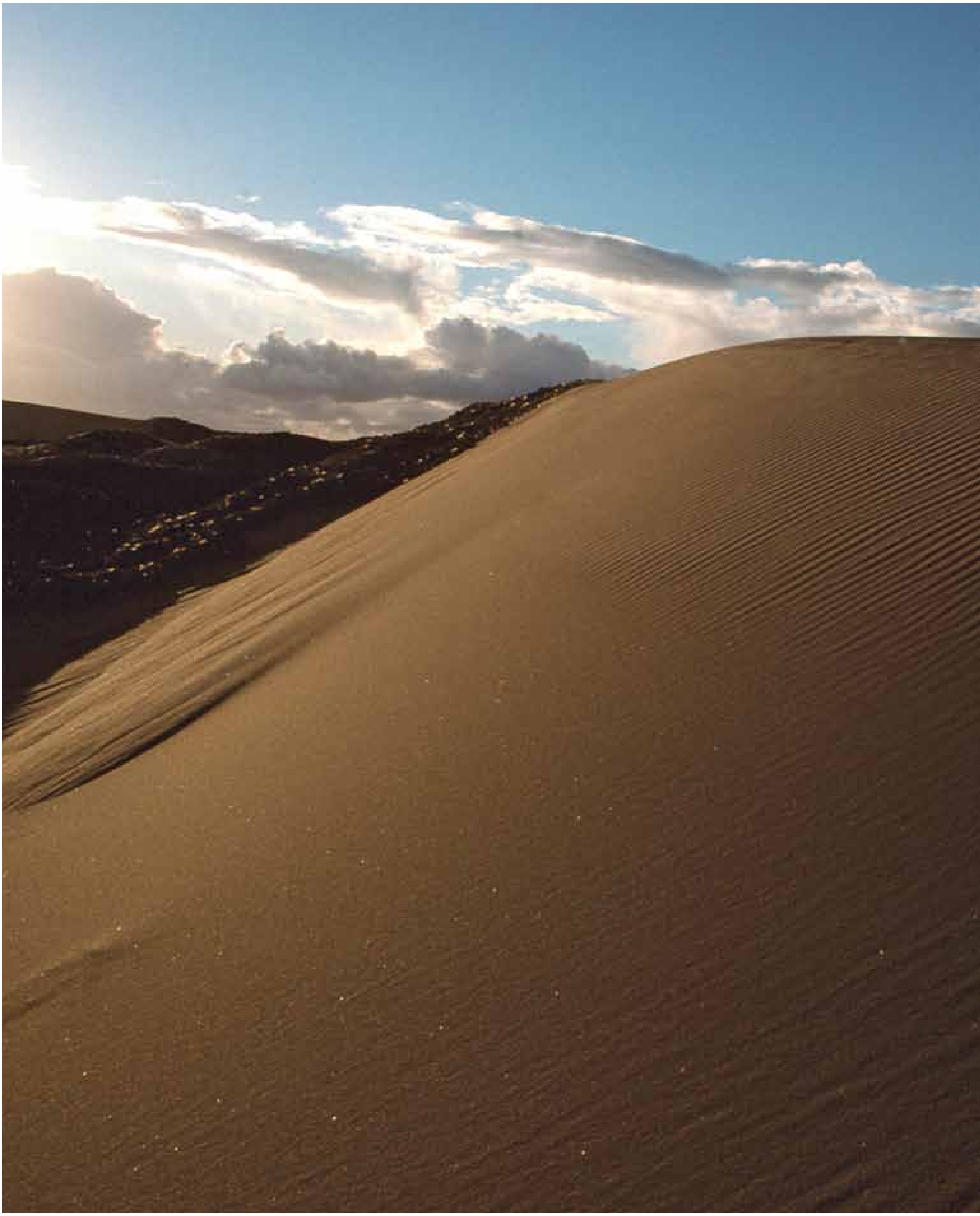
# Ecosystem Adaptation to Climate Change in California: Nine Guiding Principles

*Recommendations from an Expert Panel Convened by Resources Legacy Fund*



## PURPOSE

The goal of this project is to develop a set of scientifically sound, pragmatic, and broadly supported Guiding Principles to help ensure that conservation investments and management choices yield durable benefits in the face of climate change.

## RATIONALE

Over the next century, climate change will transform the Earth's ecosystems, and the general directions of change for California are clear (see Appendices B and C).

Temperatures are warming, precipitation patterns are shifting, sea level is rising, ambient $CO_2$ is increasing, and watershed flows are becoming more variable. These effects are likely to persist or increase over the next century. Less precipitation will fall as snow, and the snowpack will shrink and melt earlier in the spring. The summer and fall dry season will become longer, and rising temperatures will reduce soil moisture. Certain extreme events – heat waves, droughts, coastal storm surges, and inland flooding – will increase in frequency from historical norms. California's fire regimes will be further altered, and sea level rise will intensify coastal erosion and flooding.

Existing ecological systems in many, perhaps most, places will change substantially as species distributions shift in response to these changing environmental conditions (Box 1). Fundamental processes that structure ecosystems – hydrology, fire, species interactions, connectivity, etc. – will become more dynamic and less hospitable to current plant and animal communities. As humans adapt to new climate regimes, our shifting uses of water, land, and other resources will create new conflicts between the needs of people and those of nature. Today's conservation approaches, designed for the more slowly changing climate of the last 100 years, will be insufficient for meeting these challenges.

At the same time, scientific understanding of how the climate is changing and the practical implications of those changes for how society stewards the environment have advanced rapidly. The Guiding Principles presented here translate this improved scientific understanding into actionable knowledge that can be used today by natural resource planners, managers, regulators, and others. They focus on ways to sustain conditions and processes that will help ensure the persistence of diverse and well-functioning ecosystems and their delivery of benefits to society, even as California's species move and ecological systems transform.[1] The intention is for the Guiding Principles to serve as an overlay to inform state priorities and choices, and therefore to complement, but not replace, other types of conservation, ecosystem, and resource planning and management.

1. This approach is consistent with the draft vision for the new National Fish, Wildlife, and Plants Climate Adaptation Strategy under development by the federal government and partner organizations: "Ecological systems will sustain healthy, diverse and abundant populations of fish, wildlife and plants. Those systems will continue to provide valuable cultural, economic and environmental benefits in a world impacted by global climate change." For a copy of the public review draft released in January 2012 see http://www.wildlifeadaptationstrategy.gov/public-review-draft.php.

BOX 1

## SHARED ECOLOGICAL ASSUMPTIONS

The Expert Panel convened for this project came to agreement on several points related to current scientific understanding of how climate change is affecting California's species and ecosystems –summarized here and detailed in Appendix B. See also Appendix C for the panel's shared assumptions about the underlying science of climate projections.

- **Climate change is altering key factors that determine the distribution and abundance of species and the condition and resilience of ecosystems.** Scientists have high confidence in the directions of change for certain key variables at regional and larger scales; however, specific rates and impacts will vary across the landscape and at smaller scales. Although nature is rarely static, the changes now occurring in climatic conditions across the landscape are very fast in comparison to recent historical rates, and may outpace the unassisted ability of many species and ecosystems to adapt.
- **The combined ecological impacts will be pervasive.** Changes will occur in species' physiology, productivity, behavior, annual life cycles, recruitment, and survival. Altered or degraded habitats and other factors will cause shifts in many species' ranges. Some current ecological communities will break up, and novel species assemblages and ecosystems will emerge. Vegetation conversions will occur in some places. Opportunities will increase for non-native species invasions and pest outbreaks.
- **Species responses and vulnerability will vary greatly.** Each species will respond in its own particular way. Although we currently have limited ability to accurately forecast future distributions and abundances for most species, models and experiments can provide a basic understanding of how species will respond to future climatic changes. Those that can survive under a wide range of climatic conditions, can adapt to new conditions, or can move as the climate shifts, will likely fare the best.
- **Biodiversity management and conservation can no longer rely on place-based strategies for individual species.** Many areas that presently support particular rare, threatened, or endangered species; hunted and fished species; or other focal taxa, are likely to support different species in the future. Goal setting must be reoriented to reduce the emphasis on particular species at particular locations and to encourage actions that promote native biodiversity, ecosystem structure, function, and processes, as well as associated public benefits.
- **Large shifts may occur in the structure, composition, and functioning of some ecosystems, particularly during periods of rapid change.** Extreme ecological events will occur as the frequency and intensity of ecosystem processes – related to fire, water flows, coastal storm surges, species invasions, and other factors – operate further outside recent norms. This will potentially alter and, in some places, degrade the ecosystem values and services that people rely upon. Over the near-term, ecosystems that depend upon freshwater flows and systems and that exist along the coasts appear to be especially vulnerable.
- **The broader choices society makes in adapting to and mitigating climate change will have important impacts on ecosystems, while maintaining diverse and well-functioning ecosystems can support many adaptation and mitigation efforts.** Diverse choices – such as those related to land and water uses, conservation, transportation, and infrastructure – will significantly affect ecosystem condition and resilience under climate change. Conversely, healthy ecosystems can efficiently support many adaptation and mitigation efforts, such as those to protect coasts, manage water resources, and sequester carbon. Many opportunities exist to better align and optimize the co-benefits of these diverse societal choices, as described in the Guiding Principles.

## PROCESS

The Guiding Principles presented here were developed through a process that combined working with an Expert Panel of leading scientists; consulting with leaders and experts in state government, conservation organizations, and the scientific community; and iterative review of draft documents by technical experts and potential users of the principles. Appendix A lists members of the Expert Panel: This panel met in Sacramento in February 2012 and also contributed to and reviewed draft documents before and after the meeting. Appendix D lists reviewers of a previous draft of this document.

The focus of this effort is on land-based, freshwater, and tidal systems. Although some principles may be relevant, the panel did not consider marine systems in developing the Guiding Principles.

The Expert Panel assembled sets of shared assumptions about the science that undergirds its recommendations related to how the climate is changing and the ecological implications of these changes (see Box 1 and Appendices B & C). This shared understanding assisted the panel in developing and considering the feasibility of the Guiding Principles in terms of readily available scientific knowledge and analytical tools.

## DEFINITION OF A GUIDING PRINCIPLE



Each "Guiding Principle" identified below:

- Is a high-level, overarching "rule of thumb."
- Generally focuses on ecological systems, processes, and functions – not on individual species.
- When applied now will help sustain diverse and well-functioning ecosystems and their continued delivery of benefits to society in a changing climate.
- Can be applied in a variety of decision contexts.
- Is explicit and actionable.
- Can be implemented in a cost-effective way based on existing scientific and technical knowledge, although it may require analytical tools or analyses to implement (implementation costs and complexity can be scaled from low to high depending on available resources).
- Will yield benefits regardless of present uncertainties in projected climatic changes and impacts.

Box 2 lists the Guiding Principles developed by the panel. Adoption of each will have unique and important impacts; consequently, the panel did not attempt to rank or prioritize the principles. The text starting on page 6 explains each Guiding Principle in greater detail and describes the likely benefits of their respective adoption and application.

## IMPLEMENTING THE GUIDING PRINCIPLES

The Guiding Principles should be relevant to planning and decision making in diverse contexts and at local-to-statewide scales. Potential opportunities for applying the Guiding Principles include, for example, decisions related to: reserve design; land and water acquisition; land, environmental, and natural resource management; and infrastructure funding and design. Consequently, various interests may find the Guiding Principles useful – ranging from state, regional, and local government agencies to nonprofit organizations, land trusts, and collaborative planning bodies. Many of these potential users have already begun to develop frameworks and practices for climate change adaptation.[2]

All of the Guiding Principles are well supported by and actionable under existing scientific knowledge and know-how. At the same time, their adoption and application by some entities may require new capacities, technical analyses, policies, or resources. Some may find it helpful to translate the Guiding Principles into practical tools – such as decision criteria, operating goals, prioritization methods, and performance metrics – customized to specific applications and missions. This document does not take such next steps towards providing an operational roadmap. Nor does it attempt to address the specifics of how or where potential users might seek to apply these principles or to recommend modifications to any entity's authority or decision-making process.

Its purpose, instead, is to take the critical initial step of identifying those overarching principles that can inform actions over the near-term in order to secure future conservation benefits as the climate changes. Over the longer-term, refinements and additions to these Guiding Principles may be appropriate as understanding of climate change processes, ecosystem and societal impacts, user needs, and response options improves.



2. Many public and private entities in California are now actively integrating climate change adaptation into how they view and implement their missions related to conservation and natural resource management. For example, the state released the California Climate Adaptation Strategy in 2009 and a draft Adaptation Policy Guide in 2012. The Department of Water Resources has expanded attention to climate change in successive State Water Plans, and the Department of Fish and Game has developed a guiding vision and planning tools and is addressing climate change in revisions to the state Wildlife Action Plan. Various conservation organizations and land trusts have begun to integrate climate change into their planning and prioritization, while collaborative initiatives that bring together interested parties at a local level are forming to anticipate climate change impacts on ecosystems and watersheds.

BOX 2

## RECOMMENDED GUIDING PRINCIPLES

**PRINCIPLE 1:** Conserve the variety of ecological settings that will continue to support California's biodiversity and ecosystems as they shift in response to the changing climate.

**PRINCIPLE 2:** Conserve and restore landscape linkages and connectivity areas that will allow diverse species to move to new locations and will enhance overall species persistence.

**PRINCIPLE 3:** Set priorities for watershed protection and management that will yield conservation and societal benefits as water flows become more variable and potentially decline.

**PRINCIPLE 4:** Adjust flows below dams and protect coldwater habitats to support native species and aquatic ecosystems.

**PRINCIPLE 5:** Develop and implement strategies that will enhance the persistence of coastal ecosystems as sea level rises.

**PRINCIPLE 6:** Manage ecosystems for resilience in the face of extreme events.

**PRINCIPLE 7:** Align adaptation and mitigation strategies to optimize the co-benefits for people and ecosystems.

**PRINCIPLE 8:** Use best available scientific information and technical know-how to make informed decisions now and act adaptively as knowledge improves.

**PRINCIPLE 9:** Manage for the future.



## PRINCIPLE 1: CONSERVE THE VARIETY OF ECOLOGICAL SETTINGS THAT WILL CONTINUE TO SUPPORT CALIFORNIA'S BIODIVERSITY AND ECOSYSTEMS AS THEY SHIFT IN RESPONSE TO THE CHANGING CLIMATE.

Although species will move and the ecosystems in many places will change with the climate, protected areas and adjacent landscapes can be designed in ways that will provide for the persistence of biodiversity and well-functioning ecosystems in the future. This approach is likely to be useful regardless of exactly how the climate changes. It provides a method for strategically augmenting current protected area networks that were designed assuming little or no directional change in the environmental drivers that structure ecological communities and ecosystems. Working landscapes, in uses such as ranching, forestry, and farming, can make an important contribution to conserving diverse ecological settings when managed appropriately.

- To provide insurance for the future, California's present system of protected areas should be expanded and adjusted so that it:
- Encompasses the full diversity of enduring features of the landscape related to topography, geology, and soil-type.
- Encompasses the full diversity of current climate and vegetation mosaics.
- Includes high levels of climatic heterogeneity and habitat diversity.
- Includes areas that will provide local refuges for native species.
- Is better connected in comparison to protected areas designed without attention to climate change (discussed in Principle 2).

Individual protected areas designed with attention to these features will capture a wide range of ecological settings. This enhanced heterogeneity will allow some species that are sensitive to climate to shift locations within reserves. For example, protected areas that include steep climate gradients along mountainsides or diverse climates within small areas due to topographic complexity will allow species with slower dispersal rates to follow changing temperature and moisture patterns.

Many of California's protected areas, such as the Ventana Wilderness of the Los Padres National Forest, already encompass diverse ecological settings. Almost all of the state's protected areas larger than 50,000 hectares span at least 1,000 meters of elevation, and many have deep valleys that may retain cool areas even in the face of 3-4 °C of warming. Today, cooler canyons and water-retaining soils support native species at the warmer and drier ends of their ranges, such as the stands of Douglas-fir and salal found in the deep canyons of the Purisima Hills located north of Santa Barbara.

As climate change progresses, some places may change more slowly or to a lesser extent – in terms of temperature, precipitation, stream flows, and/or dominant vegetation – and therefore will at least temporarily continue to support some native species within their present ranges. Some native species also may relocate to areas that are unsuitable today, but will become hospitable environments in the future. Such places currently may be cooler, wetter, or even drier than they will become, and are located, for example, at high elevations, along north slopes, or in deep valleys and coastal watersheds. For instance, red fir in the Sierra Nevada may become confined to deep mountain valleys where cold air accumulates. Such patches of future suitable habitat will increase the possible opportunities for native species to persist and potentially will maintain source populations for colonizing other newly suitable habitats as they become available.

More generally, protected areas that contain a wide variety of ecological settings also will contain a greater diversity of species and more genetically diverse populations within any given species. This enhances the likelihood that some species and variants present in a reserve will succeed under changing and future climates. The Tejon Ranch in the western Tehachapi Mountains, for example, supports high species and genetic diversity due to its topographic, climatic, and soil diversity, as well as its location at the junction of several ecological regions. Undammed watersheds that start at high elevations and end on valley floors similarly include diverse ecological settings and are particularly likely to protect diverse aquatic species.

In many cases, modest expansion of protected areas or integration of adjacent working landscapes into area-wide stewardship approaches may be sufficient to better represent diverse soil types, topography, or other features identified above. In other cases, new protected areas, land acquisitions, or easements may be needed. Acquisition programs that have multiple objectives related to, for example, providing recreation, education opportunities, and other environmental amenities, could contribute to the extent that they assign higher priority to acquisitions that match the criteria outlined above. Regional sustainability strategies that limit open space conversion and promote infill and other smart growth approaches could also help conserve the state's full variety of ecological settings.

Routine implementation of this principle, in combination with the connectivity principle outlined in Guiding Principle 2, is likely to result in robust protected area networks that encompass a broader range of ecological settings. Such networks will capture more of today's biodiversity and, in the future, will sustain a greater diversity of species and ecological systems in comparison to protected area networks lacking these features.

### WHY FOCUS ON ECOLOGICAL SETTINGS?

The term "ecological setting" here refers to relatively stable physical attributes of the environment that, in combination, give rise to the ecological and evolutionary processes that generate and support biodiversity and ecosystems. These attributes can be directly observed (e.g., distance from the coast, geology, topography, or soil) or inferred (e.g., from spatial patterns of vegetation and climate). Using ecological settings to augment the design of protected areas will help ensure that biodiversity and well-functioning ecosystems persist, even though the particular species and ecological systems present at many sites may come and go as the climate changes.

For related concepts see: Beier, P. & B. Brost. 2010. Use of land facets to plan for climate change: Conserving the arenas, not the actors. *Conservation Biology,* 24: 701-710; Anderson, M.G. & C.E. Ferree. 2010. Conserving the stage: Climate change and the geophysical underpinnings of species diversity. *PLoS One,* 5: e11554.



**PRINCIPLE 2: CONSERVE AND RESTORE LANDSCAPE LINKAGES AND CONNECTIVITY AREAS THAT WILL ALLOW DIVERSE SPECIES TO MOVE TO NEW LOCATIONS AND WILL ENHANCE OVERALL SPECIES PERSISTENCE.**

Current connectivity planning generally focuses on linking habitats or ecosystems that are similar under today's climate. Such connections enhance gene flow between distributed populations and the potential for species recovery in disturbed areas. However, corridors designed in this way will not necessarily be enough to allow ecosystems and species to persist or to move outside of their current distributions as climate changes.

The solution is to expand and complement current connectivity areas so that they sufficiently link today's habitats with what will be suitable habitats in the future. Connectivity areas also should be designed to support viable populations of many species, including ones having various dispersal capabilities, as their geographic distributions shift.
These augmented connectivity areas should:

- Provide access to enduring features of the landscape – defined by variables such as soil characteristics, topography, and elevation – in spatial configurations that will support range shifts and help sustain biodiversity and ecological systems under any future climate.
- Include interspersed, varied, physical environments that can support rapid, short-distance movement to favorable locales during periods of rapid climatic change.
- Include riverine features, because, under all climatic conditions, rivers and their adjacent floodplains and associated riparian habitats will remain major conduits for animal movement.
- Capture existing climate gradients that will allow species to follow the shifting spatial distribution of suitable temperature and precipitation patterns, such as along elevation or exposure gradients. Some of California's large and diverse protected areas already contain important climate gradients (see Guiding Principle 1). However, additional gradients may be needed, for example, to connect uniformly warm protected areas to ones that are cooler or more climatically diverse.
- Include working landscapes, such as production forests, rangelands, and farms, managed in ways that support species movement or shifts in their distributions. Appropriate practices, depending on context, might include more extensive hedgerows and shelterbelts, wider riparian buffers, minimized road building, prescribed burning, and native planting.



Enhanced linkages and connectivity may not be enough for certain species – such as many native fishes and amphibians or specialized plants occurring only on certain soil types – that already live in highly fragmented habitats or whose dispersal rates are very slow in comparison to rates of climate change. Consideration of active translocation of species or genetic stocks may be appropriate under some circumstances, but will entail some risks and may be controversial, requiring careful weighing of costs and benefits (see also Guiding Principle 9).

Adoption of this principle in California's connectivity planning would help ensure that the state's wildlife corridors, linkages, and working landscapes will better support species range shifts and persistence as well as ecosystem transitions as climate change unfolds.



## PRINCIPLE 3: SET PRIORITIES FOR WATERSHED PROTECTION AND MANAGEMENT THAT WILL YIELD CONSERVATION AND SOCIETAL BENEFITS AS WATER FLOWS BECOME MORE VARIABLE AND POTENTIALLY DECLINE.

California's watersheds provide the natural framework through which water collects and moves through the landscape. They are the source of freshwater resources that are managed extensively to meet society's needs for drinking water, agriculture, hydropower, and other uses. Watersheds also sustain the state's freshwater, riparian, and wetland ecosystems, thereby supporting significant biodiversity and many endemic species, as well as enhancing water quality. How the lands and waters within each watershed are managed will determine the health, durability, and resilience of aquatic ecosystems, as well as the economic activities that depend upon them, in the face of climate change.

As the climate warms, runoff from the state's watersheds will become more variable from year to year, with possible long-term declines in total amount (see also Appendix C). At the same time, evaporation and plants' water use will increase, and, in the absence of significant societal change, water demand will grow. Chronic scarcity is likely. Two strategies could assist water managers as they seek to steward the state's aquatic ecosystems amid these challenges:

- Assign higher priority to the protection, restoration, and management of those watersheds that provide the greatest conservation benefits to aquatic ecosystems.
- Where possible, choose water management actions that simultaneously meet societal needs while ensuring resilient aquatic ecosystems.

The ideal management approach would be to protect entire intact watersheds that have high conservation value. However, in California, most of the reserves or management units that protect freshwater, riparian, and wetland ecosystems are not well aligned with watershed structures and functions. For example, watershed headwaters generally are better protected than middle and lower portions. Sustaining the state's vulnerable, yet important, aquatic ecosystems in a changing climate will require more intentional management of the entire watersheds that feed them (see also Guiding Principle 4).

Some watersheds will have higher value for this purpose than others and should be assigned a higher priority for conservation investments. Small investments everywhere will be less effective than concentrated efforts in fewer high-value watersheds. Likely management interventions that would improve aquatic ecosystem health in priority watersheds include: reducing erosion from poorly built logging and ranching roads; limiting discharge of agricultural and urban contaminants; managing grazing to prevent vegetation conversions; "banking" groundwater to provide alternative water sources during drier periods; widening protected riparian zones; reducing surface stream diversions and migration barriers; and rehabilitating degraded streams, meadows, flood plains, and wetlands to restore hydrologic function. Changing climatic conditions will increase the urgency and need to undertake such well-tested practices in priority watersheds.



More generally, watersheds managed in ways that sustain and restore resilient aquatic ecosystems will continue to deliver numerous benefits to society as the climate changes. Intact wetlands and riparian areas – like many in Sierra meadow systems – will help reduce harmful effects of future intensified flooding by reducing erosion and nutrient loads and by absorbing and then slowly releasing floodwaters (see also Guiding Principle 7). Protecting and restoring the connections between rivers and floodplains will enhance floodwater storage as it restores the dynamic pulses of flooding and sedimentation crucial for many native aquatic organisms and for maintaining healthy aquatic ecosystems (see also Guiding Principle 4). The Cosumnes River Preserve, south of Sacramento, is an example of the benefits of this approach. There, breaching the levees helped restore the cycle of floodplain forest generation, created habitat for juvenile salmon, and increased export of nutrients and plankton to the Delta.

Routine implementation of this principle would result in a more efficient and effective application of limited funds and resources to watershed management and protection in the state. The actions taken in high priority watersheds will make them more likely to support resilient aquatic ecosystems that continue to deliver benefits to society.



## PRINCIPLE 4: ADJUST FLOWS BELOW DAMS AND PROTECT COLD-WATER HABITATS TO SUPPORT NATIVE SPECIES AND AQUATIC ECOSYSTEMS.

The native freshwater plants and animals of California's Mediterranean climate are adapted to patterns of water flow that vary seasonally and from year to year. These patterns – commonly referred to as "natural flow regimes" – provide reproductive cues, assist in dispersal, create and maintain physical habitats, and more. Most native fishes spawn during elevated spring flows, which also trigger seed dispersal by riparian plants such as cottonwoods and willows. Temperature is another key variable that structures and sustains California's riverine and stream ecosystems. Many of the state's most iconic fishes, such as salmon and steelhead, are adapted to and depend upon narrow ranges of cold-water temperatures.

Climate change will further alter flow regimes (amount and timing of flow) and stream temperatures that have already been extensively modified by water impoundments, levees and canals, groundwater pumping, diversions, and consumptive uses. Such activities also have cut off access to cold-water spawning and rearing habitat in most of the state's rivers. Large, low-elevation, multipurpose dams throughout the Central Valley, for example, have blocked access to historic spawning habitats for salmonids on all major tributaries. Due to these alterations, many of California's aquatic ecosystems now support novel combinations of native and non-native species (see also Guiding Principle 9). The risks to freshwater ecosystems will intensify with climate change as floods and droughts become more frequent and severe, temperatures warm, the amount and timing of snowmelt shift, and demands on existing water management infrastructure increase.

Over the coming decades, maintaining the ecologically viable remnants of California's river and stream ecosystems will require:

- Re-establishing or maintaining natural flow regimes in regulated rivers where possible.
- Conserving cold-water habitats to protect fish populations.

Adjusting dam operations will be a key strategy both for restoring natural flow regimes and maintaining cold-water habitats. Most large reservoirs become stratified and maintain a pool of cold water in the deepest portions. These pools can be managed to provide cold water at critical times, and reservoirs can be operated in ways that mimic elements of the natural flow regime, to mitigate some climate change impacts. Cold-water releases are already part of the recovery strategy for winter-run Chinook salmon on the Sacramento River. However, a systematic statewide assessment is needed of the operational changes that will be required to meet desired temperature and flow standards for sustaining salmonid runs under changing climate conditions.

Conserving cold freshwater habitats required by native fishes and invertebrates also will require protecting and restoring headwater streams, large cold-water springs, and coastal streams in the fog belt. Adjustments to land use and water management practices will be needed to maintain cooler stream temperatures. Appropriate approaches include reducing warm agricultural return flows, fencing riparian areas to remove grazing animals in order to stabilize banks and regenerate vegetation, reducing groundwater pumping from wells adjacent to spring-fed streams, and replanting riparian forests to shade and cool streams.



In protecting cold-water habitats, highest priority should be assigned to the relatively few, large spring systems that feed biologically important aquatic ecosystems, such as those in the Shasta and McCloud Rivers in far northern California. Another high priority should be the streams that flow through and are cooled by the shade and fog-drip of coastal redwood and Douglas-fir forests. Those few coastal streams that lack dams and are rarely logged, such as the Smith River, will be particularly important for supporting salmonid fishes. Finally, small headwater springs, like those found in the Stanislaus National Forest, could also play an important role in continuing to provide habitat for native aquatic invertebrates, many of which have highly restricted ranges.

Implementation of this guiding principle will promote native fishes and invertebrates while enhancing the resilience of California's stream and river ecosystems. It also will help suppress invasive species that are better adapted to steady flows and warmer waters. Maintaining resilient river and stream ecosystems, in turn, will yield substantial economic and social benefits derived from robust commercial and sport fisheries, water-based recreation, fewer endangered species, improved water quality and reduced water treatment costs, and improved land values adjacent to restored rivers and streams.



## PRINCIPLE 5: DEVELOP AND IMPLEMENT STRATEGIES THAT WILL ENHANCE THE PERSISTENCE OF COASTAL ECOSYSTEMS AS SEA LEVEL RISES.

Sea level rise and related intensification of storm surges is placing California's coastal ecosystems – wetlands, dunes, bluffs, beaches, and estuaries – at unambiguous risk from flooding and accelerated erosion. Ocean intrusion will inundate tidal marshes and non-tidal wetlands. The levees protecting wildlife-rich wetlands of the San Francisco Estuary will be incapable of indefinitely holding off higher sea levels and will increasingly be vulnerable to catastrophic failure during big storm events, high tides, or earthquakes. Increased erosion and accelerating shoreline retreat will degrade coastal dunes, bluffs, and beaches, reducing and fragmenting wildlife habitats and creating new risks to coastal communities. In places, the expansion of shoreline armoring to protect infrastructure and housing is likely to compound these effects by further altering patterns of erosion and sediment deposition.

The most pronounced effects of sea level rise will occur where limited opportunities exist for coastal ecosystems to move inland, as is true of most coastal lagoons in southern California. As a result, they may simply disappear. The direction of change is unmistakable, and the time window for initiating action is limited because future options for adapting coastal ecosystems will be constrained by other decisions made today, related to land use, coastal infrastructure, shoreline protection, and other issues.

Specific actions required are to:

- Assemble and translate existing information on sea level rise projections and coastal ecosystem distributions into statewide or regional plans with prioritized actions through which California can best sustain select coastal ecosystems over the next century.[3]
- Rapidly implement these plans while opportunities still exist to protect areas critical to future coastal ecosystem functions.

The plans could, for example, identify key areas for inland migration of tidal marshes, dunes, or beaches that might be protected by acquisitions, rolling easements, or other means. They could suggest places where dikes should be breached to restore tidal function, where transitions to new configurations of tidal and freshwater marshes should be facilitated, or where engineering solutions should be put in place to restore or maintain beaches and dunes by enhanced sediment flows or retention. Suisun Marsh in the San Francisco Estuary is an example of a type of intervention that might be considered. There, breeching levees could facilitate the transformation of managed wetlands into tidal habitats and thereby assist inland migration of brackish marshes that support many native fishes.

In general, preference should be given to solutions that are simpler and self-sustaining, as opposed to those requiring large-scale construction and ongoing infrastructure maintenance. Critical evaluation may reveal some areas where protection or restoration is infeasible and, consequently, that merit low priority for conservation or management.



Implementation of this principle will help ensure that California's coastal systems continue to include functional marsh systems and the rich communities of birds, fish, and invertebrates they support. Additional benefits will accrue to the extent that these wetlands spread tidal energy over larger areas and reduce sea level rise impacts on regions that remain protected by levees (see also Principle 7). Projects that rely on wetlands and other "living shorelines" to protect infrastructure by dispersing wave energy could be designed in ways that conserve and promote the relocation of priority coastal ecosystems. This principle also will help ensure California retains, in some form, its iconic beaches, bluffs, and dunes and their significant wildlife, recreational, and cultural values.

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3. The recent National Research Council assessment of sea level rise along the West Coast provides a sound starting place for such an effort. See: National Research Council. 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. National Academies Press, Washington, D.C., 250 pp.



## PRINCIPLE 6: MANAGE ECOSYSTEMS FOR RESILIENCE IN THE FACE OF EXTREME EVENTS.

Extreme events that affect the health and persistence of California's ecosystems are expected to become more common as the climate changes. Fire, flooding, coastal storm surges, drought, unusually hot days, species invasions, and disease outbreaks all are expected to shift further from historical patterns. Consequently, ecosystem management approaches must shift from managing for mean conditions to anticipating and managing for the extremes. Failure to do so could result in widespread ecosystem transformation, often to undesirable conditions.

Managing ecosystems in ways that enhance their resilience in the face of extreme events will be an essential strategy for learning to live within new and shifting environmental regimes over the next several decades (see also Guiding Principle 9 for how ecosystem management goals may change over the longer term). The best approach – whether it involves preventing, responding to, or allowing extreme events – will vary from situation to situation, but generally will require management choices that:

- Maintain or restore fire dynamics that support native biodiversity and well-functioning ecosystems.
- Prevent undesired species invasions of disturbed areas.
- Reduce disease outbreaks and severity.
- Restore floodplain functions.
- Reduce coastal ecosystem vulnerability.

Fire is likely to drive many climate-related shifts in species ranges and ecological systems. Fire extremes – that is, fire operating outside of recent norms in terms of frequency, size, intensity, duration, seasonality, etc. – can cause vegetation conversions and contribute to species extinctions. Rising temperatures generally will diminish soil and fuel moisture and potentially increase wildfire risk. How this plays out locally, however, will depend on site-specific factors such as precipitation, shifting human activities, vegetation type, and current fuel structures resulting from recent fire management and fire history.

Over the near term, the particular approach appropriate for reducing the risks of extreme fire events will vary among ecosystems, depending on the adaptations and fire tolerances of the ecosystem's characteristic species. Management goals for some ecosystems, such as certain deserts, should include almost complete absence of fire, whereas goals for others, such as chaparral shrublands, should allow periodic high intensity fires. Depending on the ecosystem, potential management interventions might include allowing or preventing fires, introducing prescribed fire, various fuel treatments, or establishing buffers to prevent intrusion of wildfire from adjacent areas where fire suppression has resulted in high fuel loads. Over the longer-term, as the climate shifts to novel conditions, managers may need to adjust fire management approaches so that they support ecosystem transitions rather than enhance the resilience of existing ecosystems (see also Guiding Principle 9). Thus, regular re-evaluation of fire management goals will be needed.

New climate-related opportunities will arise for invasive plants and animals to expand into new locations, especially following disturbances such as fires, floods, and extreme drought. Post-disturbance monitoring and management will be essential to prevent domination by undesirable non-native species and potential ecosystem degradation. Early detection and intervention will be especially important to remove those invasive species with the potential to significantly alter habitat quality, food webs, and ecosystem processes. For example, giant reed (*Arundo donax*), a riparian area invader, alters hydrology and habitat quality and can greatly increases fire frequency and intensity. Areas with novel climates, such as those present at the hotter edge of California's climate space, may be especially vulnerable to invasive species, because fewer native species may adapt to the new conditions.

Shifts in temperature, moisture, and physiological stress will increase the vulnerability of forest tree stands to disease, pest outbreaks and diebacks. Outbreak severity may rise for some diseases, and disease distributions may shift northward or to higher elevations with warming temperatures. Enhancing forest disease resistance will be one key to limiting the impacts of pathogen outbreaks. Potential strategies for increasing disease resistance include: managing forests as a mosaic of stands that differ in disease vulnerability; planting more diverse mixes of plant species and genotypes in reforestation projects; and practicing selective thinning to enhance tree vigor. Once outbreaks have occurred, forest treatments that leave in place surviving trees may enhance the survival of tree varieties better suited to new climatic conditions.

Maintaining and restoring the capacity of floodplains to absorb and release water during episodic flooding – as discussed in Principle 3 – will improve the resilience of freshwater, riparian, and meadow ecosystems during elevated episodic flooding. Bolstering the condition and capacity of coastal ecosystems to retreat inland – as discussed in Principle 5 – will enhance resilience during intensified coastal storm events.

Broad adoption of this Guiding Principle across California's ecosystem management efforts will help prevent unwanted ecosystem degradation and transformations resulting from extreme events.

### WHAT IS ECOSYSTEM RESILIENCE?

As used here, "ecosystem resilience" refers to the capacity of an ecosystem to tolerate and rebound from disturbance. Resilient ecosystems may change in response to disturbances, but these changes serve to maintain the ecosystem's fundamental character (e.g., its functions and processes). Highly resilient ecosystems will be better able to adapt and persist within a changing climate. Definitions of ecosystem resilience in the scientific literature are nuanced and varied.

See, for example: Folke, C., S.R. Carpenter, B. Walker, M. Scheffer, T. Chapin, & J. Rockström. 2010. Resilience thinking: Integrating resilience, adaptability and transformability. *Ecology and Society*, 15: 20.



## PRINCIPLE 7: ALIGN ADAPTATION AND MITIGATION STRATEGIES TO OPTIMIZE THE CO-BENEFITS FOR PEOPLE AND ECOSYSTEMS.

The health and status of California's human communities and ecosystems will be integrally linked as the climate changes. On the one hand, intact and well-functioning ecosystems can assist in reducing climate-related threats to people. On the other, society's choices of adaptation methods to protect public safety and infrastructure and of mitigation methods to sequester carbon and reduce emissions will have important impacts – good and bad – on the state's ecosystems and the social, economic, and public health benefits they provide.

At least two approaches exist for improving the alignment of various societal goals for protecting people, public health, and infrastructure; reducing emissions or increasing carbon storage; and sustaining ecosystems:

- Rely on "ecosystem-based" solutions, where possible, that integrate functions and services from nature, for reducing climate-related hazards to people and for achieving societal adaptation and mitigation objectives.
- Minimize unintended, harmful, collateral impacts on ecosystems from "built" adaptation solutions (e.g., those involving construction and infrastructure) and from mitigation strategies.

Well-functioning ecosystems can provide significant protection to people, property, and infrastructure and can help ensure access to continued supplies of valued resources. Intact and restored riparian areas, watersheds, and coastal wetlands, for example, can reduce flood hazards, trap eroding soils, sustain fisheries, and enhance water supplies (see Guiding Principles 3 and 5). The cost effectiveness and long-term durability of protection provided by ecosystems potentially can exceed those of human-engineered protection. If other benefits are also considered (e.g., carbon storage and sequestration, nutrient and pollutant retention/filtration, recreational value, critical habitat, etc.), the cost effectiveness and sustainability of benefits from ecosystem-based solutions are even greater.

Those ecosystems that simultaneously assist in societal adaptation or mitigation efforts and are priorities for ecosystem adaptation should be among the highest priorities for protection and restoration (see Guiding Principles 1, 2, 3, 4, and 5). Certain riparian areas and watersheds have great potential to simultaneously provide water to ecological systems and to people (see Guiding Principle 3). Ensuring the persistence of coastal wetlands will sustain important wildlife habitats while sequestering carbon and reducing climate-related coastal erosion, flooding, and infrastructure risks (see Guiding Principle 5).

One important challenge of climate change adaptation and mitigation is ensuring consultation across sectors so that actions are complementary and synergistic, rather than at odds with one another. For example, water and fire management, as well as sea level rise, are areas where adaptation actions to reduce climate-related risks to public health and safety, as well as infrastructure, also will affect the state's ecosystems. Reservoirs will need to be managed in ways that accommodate the needs of people and also provide cold water for native species as water availability declines (see Guiding Principle 4). Houses rebuilt after wildfires, new developments in former natural lands, and homes inside the wildland-urban interface will need to be able to withstand natural fire activity operating in nearby ecosystems (see Guiding Principle 6). And choices about protecting coastal property and infrastructure, as sea level rises, also will need to sustain coastal ecosystems and their services (see Guiding Principle 5).

Emerging venues for collaborative planning, such as the state's Strategic Growth Council, could provide important opportunities for developing adaptation and mitigation approaches that optimize co-benefits for people and for ecosystems. For example, decisions to reduce the footprint of development by limiting sprawl or creating urban growth boundaries will simultaneously reduce carbon emissions as well as wildfire risks to homes, while they also reduce urban runoff and improve opportunities for maintaining natural fire dynamics in surrounding areas. Integrated environmental analyses that assess current and future natural hazards – related, for example, to flooding, fire risks, and sea level rise – could help ensure such decisions fully anticipate climate change impacts.

Application of Guiding Principle 7 will help ensure that strategies adopted across sectors are compatible and mutually reinforcing. Cost effectiveness of societal adaptation and mitigation measures will be greater where ecosystem-based approaches are implemented and will yield a broader range of public benefits. More, and possibly longer-term, financing options may be available for ecosystem adaptation efforts that yield demonstrable benefits for societal adaptation or mitigation. Long-term financing will be especially important to ensure the durability of ecosystem adaptation efforts that require continued intervention. Importantly, adoption of this principle also will reduce potential for unintended harm to ecosystems from built adaptation solutions.



**PRINCIPLE 8: USE BEST AVAILABLE SCIENTIFIC INFORMATION AND TECHNICAL KNOW-HOW TO MAKE INFORMED DECISIONS NOW AND ACT ADAPTIVELY AS KNOWLEDGE IMPROVES.**

Historically, action on climate change adaptation has been impeded by concerns about uncertainty and a mismatch between the relatively large spatial scale of the climate change projections ( > 100 $km^2$) and the smaller scale at which decisions are made about conservation and natural resource management (<100 $km^2$). This situation is changing. Several approaches are now available that can provide information at scales that can usefully inform real world decision making. Specifically:

- New methods for downscaling ranges of projected global climate changes and translating them into relevant habitat features can provide usable information for certain variables at a spatial resolution as low as 0.1$km^2$, and the resulting maps can assist in anticipating the patterns, rates, magnitude, and potential ranges of changing temperatures and some associated impacts across the landscape (see Appendix C).

- Current sea-level rise projections, combined with knowledge of coastal uplifting and subsidence, can provide useful information for anticipating best and worst case scenarios in planning applications (see Guiding Principle 5).
- Maps of enduring features of the landscape (e.g., soils, topography, exposure, rivers, etc.) and of existing vegetation or habitat distributions can provide useful surrogates for future ecosystem patterns and processes and for how climate change will alter ecologically important variables – information that can assist in guiding decisions about protected areas and connectivity (see Guiding Principles 1 and 2).
- Conceptual understanding, mapping, and modeling of ecosystem processes, like hydrology and fire, can assist in targeting protection, management, and restoration actions (see Guiding Principles 3, 4, and 6).

These tools and others provide the necessary scientific knowledge and know-how to undertake practical actions now that will yield benefits under a range of potential projected future climate scenarios. This may involve, where appropriate, a suite of actions to "hedge bets" and test alternative assumptions in light of uncertainties that cannot yet be reduced.

Adopting an adaptive management framework will be essential to enable and guide these actions. In a rapidly changing world, it will never be possible to resolve all uncertainties. Further, delayed action is likely to yield irreversible change and diminished options in many cases. At the same time, scientific understanding and applications related to ecosystem adaptation will continue to evolve rapidly for the foreseeable future. Measures should be put in place to routinely capture and act on this continuously improving knowledge base. An example of such an approach is the intention to regularly update the *State of California Interim Sea Level Rise Guidance Document* as scientific understanding improves.

Undertaking an adaptive management approach will require new levels of flexibility in many of the institutions, policies, and decision-making processes that affect California's ecosystems. Routine ecosystem monitoring and assessment – biological and physical – are essential, but the design and investment level should reflect the specific near- and longer-term needs of decision makers. Also essential will be a commitment to support and draw from ongoing and rapid improvements and refinements to the knowledge base and tools. Robust partnerships with scientists and with research and academic institutions will help as well.

Adoption of this Principle will assist in overcoming inertia and speeding progress on ecosystem adaptation by enabling multiple decision makers across the state to undertake informed actions now. It also will ensure continued improvements in the efficiency and the effectiveness of the state's strategies and will make them responsive to upcoming changes that are difficult to predict, such as the specific actions that people, communities, and policymakers will take in response to climate change.

### ADAPTIVE MANAGEMENT IN ECOSYSTEM ADAPTATION

Adaptive management is a pragmatic and routinely recommended approach for undertaking action with incomplete knowledge. Management actions are structured as experiments that build in processes for "learning by doing." Decisions may be adjusted and refined over time as understanding about the system that is being managed improves. In practice, the "learning by doing" element of adaptive management often is under-supported. Finding ways to ensure adequate monitoring and assessment to support sound decision making will be critical to enable adjustments that match the pace of climate change, its ecosystem impacts, and improvements to scientific understanding.

See, for example: Millar, C.I., N.L. Stephenson, & S.L. Stephens. 2007. Climate change and forests of the future: Managing in the face of uncertainty. *Ecological Applications* 17: 2145-2151.



## PRINCIPLE 9: MANAGE FOR THE FUTURE.

California's natural systems are in the early phases of a prolonged period of change that is unprecedented in human experience because of its combined speed and pervasiveness. At least three approaches must inform the state's ecosystem adaptation strategies and actions to meet this fundamental challenge:

- Assess the feasibility of current management mandates and policies under climate change and make appropriate adjustments.
- Work with dynamic species ranges and novel ecosystems.
- Anticipate future conditions and options in restoration projects.

The enormous ecological shifts now unfolding across California's landscapes could render infeasible some existing ecosystem management goals and approaches that were developed for less dynamic times. Ecosystem managers will need to revisit existing management mandates and policies and recalibrate their priorities in light of the growing knowledge base about the anticipated directions and rates of climate-driven ecological change.

Over the next few decades, setting pragmatic and feasible goals for conserving and managing California's ecosystems will necessarily involve consideration of recent conditions. Such goals typically will focus on enhancing current ecosystem resilience, maintaining ecosystem processes within recent ranges of variability, and sustaining native species where possible (see Guiding Principles 3, 4, and 6).

However, protection or restoration to maintain some ecosystems in a desired recent state may become infeasible as climate change accelerates spatial shifts in the location of existing ecosystems and the transition of familiar ecosystems to novel ones that combine new physical conditions with new species combinations. More realistic management goals will be needed. This situation already characterizes many aquatic ecosystems in California that, because of past alterations, now harbor mixtures of native and non-native fishes and invertebrates. Warming temperatures will further favor the non-native species. Under these conditions sustaining highly valued native elements, such as salmon-based systems, will require intensive interventions (see Guiding Principle 4).

Over the longer-term, management goals for some, and perhaps many, ecosystems may need to switch to facilitating transitions to new ecosystem types. In some cases these transitions may involve facilitating spatial shifts in the locations of familiar ecosystems, such as assisting inland retreat of coastal ecosystems as sea level rises (see Guiding Principles 5). In others, novel ecosystems might be managed for new environmental and societal benefits or may be better adapted to and easier to manage under new climatic conditions. However, well-developed methods do not yet exist for making intelligent decisions in real world situations about whether to concentrate management efforts on sustaining the resilience of a particular ecosystem or facilitating its transition to a new ecosystem type. Appropriate criteria, thresholds, and practices for resetting ecosystem management goals are needed. These methods should account for the potential uncertainties and risks and should be established in a transparent fashion.

The hands-on tools used for managing ecosystems will need to evolve to reflect shifts in ecosystem management goals like those described above. Current restoration projects to improve degraded ecosystems, for example, should use native species and genetic varieties whose characteristics make them likely to thrive under future conditions, rather than ones that are narrowly adapted to the conditions of today. Where such information is unavailable in projects to re-vegetate disturbed lands, a possible alternative is to introduce a diversity of potentially appropriate native plants and varieties, anticipating that only those most suited to the site's changing conditions will survive and persist.

Interest in deliberate species translocations and in using diversified genetic stock is likely to grow with improved projections of likely future shifts in the distribution of appropriate habitats and with management shifts towards facilitating ecosystem transitions. Rigorous new risk assessment protocols will be essential, however, to carefully weigh the possible benefits, risks, uncertainties, and feasibility of such proposals and to guard against unintended consequences. Such evaluations should consider the potential impacts on recipient ecosystems as well as the long-term prospects for declining species if they are not re-established in more favorable locales.

Thinking ahead about the challenges of working in a changing world, assessing the risks, and setting priorities will improve the feasibility, success, and cost effectiveness of virtually all ecosystem management and restoration efforts.

### WHAT IS A "NOVEL ECOSYSTEM"?

Ecologists use this term to describe an ecosystem "in which the species composition and/or function have been completely transformed from the historic system." At a given locale, most of the species may be non-native or may have new functional properties related, for example, to their effects on fire dynamics, nutrient cycling, or habitat quality.

See: Hobbs, R.J., E. Higgs, & J.A. Harris. 2009. Novel ecosystems: implications for conservation and restoration. *Trends in Ecology and Evolution* 24: 599-605.

## APPENDIX A – MEMBERS OF THE EXPERT PANEL

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## APPENDIX B – PANEL SHARED ECOLOGICAL ASSUMPTIONS

The Expert Panel came to agreement on the following points related to current scientific understanding of how climate change is affecting California's species and ecosystems.

### Ecologically Significant Aspects of Climate Change

Climate change is altering key factors that determine the distribution and abundances of species and the condition and resilience of ecosystems.

The general directions of these changes are clear at regional and larger scales, although the details vary across the landscape and at smaller scales. Specifically:

- Temperatures are warming, precipitation patterns are shifting, sea level is rising, ambient $CO_2$ is increasing, and watershed flows are becoming more variable. These effects are likely to persist or increase over the next century, in part because greenhouse gases have long residence times in the atmosphere.
- Certain extreme events – heat waves, droughts, coastal storm surges, and inland flooding – will shift further from recent historical patterns over the coming decades.
- Less precipitation will fall as snow, and the snowpack will shrink and melt earlier in the spring.
- The dry season (summer/fall) will become longer, and rising temperatures will result in declining soil moisture.
- Further disruption will occur to the fire regimes that are a natural feature of California's ecosystems, but that have already been extensively altered.
- Sea level rise will intensify coastal erosion and flooding of marshlands.



Scientists have high confidence in these directions of change based on current understanding of how the climate is changing (see Appendix C).

Although nature is rarely static, the changes now occurring in the distribution of climate across the landscape are very fast in comparison to historical rates within recorded human experience. They will outpace the unassisted ability of many species and ecological systems to adapt.

## Ecological Impacts

The combined ecological impacts will be pervasive and include:

- Alteration of species' physiology, plant productivity, animal behavior, annual life cycles, recruitment, and survival.
- Degraded or altered habitat quality and spatial distribution.
- Shifts in the actual and potential ranges of many species.
- Break-up of current ecological communities, and emergence of novel species assemblages, as various component species respond differently to environmental change.
- Vegetation conversions in some places (e.g., from forests to grasslands).
- Increased opportunities for invasions of non-native species and outbreaks of pest infestations and diseases in new locations and with increased severity.
- Altered and, in some places, diminished delivery of desired ecosystem services.

## Species Vulnerability

Species will vary greatly in their responses to climate-related shifts in environmental conditions. In general:

- Species that will fare most poorly are those with restricted ranges, highly fragmented or rare habitats, narrow ecological niches, long generation times, slow population growth, low genetic diversity, or low dispersal. Such species will be less likely to shift ranges or to adapt physiologically or evolutionarily in response to changing conditions. Those species that occupy shrinking climate regions, such as high alpine environments, will be particularly vulnerable, as will those whose habitats are already highly degraded and fragmented, such as many fishes and other aquatic species.
- Conversely, the species likely to fare the best are those that can rapidly shift ranges or adapt in response to new conditions. These include highly mobile species as well as many weeds, insects, and diseases. The relatively high adaptability of some pests, and possibly some desired species, to changing conditions will complicate management options. Opportunities for range expansion may be especially great for species that occupy expanding environments, such as deserts in southern California.

Our ability to predict specific responses of large numbers of individual species to climate change is currently limited, but our ability to project general directions and types of responses across larger categories of species – such as mammals, plants, insects, etc. – is more reliable. The most robust projections are those that have been informed by many different sources of information (e.g., models, experiments, historical changes). These provide a basic generic understanding of how species will respond to future climatic conditions.

Biodiversity management and conservation can no longer rely on place-based strategies for individual species. Many areas that presently support particular rare, threatened, or endangered species; hunted and fished species; or other focal taxa, are likely to support different species in the future. Goal setting must be reoriented to reduce the emphasis on particular species at particular locations and to encourage actions that promote native biodiversity, ecosystem structure and function, and associated public benefits.

## Changes to California's Ecosystems

- Certain ecological systems presently appear to be particularly vulnerable over the next few decades. Increased variability of stream flows and longer dry season conditions will threaten water-dependent systems, such as alpine meadows, shallow wetlands, riparian settings and intermittent streams. Sea level rise poses an unambiguous risk of habitat degradation to coastal ecological systems, most of which are already highly modified and limited in extent.
- Extreme ecological events will occur as the frequency and intensity of ecosystem processes – like fire, water flows, coastal wave dynamics, and species invasions – operate further outside recent historical conditions. Large alterations in environmental regimes could potentially cause large shifts in the structure, composition and functioning of some ecosystems, particularly when they occur rapidly. Such "state transitions" may alter ecosystem values and services that people rely on.
- The effects of climate change on California's ecosystems will be unevenly distributed across the landscape, because they depend both on local patterns and rates of climate-related environmental change and on a host of other environmental factors. Local land and resource uses, management approaches, and nitrogen pollution, for example, will all significantly modify outcomes. Habitat fragmentation may have especially important effects on biodiversity, because it is likely to impede range shifts by many species.
- The broader choices society makes in adapting to and mitigating climate change will have important impacts on ecosystems, while diverse and well-functioning ecosystems will better support a variety of adaptation and mitigation efforts. Diverse choices – such as those related to land and water uses, conservation, transportation, and infrastructure – will significantly affect ecosystem condition and resilience under climate change. Conversely, healthy ecosystems can efficiently support many adaptation and mitigation efforts, such as those to protect coasts, manage water resources, and sequester carbon. Many opportunities exist to better align and optimize the co-benefits of these diverse societal choices.

## APPENDIX C – PANEL SHARED ASSUMPTIONS ON THE STATUS AND APPLICATIONS OF CLIMATE CHANGE SCIENCE TO ECOSYSTEM ADAPTATION DECISIONS

The Expert Panel came to agreement on the following points related to the state of the science on climate change and how it can be integrated into decisions that are relevant to ecosystem adaptation.

- Climate change and greenhouse gas emissions are altering California's environment in ways that will affect the structure, functioning, and benefits that society derives from the state's ecosystems.
- General elements of this change include increasing temperature, altered spatial and temporal patterns of precipitation, sea level rise, higher ambient $CO_2$, intensification of extreme weather events, and further alteration of fire cycles.
- Information derived from the global climate models (GCMs) that scientists are using to understand how the earth's climate is changing provides a broad framework for environmental assessments and impacts, but may be at too large a spatial scale to be used directly in making decisions relevant to ecosystem adaptation at local-to-regional levels. Also, the current GCMs do a better job of projecting certain aspects of the climate for certain geographic regions.
- Within this context, at least three potentially complementary approaches exist for informing decisions related to ecosystem adaptation with information about how the climate is changing:
    1. The coarse scale outputs of select GCMs (spatial resolution of ~250 $km^2$) can be "downscaled" to resolutions that match the particular scale of a specific decision-making context using statistical or dynamical modeling or spatial interpolation. The downscaled climate projections can then be interpreted using hydrological or ecological models and conceptual frameworks;[4]
    2. Recent climate patterns and rates of change can be assessed and mapped at finer scales to assess existing variability and vulnerability across the landscape and to anticipate likely spatial patterns of change in climate, habitat quality, and ecological processes; and
    3. Certain types of conservation design or management choices (e.g., for reserves or migratory corridors) may be implemented to bolster ecological resilience or adaptive capacity in ways that will be effective regardless of exactly how the climate is changing or how much greenhouse gas levels rise.
- Uncertainty arises from several sources in projecting how climate change will affect California's ecological systems.
    1. We presently do not know whether or how effectively society will reduce greenhouse gas emissions and thereby slow the rate of climate change.
    2. Similarly, we cannot fully anticipate where or how other types of threats that interact with climate will alter how ecosystems respond to climate impacts.
    3. Each current GCM, as well as the new ones under development, has certain strengths and weaknesses. None yet replicates the earth's climate dynamics with complete fidelity.



4. This type of analysis might examine outputs from an ensemble of GCMs to highlight where the various model projections agree, and uncertainty is low, or certain GCMs might be selected, because they are more sensitive to specific local or regional processes of interest (e.g., coastal fog, summer monsoons).

4. Downscaling projections from climate models introduces additional uncertainties, most importantly because knowledge of historical climate patterns is imperfect and may or may not accurately predict what will happen in the future.[5] Consequently, statistical downscaling at very fine scales of key variables – such as temperature and precipitation – is difficult or hard to verify, and dynamical downscaling – currently essential for projecting fog and wind – can introduce large biases that are challenging to resolve.

5. Interpretation of how altered climate and climate-dependent aspects of habitat quality will affect species and ecological systems is based on our best available knowledge of likely ecological and evolutionary responses. However, understanding of the linkages between climate and ecosystems, and the models and conceptual tools for interpreting these linkages, are incomplete. (See also Box 1 and Appendix B).

- Today, scientists have relatively high confidence in projections of how certain aspects of California's climate are changing. With some exceptions, generally due to moderating effects of topography or coastal influences, average air temperature in California is rising and all climate models agree that it will continue to rise. The impacts of global warming on the spatial patterns of precipitation are not yet well understood. However most climate models agree that extreme events such as flooding and droughts in some regions of the state will increase in frequency and/or magnitude.
- Climate science is advancing rapidly. Over the next five to ten years, improvements to global and regional models and downscaling methods will reduce, but will not eliminate, the uncertainties. Overall, these advances will improve the usefulness of climate projections at local to regional scales.
- Present understanding of how climate change will translate into changes in other factors that will affect ecosystems is better developed in some areas than others. Projected rises in sea level and modeling approaches that project hydrologic impacts on watersheds and the landscape are particularly well developed.
- Although uncertainties will remain, informed ecosystem and resource management decisions can be made. The practical approach to dealing with the uncertainties that cannot be reduced is to develop approaches for ecosystem adaptation that reflect the sources of variability and will be robust and effective under a range of projected future climatic changes.
- Much information is available at scales that matter that can be used by decision makers now. For example, categories of particular vulnerability of ecosystems to future climate impacts can be identified with existing tools, and statistical and probabilistic models are available that describe potential changes in species distributions and composition.



5. Observations of climate and ecosystems at relevant scales (space, time) often are not available and are expensive to sustain.

## APPENDIX D – REPORT REVIEWERS

Resources Legacy Fund appreciates the thoughtful reviews of an earlier version of this document provided by the following individuals.

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