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Forest Stewardship Series 25: Adapting Forests to Climate Change

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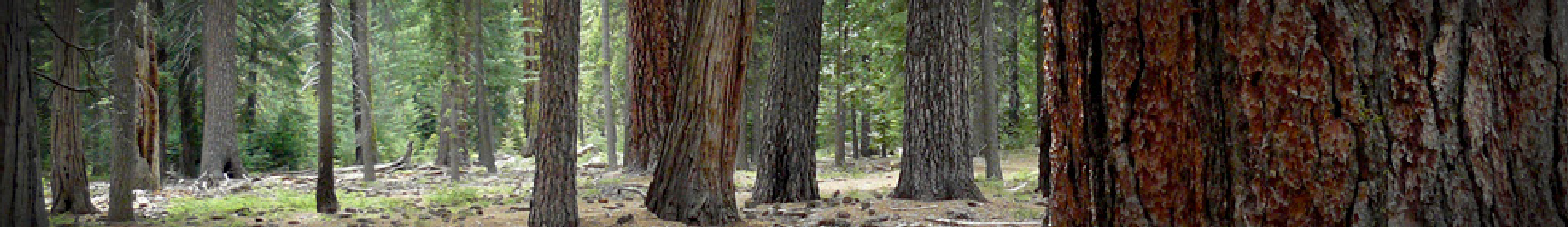

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Forest Stewardship Series 25

Adapting Forests to Climate Change

Introduction

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Managers of forest land have always been challenged to adapt to changing social conditions such as markets, human populations, and social attitudes, as well as environmental conditions including droughts and floods. However, forest managers must now also contend with rapid changes in the global climate. The goal of this publication is to help owners of California forest land better understand the evolving science of climate change, the possible effects these changes will have on forests, and the actions they can take to better adapt their forests to the climate of the future.

Forests are shaped by the climates in which they grow. Climate has always changed over time, but many of the changes we now observe have not occurred in recent decades or even thousands of years. This faster rate of change can impact forest health in many ways. As a forest landowner, there are decisions you can make now about how you manage your land that will help you protect your forest against the likely effects of a changing climate. In order to do so effectively, it is important to understand what climate change is, what impacts it may have on your forest, and what you can do to keep your forest healthy and productive.

California's forests are very diverse, as are the goals and needs of different landowners. The condition of our current forests varies greatly according to local geology and climate as well as the history of human use and fire suppression. The information presented here provides some ideas about the impacts of climate change, but regional and local forest diversity will require different responses. This publication provides broad principles that apply to many forest types.

Furthermore, our knowledge of climate change is continually evolving. While it is now clear that the climate is generally warming, the exact patterns of warming and expected changes in precipitation patterns are uncertain, as are the impacts on forests. Research continues on these topics, and we anticipate that our understanding will improve over time. For that reason, we recommend using the resources at the end of this publication to get updated information. Consult with local agencies or your registered professional forester (RPF) for the most current knowledge.

Objective

Understand the projected impacts of climate change on forests and the adaptation options available for landowners

Competencies

- *Understand that climate change is creating forest conditions that are different from recent historical conditions.*
- *Assess possible impacts of climate change on your forest.*
- *Identify strategies to adapt to climate change.*

Related Forest Stewardship Series Publications

- *A Forest Stewardship Framework* (ANR Publication 8232)
- *Forest Ecology* (ANR Publication 8233)
- *Stewardship Objectives and Planning* (ANR Publication 8248)

Climate versus Weather

Weather is what we experience on a day-to-day basis; climate is the average of weather over long periods of time, or long-term patterns in the weather. Climate has varied over time without human influence, due to physical cycles operating at multiple time scales, ranging from years to millennia and longer. This natural variation is a backdrop for the human-caused climate change occurring now due to greenhouse gas emissions and other factors. In 2014, the group of scientists that forms the Intergovernmental Panel on Climate Change agreed with more than 95 percent certainty that recent human-caused greenhouse gas emissions are responsible for most of the climate warming we have observed. As the climate warms due to human influence, we can still expect weather that varies from day to day; this is why an especially cold day, week, or even year does not contradict an overall warming trend.

Why Focus on Forests and Changing Climate?

As a forest owner or manager, you will make decisions that shape your forest for dozens or even hundreds of years into the future. The future climate that influences your forest is likely to be different from our current climate. As you decide how to manage your forest for fire resilience, timber harvest, wildlife habitat, or any other objective, it is important to consider how the future climate will influence your forest's ability to meet these objectives.

Categories of Adaptation: Resistance, Resilience, and Response

Climate change adaptation strategies are often characterized in three main categories: resistance, resilience, and response. These categories may help you choose which options best suit your management objectives. This vocabulary may also be useful when working with agencies that fund cost-share programs, such as CAL FIRE or the Natural Resources Conservation Service (NRCS). It may be useful to incorporate all three types of strategies in your planning.

Resistance strategies are short-term measures designed to save high-value resources from stresses related to climate change. An example of resistance would be creating complete fuel breaks around high-value areas if climate change increases the risk of fire in your area.

Resilience strategies are ways of managing your forest so that it is able to recover from disturbances that are associated with climate change. An example would be thinning your forest stand to a level that has been demonstrated to make it less susceptible to damage from severe wildfire or insect attack.

Response strategies recognize that the climate will change, and they facilitate the expected shift. Promoting species that are well adapted to warmer climates is an example of a response strategy.

In California, climate change is affecting forests in several ways. Water runoff from forested watersheds is coming earlier in the spring and therefore leaving less spring snow storage (fig. 1). Warmer temperatures are also promoting more frequent and severe wildfires. Tree mortality is continuing to increase, due in part to decreased soil moisture caused by warmer temperatures and drought. Stressed forests are more vulnerable to disease and insect outbreaks, the spread of invasive plants, and air pollutants not related to climate change, such as nitric acid. Tree mortality, especially widespread forest die-off, has serious ecological and economic consequences. In particular, it causes changes in forest age, species composition, and density, as well as an increase in fuels.

The way you manage your forest can have important consequences for its ability to respond to these changes. Your forest management choices may also help to reduce the rate of climate change by storing carbon; this is called climate mitigation and is not addressed in this publication.

Trends in April snowpack in the western United States, 1955–2016

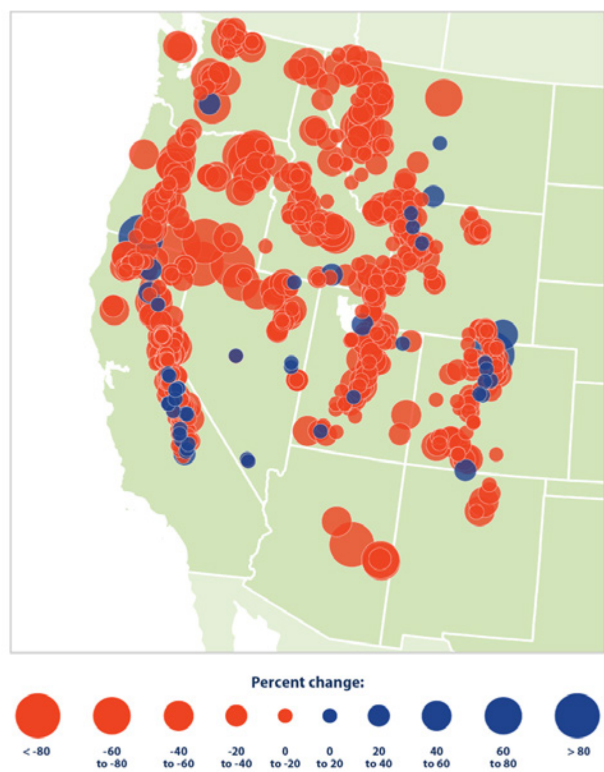

Figure 1. Changes in snowpack in the western United States from 1955 to 2016. Red indicates decrease in snowpack, while blue indicates increase. Size of circle denotes amount of change. Location of circles is based on placement of snow sensors. *Source:* U.S. EPA 2016.

Furthermore, adapting to climate change proactively may help to optimize the economic productivity of your forest.

Potential Climate Futures

The projection of future changes in climate should be understood as a current best guess rather than a forecast. There is uncertainty due to both variations in the climate system and a range of future greenhouse gas emission levels. The information presented here focuses on the changes that are most likely under many different scenarios.

Temperature

Solid scientific evidence indicates that global average temperatures have been rising over the past century, and they will likely continue to rise in the future, with impacts on natural and human systems. In California, statewide average temperatures rose by 1.7°F between 1895 and 2011. In the twenty-first century, average temperatures in California are projected to rise significantly across all models and emissions scenarios, with a range of 3.5° to 9.5°F change in temperature by the end of the century. The projections all suggest warmer temperatures, and they generally predict more significant changes in summer temperatures than winter temperatures, more severe heat waves, and more warming inland than along the coast (fig. 2). Several websites can provide information on the latest climate change projections. (For example, see the Cal-Adapt website, http://cal-adapt.org/.)

Climate Change and Evapotranspiration

Evapotranspiration refers to the movement of water out of the forest and into the atmosphere. This term includes both evaporation and transpiration. Transpiration is the process by which trees draw water out of the soil. As trees photosynthesize, they open stomata (small pores on their leaves) in order to absorb carbon dioxide. When the stomata are open to absorb carbon dioxide, water can also escape from them. Trees, in turn, draw water out of the soil in order to compensate for this loss and maintain cellular structures. Evaporation is the process by which liquid water is drawn from the forest surface into the atmosphere, without passing through a plant. Evapotranspiration, the sum of evaporation and transpiration, is an important part of the water budget. In the northern parts of California, for instance, approximately 40 to 50 percent of water that falls as precipitation leaves as evapotranspiration. And in the drier southern parts of the state, as much as 100 percent of precipitation may be evapotranspired in the warmer months. Warmer temperatures increase evapotranspiration rates. This, rather than a change in absolute amounts of precipitation, is one important reason that climate change will likely lead to drier conditions and more moisture stress in California's forests.

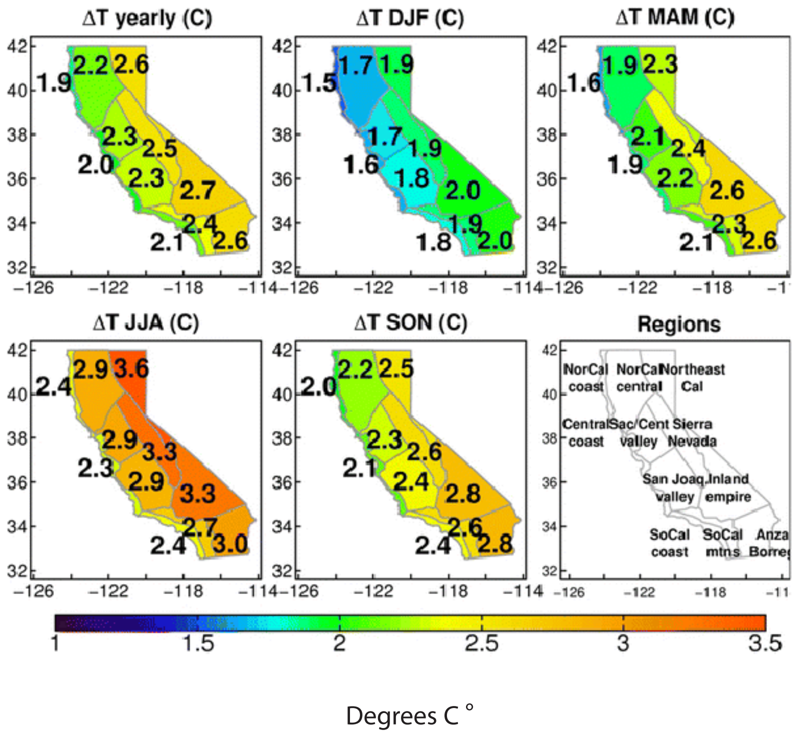

Figure 2. Projected mean temperature changes (ΔT) in Celsius from the baseline period, 1985 to 1994, to the future period, 2060 to 2069. The x- and y- axes represent longitude and latitude. DJF stands for December-January-February; JJA stands for June-July-August. The center and right maps demonstrate greater temperature increases projected for summer; all maps show greater warming in inland than coastal areas. *Source:* Pierce et al. 2013.

Water

Projected changes in annual precipitation are highly variable and include both increases and decreases in total precipitation. However, warmer temperatures are likely to make California drier overall (fig. 3). This is because in snowmelt-dominated regions, warmer temperatures cause more precipitation to fall as rain rather than snow. This leads to decreased snowpack and earlier snowmelt, resulting in higher streamflow in the winter and lower flow in the summer. In addition, when temperatures are warmer, more water evaporates and transpires from the forest. In water-limited areas, drought is already increasing in severity and duration, and it may be among the most important impacts on forest health and mortality. Many of the other impacts of climate change, such as changes in habitat suitability for certain species, as well as increases in wildfire, invasive species, and pests, are due to both the direct effects of warmer temperatures and the indirect effects of warming on water resources. Changing forest uses, including reduced harvesting, grazing, and long-term fire suppression, have led to increased forest density and decreased soil moisture in many areas.

Overall Trends for Forests in California

As you decide how to manage your forest in a changing climate, an important first step is to understand the direct and indirect impacts that climate change may have on your forest

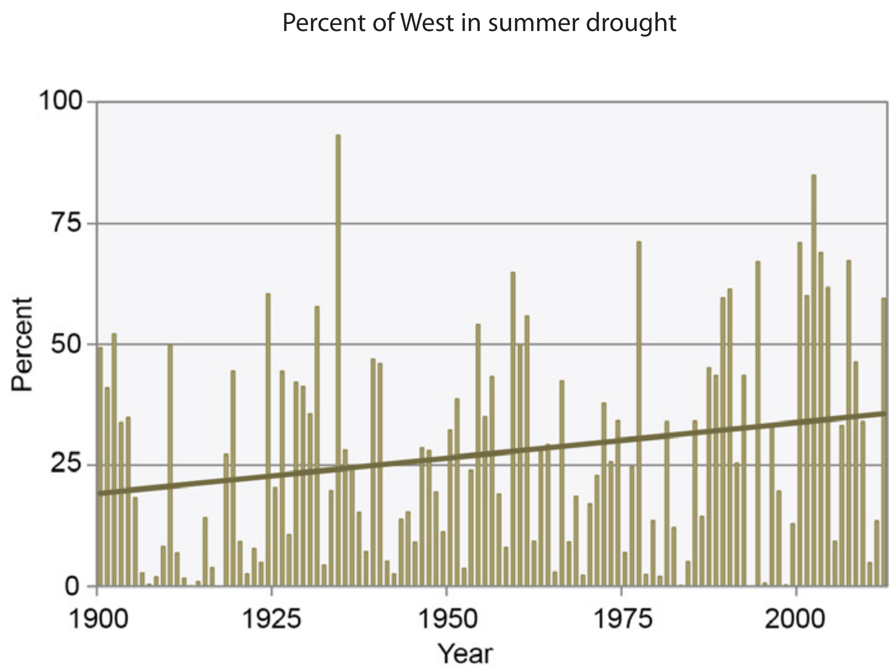

Figure 3. The area of the western United States in moderately to extremely dry conditions during summer (June-July-August) varies greatly from year to year but shows a long-term increasing trend from 1900 to 2012. *Source:* U.S. Global Change Research Program 2014.

How Do We Know?

Scientists use several lines of evidence to predict climate change impacts. Computer models called general circulation models (GCMs) simulate physical processes in the atmosphere, ocean, and land surface to model how human activities, such as greenhouse gas emissions and land use change, affect the earth's atmosphere and energy balance. These models can be confirmed and calibrated by observations of historical climate conditions. GCMs simulate climate over large areas, so scientists downscale the models to obtain climate projections for smaller regions, such as parts of California. Downscaling is an important tool for understanding regional climate change impacts, but it also introduces more uncertainty into climate model projections.

These downscaled climate models can be used to measure the anticipated impacts of climate change on ecosystems. This is sometimes done using process-based models, which simulate the processes that vegetation uses to grow, such as photosynthesis and reproduction. Another way of modeling vegetation is through species distribution models (SDMs), also called bioclimatic envelope models. SDMs use the climatic conditions where a particular organism currently lives to assess where it might be able to live in a changing climate (fig. 4). Observations of changes in vegetation over the past century can help to fine-tune the results of SDMs or process-based models, though these observations are often limited by different techniques, technology, or scale. These observations suggest that climate change is already impacting ecosystems.

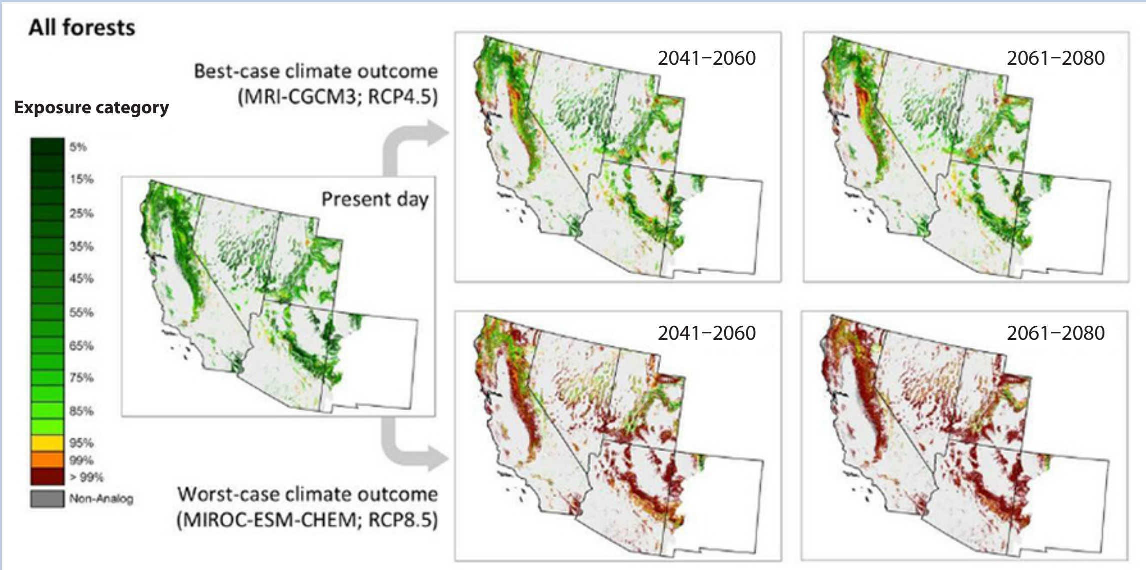

Figure 4. Climate exposure mapping for western forests. The top row of maps shows a best-case scenario, with a wetter climate model and lower emissions. The bottom row shows a worst-case" scenario, with a drier climate model and higher emissions. Orange and red areas indicate that the future climate will be very different from the forests' current climate. This figure shows the uncertainty between climate outcomes based on future greenhouse gas emissions. The ranges shown are used by scientists to bookend the projected magnitude of climate change impacts on forests. *Source:* Elias et al. 2015.

(fig. 5). Direct impacts are caused by climate variables such as temperature and precipitation. Indirect effects occur when the changing climate impacts other factors, such as forest insects and diseases, which in turn impact forests. Table 1 provides a short description of potential impacts on each of 10 major forest types found in California. A number of these are uncertain, in both observed and projected impacts. In addition, forests are a complex mix of species. Here, we make use of a categorical system that simplifies the complexity of a forest ecosystem. Consult Forest Stewardship Series 3, *Forest Ecology* (ANR Publication 8233), for more information about these forest types.

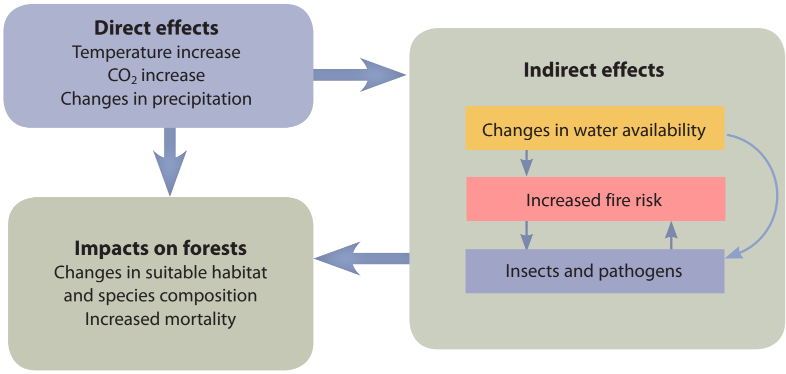

Figure 5. Conceptual diagram of the direct and indirect effects of climate change on forests. The effects listed here are by no means exhaustive, but the diagram illustrates some common interactions between causes.

Table 1. Impacts of climate change on major forest types found in California

Forest type	Observed (O) and projected (P) impacts of climate change	Factors affecting vulnerability
mixed conifer	O: increase in evergreen oaks and shade-tolerant species O and P: increase in risk of fire and pests due to increase in temperatures and decrease in snowpack	historical management practices, including fire suppression, have led to dense, homogeneous stands, which increases vulnerability
Douglas-fir	O: inconclusive P: species range shift difficult to predict	populations are adapted to local conditions, which may increase resilience
oak woodland	O: increase in oaks in montane woodlands P: decrease in total area with suitable growing conditions	mature oaks appear to be fairly resilient; growth and survival of new seedlings is more likely to be impacted by climate change; sensitive to groundwater depletion, grazing stresses, and competition from invasive species
riparian woodland	O: inconclusive P: inconclusive	reliant on streamflow, which is likely to change, but exact patterns are still uncertain
red fir	O: inconclusive P: may be threatened by reduced snowpack; need for deep soil may reduce ability to migrate	depend heavily on snowpack and deep soil
redwood	O: decrease in fog frequency; possible increase in sudden oak death (SOD) in tanoak P: future fog frequency is uncertain; SOD could be exacerbated by warm, wet conditions	long-lived; can regenerate through sprouting; heavily dependent on fog
subalpine conifer	O: tree growth increased by warming; increase in density of small trees P: highly uncertain; refugia could help resilience, but increased density could lead to increased fire frequency	high elevation sites may be especially vulnerable; new habitat is limited if old habitat becomes unsuitable
montane chaparral	O: shifted upward in elevation in one southern California study P: vegetation likely to increase, but uncertain	drought resistant; adapted to fire
pinyon-juniper	O: longer, more extreme fire seasons; large areas of pinyon die-off in the southwestern United States P: drought and bark beetle infestations could lead to further die-off	stands have increased density and have expanded in some places and had significant die-off in others; mechanisms for change are location-dependent but may include fire exclusion, recovery from past disturbance, livestock grazing, and climatic variability
aspen	O: inconclusive P: sudden aspen decline (SAD), as well as the insects and pathogens associated with it, may be exacerbated by climate change; temperature and moisture stress are threats, but fire could reduce conifer encroachment	conifer encroachment due to fire suppression has suppressed aspen; increased fire may favor aspen vigor; ability to reproduce by both seed and sprouting could provide adaptive capacity

Figure 6. Mixed-conifer forest. *Photo:* W. Suckow.

Common Forest Types

Mixed Conifer

Mixed-conifer forests (fig. 6) are broadly distributed throughout much of California, particularly in the Sierra Nevada. They are typically composed of white fir, sugar pine, ponderosa pine, incense cedar, and California black oak. A key impact of projected climate change to consider in these forests is increasing moisture stress that results from warmer temperatures. This, in turn, could lead to increased fire risk, susceptibility to pests and invasives, and changes in species composition. In many of California's mixed-conifer forests, the stress from climate change is one of several potentially interacting stressors.

Fire

Over the last century, fire severity has increased, with evidence suggesting that climate is an increasingly important regulator of fire severity and amount of area burned, although changes in fire suppression and vegetation management are also important contributing factors. As climate change continues, wildfire frequency, severity, and spread will likely continue to increase in mixed-conifer forests due to reduced snowpack and more days with severe fire weather. In much of California, changes in climate exacerbate the dangers of high fuel loads that have developed through decades of fire suppression. Owners of mixed-conifer forests should carefully consider the fire hazard in their forests, as it is already out of balance due to fire suppression, and climate change may increase wildfire susceptibility in the future.

Insects and disease

Increasing temperatures and moisture stress can make mixed-conifer forests more susceptible to outbreaks of pests, especially in the conditions of increased stand density resulting from the absence of high-frequency, low-intensity fire. As mixed-conifer forests are subjected to increasing temperatures and soil moisture stress, insect or disease outbreaks and invasive species are likely to become increasingly significant concerns. Climate change may increase the risk of bark beetle outbreak, dwarf mistletoe, and armillaria.

The incidence of many pathogens depends on whether California forests experience a warmer and drier or warmer and wetter climate. Armillaria, a root rot, could be particularly impactful in a warmer, drier climate. Needle blight *(Dothistroma pini)*, which affects Monterey and lodgepole pines, could have less impact than it does today in a warmer, drier climate, while it is likely to have more impact in a warmer, wetter climate. Bark beetle survival and reproduction increase under warmer temperatures, and trees that are stressed by high stand density and drought or that have experienced fire can be especially susceptible to bark beetle attacks. Reducing competition for water through thinning and managing for species and structural diversity can help make forests more resilient to bark beetle attack. Non-native invasive species could also become more of a concern. (For instance, some broom species spread more aggressively with reduced snowpack.)

Species distribution

The combined direct and indirect effects of climate change may lead to a shift in the conifer species that are best suited to a particular location. These shifts could occur with or without human intervention, and some have already been observed during the twentieth century. For example, in the Sierra Nevada and north coast, oaks, white fir, and incense cedar have become increasingly dominant in the past century. Sierra mixed-conifer forests have also gotten denser over the last century. Identifying the causes of these changes can be difficult, but evidence suggests that fire suppression, historic selective logging of large trees, and a changing climate all play a role. The outlook for overall productivity of mixed-conifer forests is uncertain; while warmer temperatures and increased atmospheric carbon dioxide can encourage growth, limited water and increased disturbance can reduce productivity.

Adaptation

To help your mixed-conifer forest adapt to climate change, consider ways to encourage resilience to drought, fire, and insect attacks. Strategies include thinning to reduce competition, managing for species diversity, and selecting seedlings that are likely to survive well in a warmer, drier climate. For more information on how to identify forest stock that may be well adapted to warmer temperatures in your region, consult with a registered professional forester.

Oak Woodlands

On the landscape scale, oak woodlands (fig. 7) are widely distributed and diverse, which gives them moderate to high capacity to adapt to climate change, although individual trees and seedlings in some areas may be negatively affected. Over the course of the twentieth century, there has been a shift in many parts of California toward more oaks, a pattern that is consistent with warmer, drier conditions. At the scale of individual forests, however, climate change presents several possible threats to consider. In many cases, mature oaks are fairly resilient, but seedling recruitment and survival is more sensitive to climate change stressors.

Figure 7. Oak woodlands. *Photo:* T. Swiecki.

Moisture stress

Primary climate-related stresses to consider in oak woodlands are decreased precipitation and soil moisture. These climate impacts can increase moisture stress, which in turn can increase susceptibility to herbivory, habitat conversion, pests, and invasives. As temperatures warm, the moisture stress that oaks experience is projected to increase regardless of precipitation changes, due to increased evapotranspiration.

Insects and disease

One of the primary climate-driven stressors for oak woodlands is insects and disease, both native and invasive. The non-native sudden oak death (*Phytophtora ramorum)* (SOD) is currently a significant concern, primarily in tanoak communities. One potential impact of climate change is increasing precipitation variability, and increasing spring rains could increase the episodic spread and prevalence of SOD, because it spreads in warm and wet conditions. SOD could also increase susceptibility to the impacts of fire and invasives such as broom species. If you have oak species that are susceptible to insects or disease, it is increasingly important to be vigilant about these threats as the climate warms. For SOD in particular, preventing the movement of infected leaves, wood, and soil is critical. For more information, see UC ANR Publication 8426, *Protecting Trees from Sudden Oak Death before Infection*.

Regeneration

The other primary concern for oaks in a changing climate is sapling recruitment and survival. Sapling survival may be impacted by fire, herbivory, soil moisture, and overstory conditions, and climate change is likely to exacerbate these stressors. Oak masting (dropping of acorns) is one component of sapling recruitment. Acorn crops vary widely from year to year. The mechanisms for varying acorn crops are not completely understood, but it is likely that oaks drop more acorns in years when the seasonal timing of the reproduction of certain species of oak trees is well synchronized with each other. By increasing environmental variability, climate change could impact masting negatively.

Adaptation

There are several management options for protecting oak woodlands. In areas with poor oak recruitment, consider planting seedlings or protecting new seedlings from herbivory and drought stress through use of seedling shelters. Stump sprouting may also be an important form of regeneration that leaves seedlings less vulnerable to moisture stress and herbivory. It may be helpful to consider whether groundwater use, such as well pumping, is impacting groundwater availability for oaks on your property. In warmer, drier conditions, wetter microclimates may act as refugia for some oak species, such as valley oak. If you are planting oaks, consider whether groundwater levels in the area will support their survival. For more detailed ideas on your property, consult an RPF.

Coastal Redwood Forests

The impacts of climate change on coastal redwood forests (fig. 8) are uncertain. Important factors may include the potential for changing fog frequency, impacts of sudden oak death on the tanoaks that are common in coast redwood forests, and the potential for increased fire frequency. Some evidence suggests that coastal redwoods have many traits that make them fairly resilient to climate change.

Moisture stress

Coastal redwood forests rely on cool, humid marine conditions with frequent cloud cover. Redwoods are heavily affected by the presence of clouds or fog; they use much more water on a sunny day than a cloudy one, and they are capable of absorbing water directly through their leaves. Fog frequency in coastal redwoods has declined by 33 percent since the early twentieth century. This fog decline could be the result of climate change, and it could further impact redwood forests in the future. Some models show that, regardless of changes in water inputs through fog or precipitation, the areas where redwoods live may become drier due to warmer temperatures. Areas with deep soil and those that are close to streams and rivers may provide refugia for redwood forests.

Figure 8. Coast redwood forest. *Photo:* A. Marshall.

Fire

Another question is whether coastal redwood forests will experience more severe or more frequent fires. Coastal redwoods may be fairly well adapted to fire, and some studies suggest that climate change may not increase fire frequency or severity in redwoods. The role of historical disturbance, including fire, in redwood forests is not well understood. If climate change increases disturbance such as fire, flood, or slope failure, the exact impact of these disturbances is uncertain at this point.

Adaptation

Uncertainty about changing precipitation and fog regimes, along with uncertainty about fire risks, make it difficult at this point to recommend specific adaptation strategies for coastal redwood forests. When managing in uncertain conditions, it can be helpful to inspect your property and revise management plans accordingly.

Principles for Managing Forests under Climate Change

The potential impacts of climate change are different in every forest, as are the goals, objectives, and resources of every landowner. The recommendations provided here are options to consider, but talk to your RPF or seek further resources to assess best practices for your situation.

Design and maintain your property for defensible structures and space.

The combination of historical fire suppression and a warming climate makes fire management even more important on many forest properties. Defensible structures and spaces are of paramount importance for protecting your home and keeping firefighters safe in the event of a fire. For more information about building and maintaining defensible structures, see Forest Stewardship Series 15 on wildland fire and fuel management (UC ANR Publication 8245), talk to your RPF, or visit the CAL FIRE website (www.fire.ca.gov) or the *Homeowner's Wildfire Mitigation Guide* at the UC ANR website (http://ucanr.edu/sites/Wildfire/).

Manage forest density to reduce competition and increase resilience.

In forests with limited moisture, a low-density, spatially heterogeneous structure can adapt better to several impacts of climate change, including moisture stress, fire, and insects. Thinning understory ladder fuels and reducing surface fuels are important strategies that can reduce fire risk. Reducing forest density and other competing vegetation can reduce moisture stress. For more information, see Forest Stewardship Series 5 (UC ANR Publication 8235) on tree growth and competition.

Manage for a forest with diverse species.

The exact conditions your trees will experience through their lifetimes are uncertain. One way to deal with that uncertainty is to plant or select for a diversity of species. Much like having a diverse financial portfolio, this strategy can reduce the risk if one particular species is not successful in future climates. This strategy is more appropriate in some forest types than in others; consult with your RPF. For more information, see Forest Stewardship Series 3 on forest ecology (UC ANR Publication 8233).

When choosing and planting long-lived forest trees, consider whether seedlings will thrive under 3° to 5°F warmer temperatures in 50 years.

In order to ensure that the forest seedlings you plant today will be viable in a warmer climate, you may want to consider selecting seedlings from areas that are slightly warmer than current conditions on your property. For example, seedlings adapted to slightly lower elevation or latitude than your property may be adapted to warmer temperature zones. For more information on forest planting, see Forest Stewardship Series 7 (UC ANR Publication 8237) on forest regeneration.

Prepare for increasing flood and erosion risk from extreme precipitation events.

Climate change is likely to increase flood frequency and severity in much of California. Riparian vegetation is typically well adapted to floods, and can help to reduce flood impacts by enhancing water infiltration. Riparian vegetation also has significant benefits for wildlife and ecosystems; it connects terrestrial and aquatic ecosystems and can provide wildlife corridors. One trade-off to consider is that riparian vegetation uses water, and it may increase water use and decrease runoff. See Forest Stewardship Series 10 (UC ANR Publication 8240) on riparian vegetation for more information.

Erosion control and road management are two facets of forest management that are likely to be impacted by more frequent or severe flooding. When planning any work that disturbs forest soils, ensure that erosion control measures taken can withstand more intense precipitation events. It is also wise to design infrastructure with future conditions in mind. For example, when building or maintaining roads, you may want to use culverts that allow for larger floods than you have previously observed, and plan for regular culvert maintenance. For more information, see Forest Stewardship Series 17 (UC ANR Publication 8247) on forest road management.

Current regulations for riparian vegetation, timber harvest, and road building already require many of these strategies. We provide these suggestions to alert you to their relevance to climate change and to recommend taking them into account for nonregulated activities.

Closely monitor and address the presence of native and invasive pests and diseases that may spread more aggressively in a changing climate.

Both native pests and invasive species can be directly and indirectly impacted by climate.

Perhaps the most prevalent native threat that may increase due to climate change is bark beetles. Forests that are diverse in structure and species composition are more resilient to bark beetles, because most beetle species are tree species specific. Limited moisture availability also increases susceptibility to bark beetles; maintaining an appropriately thinned forest using a stand density index for guidance may reduce drought stress. Removing brood trees and following best management practices for slash can mitigate bark beetle impacts. See Forest Stewardship Series 16 (UC ANR Publication 8246) on forest pests and diseases.

Invasive species—both plants and pests—may also spread more aggressively due to warmer temperatures and may impact native species that are stressed by warm temperatures and low moisture. They are best controlled before they spread into large areas. Learn more about invasive species management in Forest Stewardship Series 14 (UC ANR Publication 8244) on exotic pest plants.

Maintain habitat for wildlife that may be stressed by a changing climate.

Climate change impacts wildlife species in different ways, and it may reduce the habitat available for some while creating desirable conditions for others. One approach to helping species of concern is enlarging protected areas and providing connected corridors for species migration. Consider the areas around your property as well as the wildlife that may already be on your property. If you think your property may provide habitat or corridors for sensitive species, you should consider management strategies to maintain habitat quality. These strategies will depend on the species of interest. Forest Stewardship Series 8 (UC ANR 8238) on forest wildlife has more information.

Steps to Take in the Short Run

Some climate change adaptation strategies may take a while to implement, while others are steps you can take in the short term. One way to start is by using the following checklist to assess the likely impacts of climate change that may be most significant on your property.

Self-Assessment Tool

Table 2 is provided to help you assess the climate change adaptation strategies that may be most relevant on your property. The columns on the right (vulnerability, importance, cost of addressing, timeframe, and investigate further) are for you to fill in based on your knowledge of your property. If you decide that vulnerability and importance are high enough, you may want to consult with your RPF, your local extension agent, or further materials in the "Resources" section of this publication for more information.

How to Work Climate Adaptation into Your Ongoing Planning Process

When you make plans for your forest, consider how climate change might influence your decisions. If you have identified areas of concern in the checklist above and are deciding what, if any, action to take, you may want to consider the benefits and risks of acting versus not acting. There may be times when proactive management is worth the investment of time and money, and times when a "wait and see" approach is justified by low risk or high cost of acting.

It is also useful to consider the time scale of your management decisions. For example, if you are currently planning for the near future (1 year), focus on implementing "no-regrets" projects—that is, projects that will have neutral or positive effects regardless of climate change, but that may be particularly valuable in a changing climate, such as achieving appropriate forest density. If you are planning for the medium-term future (1 to 20 years), consider projects that will resist the adverse effects of climate change and promote resilience. Fuel reduction projects that protect your forest and reduce fire intensity may be in this category. Many forest management plans operate at this scale, as do timber harvest plans (3 to 5 years). A nonindustrial timber management plan (NTMP) would involve this time span and longer.

If you are currently planning for longer time spans (greater than 20 years), you may want to implement more extensive activities to promote ecosystem resilience, such as more aggressive management of fuels or forest structure. With this time frame, you may also consider response activities—for example, planting trees that will thrive in a warmer climate. When working with

Table 2. Self-assessment tool for landowners

Climate impact	Questions for self-assessment	If yes, management options to consider and applicable "Forest Stewardship Series" (FSS) publications to consult	Vulnerability	Importance	Cost to address	Time frame	Investigate further?
			High, medium, or low			Short, ongoing, or long	Yes or no
fire risk	Are your home, other structures, and the spaces around them built and maintained to be defensible in case of a fire?	Update and maintain. See *Homeowner's Wildfire Mitigation Guide* and *Home Survival in Wildfire Prone Areas: Building Materials and Design Considerations*					
	Are there significant surface or ladder fuels in your forest?	Consider fuel management strategies. See FSS 15.					
	How long has it been since your forest last burned?	Thinning; fuels management; prescribed fire. See FSS 15.					
moisture stress	Is your forest in a moisture-limited area?	Manage for appropriate stand density to reduce moisture competition. See FSS 5.					
	Is your forest at risk for indirect impacts of climate change (fire risk, pests, etc.) that may be exacerbated by moisture stress?	Manage for appropriate stand density to reduce competition for water; consider management options for indirect impacts. See FSS 5.					
native pests	Do you have conifer forest that may be susceptible to bark beetle infestation?	Manage for diversity and reduced competition for water resources. See FSS 16.					
	Are there other native pests in your forest or region that may be more successful in warm temperatures?	Seek further resources; management options vary significantly depending on species of concern.					
invasive pests and plants	Do you have oaks or sudden oak death in your region?	Avoid spreading SOD. Be vigilant in warm/wet conditions.					
	Are there invasive plants (e.g., broom species) on or near your property that may survive well in warmer temperatures?	Monitor property; identify and remove invasives before they become established. See FSS 14.					
changing streamflow	Is there riparian vegetation along your stream?	Plant or maintain riparian vegetation to create shade over the stream and control water temperatures. See FSS 10.					
	Are there aquatic species of interest that may be sensitive to warming water temperatures?	Plant or maintain riparian vegetation to create shade over the stream and control water temperatures. See FSS 10.					
	Is your property susceptible to increased flooding?	Maintain culverts, stormproof roads. Assess structures in floodplain. See FSS 17.					
changing wildlife habitat	Are there endangered species on or near your property that may be stressed by climate change?	Maintain habitat (specific actions are species-dependent). See FSS 8.					
	Does your property have refugia that may be useful for sensitive wildlife? "Refugia" are areas that may remain cool or moist as conditions warm and dry; they may be found in wet areas, valleys, or northern aspects.	Protect refugia from development or impact; account for refugia in planning.					
changing species suitability	Are the tree species on your property likely to be stressed by warmer or drier conditions? This may be the case if you are at the warmer edge of a species' range.	Favor diverse species or those that may be resilient to warmer temperatures in management activities. See FSS 3.					

an RPF to develop an NTMP, consider climate change impacts on this longer time scale. This time scale is also important if you are planning to pass your land on to future generations.

Resources

The science of climate change is constantly evolving, as are the policies in place to help landowners adapt to climate change. The resources below will help provide the most up-to-date information on the impacts of climate change and what you can do to keep your forest healthy.

The Climate Change Resource Center (http://www.fs.usda.gov/ccrc/), developed by the U.S. Forest Service, has a wealth of information on managing forests under climate change.

The Adaptation Workbook (https://adaptationworkbook.org/), from the USFS Northern Institute of Applied Climate Science, is an interactive tool that allows forest owners to set their own priorities for managing their land under a changing climate. It provides many case studies and a widely applicable menu of options from which to choose.

Cal-Adapt (http://cal-adapt.org) has user-friendly, up-to-date information about the impacts of climate change in California.

The Climate Solutions University (http://www.mfpp.org/csu/), from the Model Forest Policy Program, offers courses on climate change adaptation. This is most appropriate for those who are interested in working with a community group, rather than as individuals.

The Climate Adaptation Knowledge Exchange (http://www.cakex.org) offers information about adaptation projects that have been undertaken in different areas.

To read scientific publications about climate change and see what is being published, look at the Template for Assessing Climate Change Impacts and Management Options (TACCIMO) (http://www.taccimo.sgcp.ncsu.edu/TACCIMO/tbl_sector_list.php), which keeps an updated list of recent research.

The California Climate Commons (http://climate.calcommons.org/) aggregates publications, datasets, and web resources related to climate change in California, including many focused on forests.

The USDA Natural Resources Conservation Service provides grants to manage drought-killed trees in certain California counties, via the Forest Tree Mortality EQIP Fund Pool (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/ca/programs/financial/eqip/?cid=nrcseprd440606).

These UC ANR publications have information on building and maintaining defensible structures in wildfire-prone areas: *The Homeowner's Wildfire Mitigation Guide* (http://ucanr.edu/sites/Wildfire) and *Home Survival in Wildfire Prone Areas: Building Materials and Design Considerations* (https://anrcatalog.ucanr.edu/pdf/8393.pdf).

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Measurement Conversion Table

U.S. customary	Conversion factor for U.S. customary to metric	Conversion factor for metric to U.S. customary	Metric
Temperature			
Fahrenheit (ºF)	ºC = (ºF - 32) ÷ 1.8	ºF = (ºC × 1.8) + 32	Celsius (ºC)

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