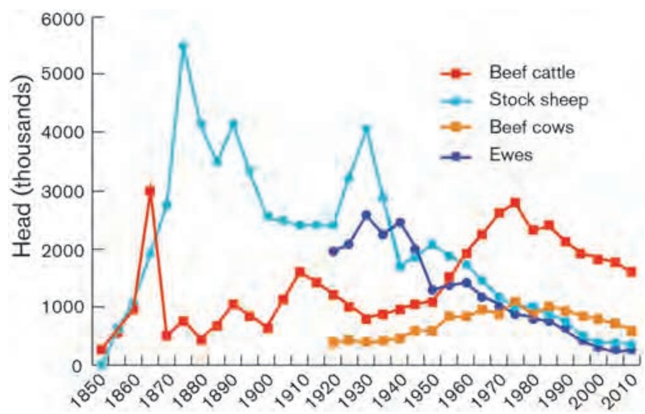
SHERI SPIEGAL, LYNN HUNTSINGER, PETER HOPKINSON, AND JAMES BARTOLOME

Livestock grazing on woodlands and grasslands is a typical pastoral scene in California. Range is a diverse class of grazed ecosystems covering about a third of the state, primarily in natural and seminatural grasslands, savannas, and shrublands. After more than two hundred years, grazing remains California's most extensive land use, with goals and practices strongly affected by patterns of land ownership. During the past several decades, sheep markets have shrunk and beef cattle numbers have slowly declined, leading to social and economic stresses within the producer community. Additionally, forage resources are increasingly limited statewide, and public range managers must now consider how their land use decisions affect use of privately owned range.

Grazing management differs considerably among the Mediterranean, desert, and montane regions of the state, as forage production is heavily influenced by local climate and soils. Cattle are the most numerous kind of range livestock at present, producing calves in fall in the Mediterranean climate zone and in spring in the intermountain zone. Warm desert livestock production cycles are less linked to season. Models predicting range vegetation responses to grazing currently emphasize nonequilibrium dynamics and integrated management goals as opposed to older, equilibrium-type models focusing on livestock production alone.

Livestock management goals today include maintaining biodiversity, controlling invasive plants, managing fuels, and protecting soil, water, and air quality. Partnerships with ranchers and rangeland landowners are essential to conserving the extensive landscapes cherished in California. Where once the ranching and environmental communities were largely at odds, today new opportunities for collaboration, based on ecological science and social demand for the multiple benefits of extensive rangelands, are emerging.

Range cattle and sheep in California, 1850– 2010.



Beef cows are brood cows, ewes are brood ewes, and both are often on rangeland. Beef cattle includes cows; the gap between the number of beef cows and beef cattle indicates the presence of yearlings (stockers) on rangelands or in feedlots within the "cattle" category. Separate data for cows and ewes were not provided until 1920. Source: Adapted from de Dios Vargas et al. 2013, in which data were recompiled from Burcham 1982, NASS 2011a, NASS 2011c, CDFA 2012.

THREATS AND RESPONSES

THREATS	RESPONSES
Hot Desert Range: Utility-scale wind and solar energy projects threaten biodiversity, hinder wildlife movements, and affect livestock production. Climate change and invasive species threaten biodiversity.	Consider integrative public policy efforts such as the Desert Renewable Energy Conservation Plan.
Cold Desert Range: Cheatgrass invasion and climate change threaten biodiversity, alter fire regimes, and affect livestock production.	See restoration science studies by the U.S. Forest Service, the USDA Agricultural Research Service, and the University of Nevada. Support development of increased knowledge of the role of grazing in cheatgrass management. The Sage Grouse Initiative with the Bureau of Land Management treats sensitive areas to keep this bird off the endangered species list.
Montane Range: Climate change coupled with reduced grazing contributes to fuel load increase, tree density increase, range contraction, and fire risk. Water quality issues are becoming more difficult to mediate.	Incorporate grazing into post-wildfire management.
Inland and Coastal Mediterranean Climate Range: Compared with other land uses, economic returns from ranching are orders of magnitude lower, and each year approximately twenty thousand acres of private ranch land are lost to development. Ten percent of private lands have been fragmented into parcels of twenty acres or less. Alternative land uses include orchards, vineyards, soil carbon farms, and housing and commercial units. Climate change, including unusually severe droughts, also threatens range ecosystems in this regional climate zone.	Encourage rangeland coalitions. Use adaptive management planning to achieve ranching goals in the face of spatiotemporal complexity and changes in climate. Increase knowledge of contribution of grazing to habitat management for rare species. Incorporate knowledge of rangeland values into land use planning processes. Recognize ranching as a multifunctional form of agriculture in land use planning and habitat conservation planning processes. Reinstate full funding of the Williamson Act. Use ecosystem service initiatives (payments from the conservation community to ranchers to maintain the natural character of land): conservation easements, cost sharing, carbon markets, grass-fed meats, fee hunting, and tax relief.

Agriculture

ALEX MCCALLA AND RICHARD E. HOWITT

California's agricultural system—the largest and most diverse in the U.S.—is a highly productive, complex, ever-changing system that is fragile and, in the judgment of many, is at present unsustainable. The managed ecosystem that is California agriculture is highly variable in both the types and productivity levels of crops grown. It reflects the diversity of the soil and water resources and the microclimates that support California agricultural production. The development of the system has been driven predominantly by three factors: changing market demand for crops, water availability and its development, and technological improvements in crops and growing methods.

This massive managed ecosystem has not evolved without severe impacts on California's natural ecosystem. Irrigated agricultural development on this scale has had a major impact on historical wetland areas and riparian corridors, leading to a loss of many ecosystem services. Construction of dams for surface water storage on most of the state's major rivers has led to severe reductions in aquatic ecosystem functioning, such as the loss of natural salmon spawning grounds. The development of fish hatcheries has not compensated for this loss of spawning grounds. In addition, the development of highly sophisticated irrigated agriculture has led to a number of unintentional, by-product pollutants in the ecosystem. The overdevelopment of groundwater pumping in some regions has led to land subsidence and loss of some vernal pools.

On the positive side, California agriculture is immensely valuable in terms of the products and jobs produced and welfare generated. In recent years, the agricultural industry has become more conscious of both ecological impacts and values. It has reduced its ecological impacts in some areas by reducing excessive pesticide use and agricultural burning. In addition, some crops are now grown in ways that enhance ecosystem benefits from their production. Notable examples include rice production in the Sacramento Valley and field crop production on floodplains, which have both been shown to directly contribute to the food webs of wild fishes and birds. We anticipate that this trend toward reconciling agricultural production and ecosystem benefits will continue at an increasing rate in the future.

THREATS AND RESPONSES

THREATS	RESPONSES
The common-pool nature of most California groundwater basins, coupled with the concept of correlative and, in many cases, practically unlimited rights to pump groundwater, has led to an annual groundwater overdraft that the California Department of Water Resources estimates is about 5 percent of developed water supply. Overdraft of groundwater not only reduces supply but also can cause land subsidence, leading to substantial costs in upgrading and repairing infrastructure.	Wider adoption of monitoring and measurement of groundwater and clear, quantitative specification of overlying rights are essential to thwart the problem of groundwater overdraft.
Water contamination is a significant threat in agricultural ecosystems. The expansion of irrigation has resulted in agricultural water drainage issues. Without a natural drainage pathway, concentrations of selenium and other elements, in addition to normal salinity in drainage water, can create toxic exposure for waterfowl and other species. Additionally, nitrate pollution coming from irrigated crops and confined animal feeding operations contaminates groundwater. Nitrate contamination is expected to increase in groundwater due to the long period of time it takes for nitrate pollution to percolate down to active groundwater areas.	Once drainage water evaporates, the toxic elements present are then concentrated and must be used or disposed of. For nitrate contamination of groundwater, direct remediation is cost prohibitive, but nitrate levels can be reduced slowly over time using a "pump and fertilize" approach that involves persuading farmers to use the nitrates present in groundwater as part of the fertilization requirements. A subsidized program of monitoring and treatment for moderate-sized local water utilities, and bottled water as an alternative drinking supply for the smallest water systems that exceed the state's contamination standards, is the optimal policy.
Infrastructure developments have caused a host of ecological problems, such as the damming of rivers that prevents migration of salmon and other species to upstream spawning grounds. Changes in water quality, habitat, invasive species, and other stressors have resulted in an estimated 73 percent of native fish species in decline.	Development of fish hatcheries is useful but does not compensate for the loss of spawning grounds caused by infrastructure development. The impacts of development on fish abundance can inform future decision making on major agricultural infrastructure development going forward.
Demand for California agricultural products is likely to go up, and with increased demand comes an increase in current stressors like nitrate pollution and water resource issues. This creates a trade-off between ecosystem health and economic growth.	The inherent tension between agricultural and environmental water use can be modified only if the environmental sector has some degree of control over water resources, allowing it to actively respond to varying interannual scarcity, using trade-offs and triage to ensure stable environmental systems. By looking for opportunities for joint production of ecosystem services and agricultural crops, which can be incorporated into the structure of California agriculture, managers can accommodate the increasing need for ecosystem goods in the future.

Urban Ecosystems

DIANE E. PATAKI, G. DARREL JENERETTE, STEPHANIE PINCETL, TARA L.E. TRAMMELL, AND LA'SHAYE ERVIN

California is the most highly urbanized state in the U.S., with almost 95 percent of its population living in U.S. Census–defined urban areas. While urban areas are ecosystems by virtually every definition, until recently textbooks and field guides about California's ecology only mentioned urban ecosystems in the context of destruction of native habitat.

In addition to dynamic and complex human-environment relationships, cities host diverse plant, faunal, and microbial species, sometimes with greater species richness than in natural ecosystems. However, unanticipated consequences of rapid urban development, such as air and water pollution and changes in fire frequencies, can occur. Scientists are attempting to quantify these effects with studies of urban metabolism, ecological footprints, and life cycle assessment. These studies will help evaluate the effectiveness of new programs to reduce the negative environmental impacts of urbanization.

California's cities are implementing new programs in alternative energy generation, green infrastructure, and restrictions on outdoor water use. A major uncertainty in designing these urban landscape elements is the relationship between the built and biological environment. The extent to which biological characteristics such as biodiversity and species composition influence urban functioning and pollution is unknown. Many questions also persist as to how aspects of the urban environment influence human health and well-being.

Overall, increasing walkability, reducing carbon-based energy use, and replacing some features of cities' built environment with green infrastructure could contribute to mitigating environmental problems and improving quality of life. New strategies and policies in urban planning in California are attempting to integrate green space, open space, and ecosystem services into land use and transportation planning, which requires new consortia of urban planners, engineers, policy experts, ecologists, and other scientists. California is continuing to test new policies and strategies for urban sustainability. The results of current programs will inform the future for the state and beyond.

THREATS AND RESPONSES

THREATS	RESPONSES
Fire at the urban-wildland interface is a perennial challenge in much of California. The most recent five-year average (2006-2011) found 5,084 fires burned 8,439 hectares annually within California. Increasing fire risk near urbanized areas is linked with increasing ignition sources, past practices of suppression that have increased standing fuel loads, and an increasingly complex matrix of low-density urban development in high-risk fire areas.	Working together, consortia of land use planners, urban planners, engineers, policy experts, ecologists, and other scientists can reduce issues such as wildfires near urban areas.
Air and water pollution from urban areas is a major contributor to degradation of wildland ecosystems. At present, nitrogen emissions have caused 29 to 54 percent of nonurban vegetation cover to exceed critical loads for nitrogen. High nitrogen concentrations near urban areas have led to declines in native conifer trees. Contamination of water from urbanization and pollutants, such as sewage, nutrients, pharmaceuticals, and toxins, can lead to recurring human health issues. Pollutant runoff patterns can interact with fires because airborne particles become mobilized after fire events, causing large rates of surface water contamination.	California will require continual advancements and refinements in theories and concepts concerning coupled human-environment interactions and the functioning of novel ecosystems. Scientists are attempting to quantify effects of pollution with studies of urban metabolism, ecological footprints, and life cycle assessment, which will help evaluate the effectiveness of new programs to reduce the negative environmental impacts of urbanization.
Urbanization can alter species communities. Habitat fragmentation in wildlands adjacent to cities can reduce animal population size, decrease metapopulation connectivity, and increase invasive species, leading to increased risk of native species die offs.	Information on the impacts of urban activities on wildland health can be used in regional planning and conservation development, a form of controlled development intended to preserve or restore natural ecosystems while allowing limited growth. Careful planning is required in selecting species for greening efforts to avoid negative externalities.
At broader scales, urban areas are dominant contributors of greenhouse gas emissions which affect global climate change through emissions of CO_2 from buildings, industry, and transportation, as well as N_2O emissions from irrigated and fertilized lawns.	California cities are increasing their reliance on renewable energy sources, with both large-scale solar and wind power plants adjacent to urban centers as well as broad adoption of rooftop solar collectors. Interest is also increasing in mass transit options to increase connections within and between urban centers to reduce traffic congestion which contributes to greenhouse gas emissions. Overall, increasing walkability, reducing carbon-based energy use, and replacing some features of the built environment of cities with green infrastructure is expected to help mitigate environmental problems and improve quality of life.
Continued drought will imperil the water supply of California's cities, making the balance between water allocations for environmental, agricultural, and urban use even more difficult. In many California cities, outdoor irrigation to manage residential yards, parks, and green spaces constitutes the majority of municipal water use.	California is currently considering methods of quantifying the water needs of cities based on their population, land use, and vegetation. Mandatory watering restrictions and financial incentives to remove turf grass are changing the composition of plant communities and vegetation cover. A number of government and nongovernmental agencies are considering the future of urban landscapes that provide ecosystem services with sustainable use of imported water.

Land Use Regulation for Resource Conservation

STEPHANIE PINCETL, TERRILL WATT, AND MARIA JOÃO FERREIRS DOS SANTOS

Over the past 150 years, a great deal of California's most scenic landscapes has been conserved because of the state's exceptional biodiversity. However, urbanization has brought once isolated ecosystems close to cities. These lands are the new frontier for conservation efforts and also face unprecedented, unmet challenges such as those likely posed by climate change.

Conflicts between land conservation and development are local because land use planning—determining zoning and where development will occur—is the prerogative of cities and counties, and there is no regional coordination or goal setting for future growth. Urban growth is still seen as the key to the prosperity of localities, so little incentive exists to conserve land; to build denser, more contained cities; and to collaborate across jurisdictions for infrastructure, land use, or revenue sharing. This problem is further complicated by the legacy of the Fifth Amendment of the state's constitution, which stipulates that in order for land to be conserved, it must be purchased at a fair price from its legal owners, in the context of increasing constraints on local government's ability to raise taxes or other funds.

The state legislature and voters, through the ballot initiative process, have passed a number of laws and created new agencies to attempt to improve conservation planning and protect conservation lands. But with the reduction of funding since the early 1980s due to ballot initiatives, conserving California's lands has become more difficult. Because government must purchase its land, and since land in California is expensive, conserving more lands is costly. Despite this challenge, innovative funding streams have emerged—especially with the greater participation of public parties in conservation land acquisition—as well as alternative forms of land conservation such as conservation easements.

Better land use is at the heart of conservation of California's magnificent heritage. In the end, conservation rests upon political will and the support of the state's residents. The state legislature will have to restructure the state's taxation system and the way in which private property rights are interpreted and create new governmental regulations to ensure the state's social and ecological resilience to climate change. Successful conservation will require a change in land development patterns and fundamentally in the way people live on the land.

Open Space Area in California Counties

County	County area (km^2)	Open space area (km^2)	Area of county in open space (%)
San Diego	10,973.57	5,286.15	48.17
Los Angeles	10,242.41	3,375.85	32.96
San Mateo	1,430.55	435.12	30.42
Santa Clara	3,378.21	811.63	24.03
Alameda	2,126.87	469.39	22.07
Sacramento	2,580.21	225.94	8.76
San Francisco	277.02	22.12	7.98

Source: Santos et al. 2014b.

THREATS AND RESPONSES

THREATS	RESPONSES
With increased urbanization, cities are spreading increasingly close to ecosystems, if not intermingling with ecosystems, due to suburban development. Development is also occurring up to the edge of protected wildlands, subjecting them to increased fire risk and other pressures.	There are new, collaborative planning tools that engage the public in visions for the long-term future, including the blueprint process that associates growth across the region to enable the public to understand trade-offs and can help implement the sustainable communities strategy under Senate Bill 375.
Land use zoning and urbanization is driven by revenue needs for localities, challenging habitat conservation at the urban fringe.	The greenprint process takes the blueprint process a step further in mapping a region's important open space, including allowances for a full range of ecosystem services such as CO_2 sequestration.
There are significant mismatches between policy goals and legislative tools, including the implementation of Assembly Bill 32 and Senate Bill 375, all of which would shift development to more compact urban areas and infill, relieving the stress on wildlands and ecosystems. There is also a mismatch between general plans and their implementation tools that consist of the general plan elements. Consistency is required, but not enforced.	Cap and trade funds may be available to invest in land conservation for CO_2 sequestration.

Stewardship, Conservation, and Restoration in the Context of Environmental Change

ADINA M. MERENLENDER, DAVID D. ACKERLY, KATHARINE N. SUDING, M. REBECCA SHAW, AND ERIKA ZAVALETA

California's ecosystems are diverse and dynamic; they have always experienced change. However, given continued rates of land use change, the increasing influence of climate change, and the transient nature of California's ecosystems, it is time to reconsider some of our current approaches to conservation, stewardship, and restoration.

Time lags between our actions today and species and ecosystem responses in the future make conservation efforts even more critical. We need renewed, immediate protection against habitat loss and fragmentation from continued urban and agricultural development throughout California. The state should set clear targets that meet or exceed international standards for conservation and restoration of every ecosystem type.

Given increased rates of change and the resulting widespread existence of novel communities, we must adopt and pursue innovative approaches to restoration and advance ecosystem stewardship. Given expected change and uncertainty, the focus should shift from maintaining historical conditions toward managing the dynamics, pathways, and rates of ecological change.

Future important directions for many of California's ecosystems include fire management, freshwater conservation, ecological monitoring, and improved land use and environmental protection policies. Fire is a key disturbance agent integral to California's plant community dynamics and is an essential management tool for replicating natural ecological processes. Managing wetlands and freshwater at a larger scale requires balancing socioeconomic demands on the system, and California's water policies are completely inadequate to structure effective allocation of water. Monitoring is especially critical, given the uncertainties associated with increased rates of change. While environmental policy improvements are needed in California, demands for mitigation and conservation protection that are emerging to support greenhouse gas emission reductions could provide a way forward.

Advancing our understanding of California's ecosystems and their responses to environmental changes is at the heart of advancing ecosystem stewardship goals. Better stewardship requires a stronger state funding stream for targeted biophysical research on ecosystem dynamics and applied, interdisciplinary research on environmental disturbances, restoration, and management. Equally important is that we must implement monitoring networks within and across California's ecosystems and take advantage of new technologies, as well as public participation, to be successful in this endeavor.

In sum, coping with rapid environmental changes requires increased focus on strategic conservation planning, collaborative stewardship efforts, new approaches to restoration that improve the returns on our investment, and an integrated, targeted research and extension agenda.

THREATS AND RESPONSES

THREATS	RESPONSES
Given the trajectory of projected change in the state, our greatest challenge is to ensure that California's ecosystems persist and retain their capacity to sustain vital ecosystem services and biological diversity while building a sustainable and resilient society.	We need a new ecosystem stewardship framework focused on resiliency. This framework will require management approaches capable of maintaining diversity as well as core ecosystem functions and important services.
Industrialization, development, and globalization have led to increasing homogenization of natural communities at unprecedented rates.	California should lead the way in ecosystem conservation by meeting the standards of the international Convention on Biological Diversity. These call for preventing continued large-scale conversion of native vegetation and setting targets to provide full protection for 17 percent or more of every terrestrial ecosystem, restoring 15 percent of degraded areas within each ecosystem, and moving 10 percent of the state's marine and coastal areas to the highest level of protection.
Unprecedented human activity and associated impacts have resulted in habitat loss and fragmentation. Global climate change and a growing human population will exacerbate these impacts.	Enlarge core reserves and maintain and restore habitat that will provide pathways among protected natural areas for wildlife movement. Enhance the permeability of the matrix landscape surrounding protected areas through measures such as diversifying agricultural landscapes, adding wildlife highway crossings, and removing fences to facilitate as much species movement as possible.
Changes in the fire regime could be the most important consequence of continued development in the wildland-urban interface, with large impacts to natural ecosystems.	Prescribed fire should be encouraged as the most efficient means to promote forest resilience in many parts of the state.
Close to 80 percent of California's native freshwater fishes are at risk of becoming extinct due to impacts from dams and other water management projects.	With less than 10 percent of California's wetlands remaining, wetland restoration is essential in most parts of the state. Equally important is the need to revise California's water policies to structure effective allocation of water that includes environmental benefits. In particular, we need a statewide, open-access database on restoration outcomes monitoring to foster evidence-based restoration and management actions.
In the face of growing development, many restoration and mitigation projects fail to deliver functioning ecosystems, and result in the conservation of small, unconnected mitigation sites and projects disconnected from conservation priorities.	Investments in greenhouse gas offsets associated with climate change mitigation should be directed to protect the conservation priorities outlined in existing regional and state conservation plans. The state needs to expand the approach used by regional transportation plans that fully assess cumulative and site impacts of development, aggregate proposed greenhouse gas offsets, and direct them toward meaningful conservation investments.
Recreation is not always compatible with conservation objectives. Growing evidence indicates that even nonmotorized activities have negative impacts on a wide range of wildlife species.	While we need to foster outdoor experiences and education, some areas must be protected from recreation impacts for natural community conservation. Additional research on recreation levels, impacts to threatened species and natural communities, and alternative management solutions is essential.
The lack of ecological monitoring across protected areas and restoration efforts limits the implementation of adaptive ecosystem management and threatens biodiversity conservation.	Remote monitoring technologies are increasingly important tools to assess the condition, composition, and changes that will occur. In particular, we need networks of "sentinel" sites spanning bioregions and ecosystems across the state, providing continuous monitoring and early detection of changes.

Environmental illiteracy, insufficient data, and lack of public and private institutional capacity to manage land and water resources threaten the vitality of natural systems.	Participatory research provides opportunities to expand monitoring and increase environmental and science literacy. In particular, we need citizen monitoring for early detection of new arrivals and diseases and to observe changes in flowering timing, seed set, and other life-cycle events in relation to environmental cues. We need citizen photography of historic photo points and citizen supervision of monitoring instruments. Outreach to small-parcel landowners is critical and should include sustainable land management practices.

Photo and Illustration Credits

Cover
Albert Bierstadt

Introduction
Ed Dickie

Fire as an Ecosystem Process
Dan Lindsay
Safford and Van de Water 2014

Geomorphology and Soils
Tom Rice
Chris Savastio (1)
Chris Savastio (2)

Atmospheric Chemistry
Andrzej Bytnerowicz
Photo A – Andrzej Bytnerowicz
Photo B – Andrzej Bynerowicz

Ecosystems Past:
Vegetation Prehistory
Wallace Woolfenden
Blakey, 2008

Biodiversity
Ed Dickie

Vegetation
Todd Keeler-Wolf
Dolanc

Biological Invasions
Ed Dickie

Climate Change Impact
Kelly M. Grow, California Department of Water Resources

Introduction to Concepts of Biodiversity, Ecosystem Functioning, Ecosystem Services, and Natural Capital
Ed Dickie

The Offshore Ecosystem
Elliott L. Hazen

Shadow Rocky Reefs and Kelp Forests
Chad King

Intertidal Summary
Luke P. Miller

Estuaries: Life on Edge
California Historical Society

Sandy Beaches
David Hubbard

Coastal Dunes
National Park Service

Coastal Sage Scrub
Jessica D. Pratt
Jennifer Funk
Fenn et al. 2010

Grasslands
Valerie Eviner (1)
Valerie Eviner (2)

Chaparral
R. Brandon Pratt

Oak Woodlands
C Tyler
U.S. Geological Survey, Gap Analysis Program (GAP).
Map: Parker Welch, Center for Integrated Spatial Research (CISR)

Coastal Redwood Forests
Anthony Ambrose

Montane Forests
Marc Meyer
Steve Oerding

Subalpine Forests
Constance Millar (1)
Constance Millar (2)
Constance Millar (3)
Constance Millar (4)

Alpine Ecosystems
Jeffrey Wyneken
Andrey Shcherbina

Deserts
Todd C. Esque

Wetlands
Robert McLandress

Rivers
Carson Jeffres

Inland Ecosystems
Daniel V. Richards

Marine Fisheries
Rick Starr

Forestry
Rob York
Chart: Morgan et al. 2012

Range Ecosystems
Rebecca C. Wenk
Adapted from de Dios Vargas et al. 2013

Agriculture
Aerial Archives/Alamy

Urban Ecosystems
Shutterstock

Land Use Regulation for Resource Conservation
Larry Ford

Stewardship, Conservation, and Restoration in the Context of Environmental Change
Greg Damron