Knobcone Pine and Cypress Species

Northern California Climate Change Vulnerability Assessment Synthesis

An Important Note About this Document: *This document represents an initial evaluation of vulnerability for knobcone pine and cypress species in northern California based on expert input and existing information. Specifically, the information presented below comprises vulnerability factors selected and scored by regional experts, relevant references from the scientific literature, and peer-review comments and revisions (see end of document for a glossary of terms and brief overview of study methods). The aim of this document is to expand understanding of habitat vulnerability to changing climate conditions, and to provide a foundation for developing appropriate adaptation responses.*

Peer review for this document was provided by Kyle Merriam (U.S. Forest Service). Vulnerability scores were provided by Eureka workshop participants. Upper Lake workshop participants provided additional comments on the climate change vulnerability of this species group.

Table of Contents

Habitat Description

Knobcone pine occurs in small patches within the Northern Coast Range, Klamath Mountains, and southern Cascades at elevations from sea level to 1,700 m (5,600 ft), often on steep slopes, north-facing aspects, and/or on ridgetops (Vogl 1973; Vogl et al. 1977; Howard 1992; Barbour 2007; Fry et al. 2012). Knobcone pine is a shade-intolerant pioneer species with serotinous cones. It depends on fire for recruitment and life span is generally determined by the length of the fire return interval (Howard 1992; Fry et al. 2012). It often occurs in even-aged stands that are established following moderate to severe fires, but uneven-aged stands may occur where low-intensity fire allows both seedling recruitment and the survival of some mature trees (Fry et al. 2012). Knobcone pine stands are often interspersed with chaparral, oak woodlands, and mixed evergreen forests (Howard 1992; Fry et al. 2012). Associated species can include Douglas-fir (*Pseudotsuga menziesii*), Pacific madrone (*Arbutus menziesii*), California bay (*Umbellularia californica*), canyon live oak (*Quercus chrysolepis*), California black oak (*Q. kelloggii*), foothill pine (*Pinus sabiniana*), shore pine (*P. contorta* spp. *contorta*), tanoak (*Lithocarpus densiflora*), golden chinquapin (*Chrysolepis chrysophylla*), incense cedar (*Calocedrus decurrens*), sugar pine (*P. lambertiana*), Pacific yew (*Taxus brevifolia*), MacNab cypress (*Hesperocyparis macnabiana*), various shrub oaks (*Quercus* spp.), chamise (*Adenostoma fasciculatum*), and manzanita (*Arctostaphylos* spp.), among others; Howard 1992; Fry et al. 2012). Knobcone pine often dominates serpentine soils due to its tolerance of nutrient-poor substrates that limit competition from other species (Vogl 1973; Howard 1992).

Although many cypress species are endemic to California, only Baker cypress (*H. bakeri*), MacNab cypress, and Sargent's cypress (*H. sargentii*) are distributed on federally-owned lands within the northern California study area.[1] These species have highly restricted ranges and occur in disjunct populations across the study area (Vogl et al. 1977; Mallek 2009; Bower & Hipkins 2017). However, where they do occur they typically dominate the stand (Vogl et al. 1977). Endemic cypress species are often associated with harsh, dry sites and serpentine or volcanic substrates (Vogl et al. 1977; Barbour 2007). All three species are serotinous and dependent on fire for regeneration (Ne'eman et al. 1999; Mallek 2009; Merriam & Rentz 2010). Even-aged stands established following large, severe fires are most common, but Baker and MacNab cypress also occur in uneven-aged stands where heterogeneous fire effects have allowed some older trees to survive (Mallek 2009; Merriam & Rentz 2010).

Baker cypress is found in eleven disjunct populations scattered across northern California and southwestern Oregon at elevations between 925 and 2120 m (3,035–6,955 ft; Merriam & Rentz 2010; Bower & Hipkins 2017). It generally occurs as an early-seral species within mixed conifer forests (Vogl et al. 1977) on serpentine or granitic substrates in the Siskiyou Mountains and on volcanic substrates in the southern Cascades (Griffin & Critchfield 1972; Esser 1994a). Commonly-associated species include white fir (*Abies concolor*), red fir (*A. magnifica*), incense cedar, knobcone pine, Jeffrey pine (*P. jeffreyi*), sugar pine, ponderosa pine (*Pinus ponderosa*), and Douglas-fir (*Pseudotsuga menziesii*; CNPS 2019).

MacNab cypress is the most widespread and abundant cypress in the study area (Griffin & Critchfield 1972; Vogl et al. 1977), occurring in isolated groves in the North Coast Range, southern Cascade Range, and western foothills of the northern Sierra Nevada at elevations from 300 to 1,100 m (990 to 3,610 ft), often on serpentine soils (Barbour 2007; Mallek 2009; Hidalgo-Triana et al. 2018). Associated species often include other fire-dependent trees and shrubs, including whiteleaf manzanita (*A. viscida*), chamise, leather oak (*Q. durata*), and foothill

[1] Gowen cypress (*H. goveniana*) and pygmy cypress (*H. pygmaea*) also occur in the region but are not found on BLM or USFS lands (J. Weigand, pers. comm., 2018).

pine (Mallek 2009; Hidalgo-Triana et al. 2018). The understory ranges from sparse (in the North Coast range) to continuous (in the southern Cascades), and is usually dominated by grasses (Mallek 2009).

Sargent's cypress occurs in the North Coast Range of Mendocino County, with the northern edge of its range, which extends south to Santa Barbara County (Vogl et al. 1977; Barbour 2007). This species is associated with serpentine soils, and stands often occur in coastal chaparral ecosystems, as well as in scrubby, fire-maintained forests on open slopes and ridges (Barbour 2007; CNPS 2019). Commonly associated species include MacNab cypress, knobcone pine, foothill pine, Douglas-fir, interior live oak (*Q. wislizeni*), and California bay (CNPS 2019).

Executive Summary

The relative vulnerability of knobcone pine and cypress species in northern California was evaluated as moderate-high by regional experts due to high sensitivity to climate and non-climate stressors, moderate exposure to projected future climate changes, and low-moderate adaptive capacity.

Knobcone Pine & Cypress Species	Rank	Confidence
Sensitivity	High	High
Future Exposure	Moderate	Moderate
Adaptive Capacity	Low-Moderate	High
Vulnerability	**Moderate-High**	**High**

Sensitivity & Exposure Summary	
	<u>*Climate and climate-driven factors*</u>: • Precipitation amount and timing, soil moisture, drought, heat waves <u>*Disturbance regimes*</u>: • Wildfire, disease <u>*Non-climate stressors*</u>: • Fire exclusion, fuel management activities (e.g., mastication, selective thinning, prescribed burning), recreation, roads/highways/trails, mining

Knobcone pines and cypresses are adapted to dry conditions and, like other serotinous species, they depend on fire for seed release and stand regeneration. However, they are extremely sensitive to the interval between fires, which must occur frequently enough to allow regeneration within the lifespan of the seed bank but not so frequently that regenerating trees are killed before they mature and produce cones. Thus, altered fire regimes driven by climate change (e.g., low rainfall, increased drought, heat waves) significantly increase the vulnerability of these species to stand extirpation and/or extinction. However, observed increases in fire frequency over the last several years have allowed regeneration in some stands that were previously in poor condition due to fire exclusion. Other non-climate stressors that may contribute to stand degradation and/or fragmentation include fuel reduction treatments, recreation, roads/highways/trails, and mining.

Adaptive Capacity Summary	
	Factors that enhance adaptive capacity: + Large stands of MacNab cypress, Sargent's cypress, and knobcone pine occur on Walker Ridge in Colusa and Lake Counties + High topographic diversity in the region allowed refugial populations to survive following previous periods of rapid climate changes + Tolerance of stressful edaphic environments suggests potential for adaptation + Knobcone pine demonstrates partial serotiny in portions of its range, suggesting the potential for decoupling of regeneration from fire regimes + Abundant natural regeneration generally occurs following correctly-timed fires *Factors that undermine adaptive capacity*: – Many stands are in poor health due to decades of fire suppression – Little information is available about genetic diversity and phenotypic plasticity in most endemic cypress species – Very low resistance to short fire return intervals, which can result in population extirpation

Knobcone pine and cypress stands occur across the region but are relatively rare and highly fragmented, and the size and integrity of these stands varies widely. This fragmentation is due in large part to the survival of serotinous conifers in refugia following past periods of rapid environmental change, and the high topographic diversity in the region is likely to continue to provide refugia for these species over the next century. Knobcone pine populations have high genetic diversity, and variability in tree size and growth form, as well as the existence of partial serotiny in portions of the species' range, suggest some degree of phenotypic plasticity. Less is known about genetic diversity and phenotypic plasticity in cypress species, though Baker cypress appears to have experienced past bottlenecks and inbreeding that could limit adaptation to future changes. Resistance is compromised in degraded stands that are experiencing increased competition from other trees, and these species generally have very low resistance to short fire return intervals. However, post-fire recovery is rapid when fires are suitably timed. Serotiny offers benefits by storing large amounts of seed in the canopy until released into suitable post-fire growing conditions, which allows serotinous conifers to dominate the post-fire landscape. Management of these species is likely to focus on mitigating the risk of stands burning at short intervals, which is a significant risk as fire activity in the region is expected to increase over the next century. Allowing older stands to burn is also important to stimulate regeneration, and seed collection and storage will help protect the genetic diversity of rare trees such as these.

Sensitivity and Exposure

Knobcone pine and cypress species were evaluated by regional experts as having high overall sensitivity (high confidence in evaluation) and moderate overall future exposure (moderate confidence) to climate and climate-driven factors, changes in disturbance regimes, and non-climate stressors.

Several studies suggest that the rare trees considered in this assessment will experience shifts in distribution over the coming century. For instance, modeling focused on changes in vegetation distribution in response to climate change in the San Francisco Bay region suggests that knobcone pine may expand as temperatures increase (Ackerly et al. 2015). Paleoecological studies have found that knobcone pine and cypress species have already demonstrated range expansions in response to warmer, drier conditions during periods of rapid climate change within the last 17,000 years (Briles et al. 2005). At lower elevations, drainages and other topographically sheltered sites may act as refugia from extreme fire intensities or increasingly frequent fires that could kill regenerating trees before they mature and produce seeds (Barton & Poulos 2019; Vuln. Assessment Reviewer, pers. comm., 2019).

Sensitivity and future exposure to climate and climate-driven factors

Regional experts evaluated knobcone pine and cypress species as having moderate sensitivity to climate and climate-driven factors (high confidence in evaluation), with an overall moderate-high future exposure to these factors within the study region (low confidence). Key climatic factors that affect knobcone pine and cypress species include precipitation amount and timing, soil moisture, drought, and heat waves (see Table 1).[2]

Table 1. Current and projected future trends in key climate and climate-driven factors within the study region, as well as their potential impacts on knobcone pine and cypress species.

Precipitation amount/timing, soil moisture, and drought[3]	
Historical & current trends: • 7.2–9.4 cm (2.8–3.7 in) increase in mean annual precipitation and between 1900 and 2009 for the Northwestern California and Southern Cascade ecoregions (Rapacciuolo et al. 2014) • Drought years have occurred twice as often over the last two decades compared to the previous century (Diffenbaugh et al. 2015) • 2012–2014 drought set records for lowest precipitation, highest temperatures, and most extreme drought indicators on record (Griffin & Anchukaitis 2014; Diffenbaugh et al. 2015) • No trends available for soil moisture	*Projected future trends:* • 20% decrease to 34% increase in mean annual precipitation by 2100 (compared to 1951–1980) for the North Coast, Northern Coast Range, Northern Interior Coast Range, Klamath Mountain, and Southern Cascade ecoregions (Flint et al. 2013; Flint & Flint 2014)[4] • Seasonal changes are projected to be more significant as the wet season becomes wetter and shorter (i.e., later onset of fall rains and earlier onset of summer drought) and the dry season becomes drier and longer (Pierce et al. 2018; Swain et al. 2018)

[2] All climate and climate-driven factors presented were ranked as having a moderate or higher impact on one or more of the trees considered in this species group.

[3] Trends in climate factors and natural disturbance regimes presented in this and subsequent summary tables are not species group-specific; rather, they represent broad trends and future projections for the study region. The precipitation, temperature, climatic water deficit, and snowpack projections for this project are derived from the Basin Characterization Model, which uses modified Jepson ecoregions (Flint et al. 2013; Flint & Flint 2014). Projections for all other factors are based on a review of relevant studies in the scientific literature. For this project, exposure was evaluated by calculating the magnitude and direction of projected change within the modified Jepson ecoregions that include habitat distribution within the study geography.

[4] Projections for changes in annual and seasonal precipitation by ecoregion can be found in the full climate impacts table (https://bit.ly/2LHgZaG).

	• Overall, interannual variability is expected to increase (Pierce et al. 2018; Swain et al. 2018) • Decreased top-level soil moisture is likely even if precipitation increases due to temperature-related changes in evaporative demand (Pierce et al. 2018) • Drought years are twice as likely to occur over the next several decades due to increased co-occurrence of dry years with very warm years (Cook et al. 2015) • 80% chance of multi-decadal drought by 2100 under a high-emissions scenario (Cook et al. 2015) • Severe droughts that now occur once every 20 years will occur once every 10 years by 2100 and once-in-a-century drought will occur once every 20 years (Pierce et al. 2018)

Summary of Potential Impacts on Species Group

- Although cypresses are generally adapted to dry conditions, periods of severe drought may impact seed production (Vuln. Assessment Workshop, pers. comm., 2017).
- Warmer, drier conditions are projected to increase the risk of fire in northern California, particularly during periods of drought (Abatzoglou & Kolden 2013; Abatzoglou & Williams 2016; Mann et al. 2016; Westerling 2016). Because these species are extremely sensitive to the length of time between fires, climate-driven increases in fire frequency may result in stand extirpation (see wildfire section of Table 2; Enright et al. 2014, 2015).

Heat waves

Historical & current trends:	*Projected future trends:*
• Increase in the frequency of humid nighttime events over the past several decades (Gershunov & Guirguis 2012) • High interannual and interdecadal variability in heat waves (Gershunov & Guirguis 2012)	• Increased heat waves, with the greatest increase in humid nighttime heat waves and in coastal areas (Gershunov & Guirguis 2012) • 2–6°C (3.6–10.8°F) increase in the temperature of the hottest day of the year by 2100 (Pierce et al. 2018)

Summary of Potential Impacts on Species Group

- In cypress species, heat waves may cause premature seed release; however, seedling survival is likely to be low in the absence of fire due to competition from adult trees (Vuln. Assessment Workshop, pers. comm., 2017).
- In northern California, late summer and fall heat waves are frequently associated with the persistent high pressure systems that produces prolonged periods of high temperatures and low humidity (Schroeder et al. 1964). Wildfire risk increases dramatically during heat waves (Schroeder et al. 1964), and high temperatures are correlated with increases in fire size, rate of spread, and severity (Sharples 2009; Estes et al. 2017). Extreme fire conditions can occur when the high pressure system also produces warm, dry east winds (i.e. foehn winds; Schroeder et al. 1964).

Sensitivity and future exposure to changes in natural disturbance regimes

Regional experts evaluated knobcone pine and cypress species as having high sensitivity to changes in natural disturbance regimes (high confidence in evaluation). Knobcone pine was evaluated as having an overall low-moderate future exposure to these stressors within the study region (moderate confidence), while cypress species were evaluated as having an overall moderate future exposure to these stressors (moderate confidence). Key disturbance regimes that affect knobcone pine and cypress species are wildfire and disease (see Table 2).[5]

Table 2. Current and projected future trends in natural disturbance regimes, as well as potential impacts on knobcone pine and cypress species.

Wildfire	

Historical & current trends:
• 85% of U.S. Forest Service lands in northern California are burning less frequently compared to pre-1850 fire return intervals, largely due to fire suppression (Safford & Van de Water 2014)
• Fire size and total area burned increased on U.S. Forest Service lands in northwestern California between 1910-2008, with the highest values occurring after 2000 (Miller et al. 2012)
• Changes in large fires (over 400 ha) in the inland northern California/Sierra Nevada region since the 1970s (Westerling 2016):
  ○ 184–274% increase in frequency
  ○ 270–492% increase in total area burned
  ○ 215% increase in length of the fire season
• Changes in fire size, area burned, and fire frequency over the past several decades remain well below historical tribally-influenced frequency and extent of burning in California (Stephens et al. 2007)
• No significant trends in the average areal proportion of high-severity fire were documented in northwestern CA from 1984–2008 (Miller et al. 2012; Parks et al. 2015; Law & Waring 2015; Keyser & Westerling 2017)
  ○ The relatively short period of record for fire severity data may obscure long-term trends
  ○ To date, there are no peer-reviewed studies on trends in northern California fire severity that include data from the last ten years
	Projected future trends:
	• State-wide, up to 77% increase in mean annual area burned and 50% increase in the frequency of extremely large fires (>10,000 ha) by 2100 (Westerling 2018)
	  ○ Greatest increases in burned area (up to 400%) occur in montane forested areas in northern California (Westerling et al. 2011; Westerling 2018)
	  ○ Less significant increases or possible decrease along the North Coast (Westerling et al. 2011)
	• Little projected change in fire severity in northwestern California by 2050 in models based solely on historical fire-climate relationships (Parks et al. 2016)
	  ○ However, human activity and fuel buildup from decades of fire suppression have altered historical fire-climate relationships (Taylor et al. 2016; Syphard et al. 2017; Wahl et al. 2019), and projections that incorporate these factors suggest that more significant increases in fire severity and size may occur (Mann et al. 2016; Wahl et al. 2019)
	• The majority of impacts to natural and human ecosystems come from extreme fire events (i.e., fires that have a low probability of occurring in any given place and time), which are likely to increase over the coming century (Westerling 2018)

[5] All disturbance regimes presented were ranked as having a moderate or higher impact on the species group.

	○ Generally, these patterns are not well-represented in studies that evaluate indices of mean fire size, intensity/severity, etc.

Summary of Potential Impacts on Species Group

- Knobcone pine and cypresses are serotinous conifers that are dependent on fire for recruitment, which causes mortality in mature trees and allows the release of seeds from cones that have accumulated in the canopy throughout a tree's lifespan (Howard 1992; Mallek 2009; Merriam & Rentz 2010).
    - Some serotinous species exhibit partial serotiny (i.e., cones can open in the absence of fire; (Tonnabel et al. 2012), though seedling establishment is generally low under these conditions (Bond & Keeley 2005). For instance, Baker and MacNab cypress can germinate at very low rates on recently disturbed sites, even in the absence of fire, but regeneration is inadequate to maintain the species over longer time periods (Merriam & Rentz 2010).
    - The degree of heating required to open serotinous cones varies by species (Milich et al. 2012). Generally, seed viability decreases with increasing time of fire exposure and (to a lesser extent) higher temperatures. Thus, there is a trade-off between the necessary temperature and exposure conditions required to open the cone and those that reduce seed germination rates. Mass seed release following fire likely compensates for low germination rates in cypress species (Milich et al. 2012).
- Traits such as flammable foliage, retention of dead branches, and dense stand structures likely increase the likelihood of crown fires, which provide the conditions necessary to open serotinous cones and provide favorable conditions for prolific post-fire regeneration (e.g., bare mineral soil, reduced competition from other trees and shrubs; Ne'eman et al. 1999; Merriam & Rentz 2010; Milich et al. 2012).
- The frequency and timing of fire is critical for the maintenance of serotinous conifer populations. Stand extirpation can occur if regenerating areas burn in subsequent fires, killing seedlings before they mature and produce cones (i.e., "interval squeeze" or "immaturity risk"; Ne'eman et al. 1999; de Gouvenain & Ansary 2006; Bowman et al. 2014; Enright et al. 2014, 2015; Brennan & Keeley 2019; McNamara et al. 2019b). Losses can also occur if fire return intervals are longer than the lifespan of the tree or its seed bank (i.e., "'senescence risk"), resulting in eventual replacement by longer-lived, more shade-tolerant trees (Vogl 1973; Ne'eman et al. 1999; Fry et al. 2012).
- Estimates of fire frequency prior to Euro-American settlement within the state of California ranges from 30–90 years for serotinous conifers (Van de Water & Safford 2011). Fire return intervals increased during the 20th century, resulting in the degradation and/or loss of some stands (see discussion of fire suppression in Table 4; Merriam & Rentz 2010; Reilly et al. 2019). Recent observed increases in fire activity in the region and across these species' ranges (Miller et al. 2012; Reilly et al. 2019) have allowed some degraded stands to recover (Merriam & Rentz 2010; Reilly et al. 2019). However, stands that occur in areas that reburned within 10-20 years are highly vulnerable to extirpation (Reilly et al. 2019; McNamara et al. 2019b).
- A study of Tecate cypress (*Hesperocyparis forbesii*) in the Santa Ana Mountains suggests that larger and more spatially homogenous fires are associated with increased extinction risk due to a greater likelihood of entire populations being killed when fires are too frequent (Rodríguez-Buriticá & Suding 2013). This suggests that the topographically complex landscape of northern California may represent important areas of fire refugia for these species.

Disease	
Historical & current trends: • No trends available for disease	*Historical & current trends:* • No projections available for disease
Summary of Potential Impacts on Species Group • Although disease is fairly uncommon among cypresses (Vuln. Assessment Reviewer, pers. comm., 2019), seedlings are vulnerable to fungal infections (Vogl et al. 1977). • Increased temperature and rainfall may increase cypress seedling fungal sensitivity (Vuln. Assessment Workshop, pers. comm., 2017).	

Dependency on habitat and/or other factors

Regional experts evaluated knobcone pine and cypress species as having high dependency on sensitive habitats (high confidence in evaluation; see Table 3).

Table 3. Dependence on sensitive/specialized habitats and/or other factors that may increase sensitivity to climate change.

Dependencies
• The serotinous species covered in this assessment (knobcone pine and Baker, MacNab, and Sargent's cypress) are all dependent on fire for seed dispersal and conditions suitable for seedling recruitment (e.g., bare mineral soil, direct sunlight; Vogl et al. 1977; Mallek 2009; Merriam & Rentz 2010). In the absence of fire, these species are not able to persist on the landscape (Merriam & Rentz 2010). • Knobcone pine can tolerate a wide variety of soil types and site conditions, including ultramafic and volcanic substrates (Vogl 1973).

Sensitivity and current exposure to non-climate stressors

Regional experts evaluated knobcone pine and cypress species as having high sensitivity to non-climate stressors (high confidence in evaluation). Knobcone pine was evaluated as having an overall moderate current exposure to these stressors within the study region (high confidence), while cypress species were evaluated as having moderate-high current exposure (moderate confidence). Key non-climate stressors that affect knobcone pine and cypress species include fire exclusion, fuel management activities (e.g., mastication, selective thinning, and prescribed burning), recreation, roads/highways/trails, and mining (see Table 4).[6]

[6] All non-climate stressors presented were ranked as having a moderate or higher impact on the species group. Vulnerability assessment reviewers also noted that Baker cypress has been cut for firewood.

Table 4. Key non-climate stressors that affect the overall sensitivity of knobcone pine and cypress species to climate change.

Fire exclusion (including fire suppression) and fuels reduction treatments

• Fire exclusion may result in population declines and eventual stand extirpation due to the lack of fire needed for regeneration within a tree's reproductive lifespan (Vogl 1973; Ne'eman et al. 1999; Fry et al. 2012). Additionally, declining seed viability in older cones can result in reduced rates of regeneration when fires do occur (Mallek 2009; Merriam & Rentz 2010; Milich et al. 2012).
  ○ Knobcone pine stands undisturbed for over 60 years generally experience encroachment by species from surrounding communities (chaparral shrub species at lower elevations and conifers at higher elevations). This is largely due to accumulating organic matter on unburned sites that reduces edaphic barriers imposed by serpentine substrates (Vogl 1973; Agee 1991).
  ○ Some Baker and MacNab cypress stands have experienced increases in shade-tolerant species, enhancing interspecific competition and contributing to generally poor stand conditions in areas that have not experienced recent fire (Mallek 2009; Merriam & Rentz 2010; Milich et al. 2012).
• Since the implementation of effective fire suppression practices in the 1940s, fire return intervals have significantly increased for all tree species considered in this assessment (Mallek 2009; Merriam & Rentz 2010; Steel et al. 2015). Recent observed increases in regional fire activity in the region (Miller et al. 2012; Reilly et al. 2019) have burned many stands that were previously in poor health due to fire exclusion (Mallek 2009; Merriam & Rentz 2010; Reilly et al. 2019). However, recently burned stands are vulnerable to extirpation if they reburn before trees mature and produce cones (Enright et al. 2014, 2015; Reilly et al. 2019; McNamara et al. 2019b).
  ○ Three Baker cypress populations have burned since 2008, representing 27% of the population that is now vulnerable to immaturity risk (K. Merriam, pers. comm., 2019).
• Under the right circumstances, fire suppression can promote resistance in serotinous species if it is used to maintain sufficiently long fire return intervals (McNamara et al. 2019b; Vuln. Assessment Reviewer, pers. comm., 2019). However, fuel management activities (e.g., mastication, selective thinning, prescribed burning) designed to reduce fire risk in the surrounding forest can result in damage to Baker and MacNab cypress stands (Vuln. Assessment Reviewer, pers. comm., 2019).

Recreation and roads/highways/trails
• Rare trees distributed primarily at low elevations (e.g., cypresses) are at greater risk of habitat loss and fragmentation due to motorized recreation and other human activities (Vuln. Assessment Workshop, pers. comm., 2017). These can also occur at higher elevations, but likely pose a minimal threat (Vuln. Assessment Reviewer, pers. comm., 2019). • Roads, highways and trails contribute to the spread of invasive plants (Vuln. Assessment Workshop, pers. comm., 2017).
Mining
• Mining can eliminate rare tree populations and cause fragmentation of remnant habitat area (Vuln. Assessment Workshop, pers. comm., 2017).

Adaptive Capacity

Knobcone pine and cypress species were evaluated by regional experts as having low-moderate overall adaptive capacity (high confidence in evaluation; see Table 5).

Table 4. Adaptive capacity factors that influence the ability of knobcone pine and cypress species to adapt to projected future climate changes. Factors that receive a ranking of "High" enhance adaptive capacity for this habitat (+), while factors that receive a "Low" ranking undermine adaptive capacity (-).

Adaptive Capacity Factors	
Species group extent, integrity, and connectivity **Knobcone pine:** Moderate extent (high confidence), low-moderate integrity (high confidence), low connectivity (high confidence) **Cypress species:** Low extent (high confidence), low-moderate integrity (high confidence), low connectivity (high confidence)	• Walker Ridge (in Colusa and Lake Counties) has large areas of serpentine soils, containing one of the world's largest stands of MacNab cypress and several large stands of Sargent's cypress and knobcone pine (Suba 2011). • Although endemic cypress stands are widely distributed across the region, they are rare due to population fragmentation within refugia in response to past changes in climatic conditions (Terry et al. 2016). • The size of cypress stands varies widely. For instance, Baker cypress stands vary in size from 1.2 to 2,800 hectares, but a quarter of these are less than 8 hectares and two-thirds are under 140 hectares (Merriam & Rentz 2010). • Many cypress stands are in poor health due to decades of fire suppression, particularly small stands (Merriam & Rentz 2010; Vuln. Assessment Workshop, pers. comm., 2017). Affected stands have very low recruitment and are impacted by insects to a greater degree (Vuln. Assessment Workshop, pers. comm., 2017).
Dispersal ability and barriers to dispersal **Knobcone pine:** Moderate dispersal ability (high confidence), moderate-high impact of barriers (high confidence) **Cypress species:** Low dispersal ability (high confidence), low impact of barriers (high confidence)	*Knobcone pine* • For knobcone pine, edaphic/soil chemistry factors (e.g., distribution on serpentine soils) pose the most significant barriers to dispersal. To a lesser degree, roads/highways/trails and mining may act as barriers (Vuln. Assessment Workshop, pers. comm., 2017). • Knobcone pine has a long seed wing length, allowing dispersal beyond the immediate burned area (Keeler-Wolf 1986). Birds are attracted to the partially-opened cones, and aid in seed dispersal (Vogl 1973). *Cypress species* • Barriers to dispersal include geologic features (e.g., edaphic/soil chemistry conditions) and seed biology (Vuln. Assessment Workshop, pers. comm., 2017). • Baker cypress has poor dispersal capacity, with most post-fire seedlings established within 5 m (16 ft) of the parent tree and a maximum dispersal distance of 48.5 m (160 ft). This suggests that species migration in response to rapid climate change is unlikely for this species due to dispersal constraints (McNamara et al. 2019a).

Interspecific/life history diversity **Knobcone pine:** Low life history diversity (high confidence), high genetic diversity (moderate confidence), moderate phenotypic plasticity (moderate confidence) **Cypress species:** Low life history diversity (high confidence), moderate genetic diversity (moderate confidence), low-moderate phenotypic plasticity (moderate confidence)	• The tolerance of knobcone pine and several cypress species for stressful edaphic environments (e.g., serpentine soils) suggest the possibility for adaptation (O'Dell & Rajakaruna 2011; Vuln. Assessment Workshop, pers. comm., 2017). • High topographic diversity within northern California likely contributed to the survival of refugial populations during past times of rapid environmental change, which provided sources for expansion during more periods of more favorable conditions (Millar & Woolfenden 2016). *Knobcone pine* • Knobcone pine populations in northern California demonstrate high levels of outcrossing, resulting in high genetic diversity (Burczyk et al. 1997), consistent with previous studies of populations in southern California (Millar et al. 1988). • Tree size and growth form vary regionally (CNPS 2019), suggesting some degree of phenotypic plasticity. • Partial serotiny has been observed in portions of the species' range (Reilly et al. 2019), which could allow some decoupling of regeneration from fire regimes (e.g., Tonnabel et al. 2012). *Cypress species* • Baker cypress has relatively high genetic diversity despite its limited distribution and highly disjunct remaining populations. However, there is evidence of past bottlenecks and inbreeding which could increase the susceptibility of this species to climate change (Bower & Hipkins 2017). ○ Low levels of differentiation among disjunct populations suggest that the Baker cypress was formerly widespread, and experienced relatively recent range contractions (Bower & Hipkins 2017). • Little information is available about the genetic diversity and stand structure of other endemic cypress species in California (Bower & Hipkins 2017).
Resistance and recovery **Knobcone pine:** Low resistance (high confidence), moderate recovery (moderate confidence) **Cypress species:** Moderate resistance (high confidence), moderate recovery (high confidence)	• Serotinous species such as knobcone pine and cypresses generally have very low resistance to short fire return intervals compared to other functional groups (Enright et al. 2014). Thus, although cypress and knobcone pine communities regenerate rapidly following fire at suitably-timed intervals (Mallek 2009; Merriam & Rentz 2010; Brennan & Keeley 2019; Reilly et al. 2019), the recurrence of fire before regenerating trees mature and produce cones can result in stand extirpation (Ne'eman et al. 1999; de Gouvenain & Ansary 2006; Bowman et al. 2014; Enright et al. 2014, 2015; Brennan & Keeley 2019; McNamara et al. 2019b). • Increased competition from other trees compromises resistance in serotinous conifers (Esser 1994a; Enright et al. 2014). However, post-fire germination can be dense even in stands that were previously in poor condition due to fire suppression (Merriam & Rentz 2010). • Knobcone pine seeds are drought-tolerant and can remain viable in the soil for over 25 years (Howard 1992; CNPS 2019). • Cypresses can produce thousands of viable seeds per tree, resulting in very high post-fire seedling densities (up to 79 seedlings/m^2; Rentz & Merriam

	2011). The adaptive benefit of serotiny is that seeds are stored in the canopy and then dispersed in very large numbers following fire that creates suitable growing conditions for germination and survival; this allows them to effectively dominate the post-fire landscape (Lamont 1991). • McNab cypress cones can sometimes open in response to damage and subsequent desiccation rather than heat (as is the case in serotinous pines and many other cypresses). As a result, injury or death of individual trees due to storm damage, insects, or disease can result in low levels of seed dispersal and regeneration. However, seedlings are much less likely to become established under a closed forest canopy (Mallek 2009).
Public and societal value **Knobcone pine:** Low-moderate value (high confidence) **Cypress species:** Low value (high confidence)	• None of the species considered in this assessment are state- or federally-listed as threatened or endangered (Vuln. Assessment Workshop, pers. comm., 2017; CDFW 2019). • Knobcone pine and cypresses are not valuable for timber or in the landscape industry (Howard 1992; Esser 1994a, 1994b, 1994c). • Knobcone pine x Monterey pine (KMX) hybrids, which are used in forestry in Oregon, California, and New Zealand (Vuln. Assessment Workshop, pers. comm., 2017). • There is a general lack of public awareness and knowledge about knobcone pine and cypresses and the ecosystem services that they provide. However, conservation is supported by the California Native Plant Society, academic communities, and other conservation advocacy groups (e.g., Tuleyome; Vuln. Assessment Workshop, pers. comm., 2017). • Most Sargent's and Baker cypress populations and several populations of MacNab cypress occur within protected areas (Farjon 2013a, 2013b).
Management capacity and ability to alleviate impacts of climate change[7] **Knobcone pine:** Low-moderate capacity/ability (high confidence) **Cypress species:** Low capacity/ability (moderate confidence)	• Although land managers have good intentions for the management of cypress populations, an incomplete understanding of serotiny can sometimes lead to unproductive outcomes (Vuln. Assessment Reviewer, pers. comm., 2019). • The most important restoration action for serotinous conifers right now is to mitigate immaturity risk by preventing fires from burning stands at short intervals (Reilly et al. 2019; McNamara et al. 2019b). For older stands, stimulating regeneration by allowing wildfire to burn is likely the best option, as prescribed fires are generally not allowed to burn at sufficient intensity to open cones and kill trees (Vuln. Assessment Reviewer, pers. comm., 2019). • Seed collection and storage are important to ensure the protection of genetic diversity in cypress populations (Bower & Hipkins 2017).
Ecosystem services	• Knobcone pines and cypresses provide a variety of ecosystem services, including: ○ Provisioning of genetic resources, medicines, and ornamental resources;

[7] Further information on climate adaptation strategies and actions for northern California can be found on the project page (https://bit.ly/31AUGs5).

	○ Regulation of air quality, climate/microenvironments (e.g., shade), and erosion control; ○ Support of primary production, oxygen production, soil formation/retention, and nutrient cycling; and ○ Cultural/tribal uses for spiritual/religious purposes, knowledge systems, educational values, aesthetic values, social relations, sense of place, cultural heritage, inspiration, and recreation (Vuln. Assessment Workshop, pers. comm., 2017).

Recommended Citation

Sims, SA, Hilberg LE, Reynier WA, Kershner JM. 2019. Knobcone Pine and Cypress Species: Northern California Climate Change Vulnerability Assessment Synthesis. Version 1.0. EcoAdapt, Bainbridge Island, WA.

Further information on the Northern California Climate Adaptation Project is available on the project website (https://tinyurl.com/NorCalAdaptation).

Literature Cited

Abatzoglou JT, Kolden CA. 2013. Relationships between climate and macroscale area burned in the western United States. International Journal of Wildland Fire **22**:1003–1020.

Abatzoglou JT, Williams AP. 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences **113**:11770–11775.

Ackerly DD, Cornwell WK, Weiss SB, Flint LE, Flint AL. 2015. A geographic mosaic of climate change impacts on terrestrial vegetation: which areas are most at risk? PLoS ONE **10**:e0130629.

Agee JK. 1991. Fire history along an elevational gradient in the Siskiyou Mountains, Oregon. Northwest Science **65**:188–199.

Barbour MG. 2007. Closed-cone pine and cypress forests. Pages 296–312 in Barbour, Michael G., T. Keeler-Wolf, and A. A. Schoenherr, editors. Terrestrial vegetation of California, 3rd edition. University of California Press, Berkeley, CA.

Barton AM, Poulos HM. 2019. Response of Arizona cypress (*Hesperocyparis arizonica*) to the Horseshoe Two Megafire in a south-eastern Arizona Sky Island mountain range. International Journal of Wildland Fire **28**:62–69.

Bond WJ, Keeley JE. 2005. Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems. Trends in Ecology & Evolution **20**:387–394.

Bower AD, Hipkins V. 2017. Genetic diversity and population structure in the rare, endemic Baker cypress (*Hesperocyparis bakeri*). Madroño **64**:71–82.

Bowman DMJS, Murphy BP, Neyland DLJ, Williamson GJ, Prior LD. 2014. Abrupt fire regime change may cause landscape-wide loss of mature obligate seeder forests. Global Change Biology **20**:1008–1015.

Brennan TJ, Keeley JE. 2019. Postfire population dynamics of a fire-dependent cypress. Plant Ecology **220**:605–617.

Briles CE, Whitlock C, Bartlein PJ. 2005. Postglacial vegetation, fire, and climate history of the Siskiyou Mountains, Oregon, USA. Quaternary Research **64**:44–56.

Burczyk J, Adams WT, Shimizu JY. 1997. Mating system and genetic diversity in natural populations of knobcone pine (*Pinus attenuata*). International Journal of Forest Genetics **4**:223–226.

CDFW. 2019. State and federally listed Endangered and Threatened animals in California: April 23, 2019. California Department of Fish and Wildlife, Sacramento, CA. Available from http://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=109405&inline (accessed May 8, 2019).

CNPS. 2019. A manual of California vegetation, online edition. California Native Plant Society Press. Available from http://www.cnps.org/cnps/vegetation/ (accessed January 2, 2019).

Cook BI, Ault TR, Smerdon JE. 2015. Unprecedented 21st century drought risk in the American Southwest and Central Plains. Science Advances **1**:e1400082.

de Gouvenain RC, Ansary AM. 2006. Association between fire return interval and population dynamics in four California populations of Tecate cypress (*Cupressus forbesii*). The Southwestern Naturalist **51**:447–454.

Diffenbaugh NS, Swain DL, Touma D. 2015. Anthropogenic warming has increased drought risk in California. Proceedings of the National Academy of Sciences **112**:3931–3936.

Enright NJ, Fontaine JB, Bowman DMJS, Bradstock RA, Williams RJ. 2015. Interval squeeze: altered fire regimes and demographic responses interact to threaten woody species persistence as climate changes. Frontiers in Ecology and the Environment **13**:265–272.

Enright NJ, Fontaine JB, Lamont BB, Miller BP, Westcott VC. 2014. Resistance and resilience to changing climate and fire regime depend on plant functional traits. Journal of Ecology **102**:1572–1581.

Esser L. 1994a. *Hesperocyparis bakeri*. In: Fire Effects Information System [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available from https://www.fs.fed.us/database/feis/plants/tree/hesbak/all.html (accessed March 21, 2019).

Esser L. 1994b. *Hesperocyparis macnabiana*. In: Fire Effects Information System [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available from https://www.fs.fed.us/database/feis/plants/tree/hesman/all.html (accessed March 21, 2019).

Esser L. 1994c. *Hesperocyparis sargentii*. In: Fire Effects Information System [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available from https://www.fs.fed.us/database/feis/plants/tree/hessar/all.html (accessed March 21, 2019).

Estes BL, Knapp EE, Skinner CN, Miller JD, Preisler HK. 2017. Factors influencing fire severity under moderate burning conditions in the Klamath Mountains, northern California, USA. Ecosphere **8**:e01794.

Farjon A. 2013a. *Cupressus sargentii*. The IUCN Red List of Threatened Species 2013: e.T42258A2967745. Available from http://www.iucnredlist.org/details/42258/0 (accessed December 4, 2017).

Farjon A. 2013b. *Cupressus macnabiana*. The IUCN Red List of Threatened Species 2013: e.T42222A2962703. Available from http://www.iucnredlist.org/details/42222/0 (accessed December 4, 2017).

Flint LE, Flint AL. 2014. California Basin Characterization Model: a dataset of historical and future hydrologic response to climate change (Ver. 1.1, May 2017). U.S. Geological Survey Data Release. Available from https://doi.org/10.5066/F76T0JPB.

Flint LE, Flint AL, Thorne JH, Boynton R. 2013. Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance. Ecological Processes **2**:25.

Fry DL, Dawson J, Stephens SL. 2012. Age and structure of mature knobcone pine forests in the northern California Coast Range, USA. Fire Ecology **8**:49–62.

Gershunov A, Guirguis K. 2012. California heat waves in the present and future. Geophysical Research Letters **39**:L18710.

Griffin D, Anchukaitis KJ. 2014. How unusual is the 2012–2014 California drought? Geophysical Research Letters **41**:9017–9023.

Griffin JR, Critchfield WB. 1972. The distribution of forest trees in California. Res. Pap. PSW-RP-82. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Hidalgo-Triana N, Pérez Latorre AV, Thorne JH. 2018. Plant functional traits and groups in a Californian serpentine chaparral. Ecological Research **33**:525–535.

Howard JL. 1992. *Pinus attenuata*. In: Fire Effects Information System [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available from https://www.fs.fed.us/database/feis/plants/tree/pinatt/all.html (accessed January 29, 2019).

Keeler-Wolf T. 1986. An ecological survey of the proposed Stone Corral-Josephine Peridotite Research Natural Area (LE Horton-Darlingtonia Bog Research Natural Area) on the Six Rivers National Forest, Del Norte County, California. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Keyser A, Westerling AL. 2017. Climate drives inter-annual variability in probability of high severity fire occurrence in the western United States. Environmental Research Letters **12**:065003.

Lamont BB. 1991. Canopy seed storage and release: what's in a name? Oikos **60**:266–268.

Law BE, Waring RH. 2015. Carbon implications of current and future effects of drought, fire and management on Pacific Northwest forests. Forest Ecology and Management **355**:4–14.

Mallek CR. 2009. Fire history, stand origins, and the persistence of McNab cypress, northern California, USA. Fire Ecology **5**:100–119.

Mann ML, Batllori E, Moritz MA, Waller EK, Berck P, Flint AL, Flint LE, Dolfi E. 2016. Incorporating anthropogenic influences into fire probability models: effects of human activity and climate change on fire activity in California. PLoS ONE **11**:e0153589.

McNamara BA, Greene DF, Kane JM. 2019a. Strong dispersal limitation in postfire regeneration of Baker cypress, a rare serotinous conifer. American Journal of Botany **106**:1566–1574.

McNamara BA, Kane JM, Greene DF. 2019b. Post-fire fuel succession in a rare California, USA, closed-cone conifer. Fire Ecology **15**:39.

Merriam KE, Rentz E. 2010. Restoring fire to endemic cypress populations in northern California. Final report to the Joint Fire Science Program. JFSP Project No. 06-2-1-17. Available from https://www.frames.gov/catalog/24925 (accessed October 7, 2019).

Milich KL, Stuart JD, Varner JM, Merriam KE. 2012. Seed viability and fire-related temperature treatments in serotinous California native *Hesperocyparis* species. Fire Ecology **8**:107–124.

Millar CI, Strauss SH, Conkle MT, Westfall RD. 1988. Allozyme differentiation and biosystematics of the Californian closed-cone pines (*Pinus* subsect. *Oocarpae*). Systematic Botany **13**:351–370.

Millar CI, Woolfenden WB. 2016. Ecosystems past: vegetation prehistory. Pages 131–154 in H. Mooney and E. Zavaleta, editors. Ecosystems of California. University of California Press, Oakland, CA.

Miller JD, Skinner CN, Safford HD, Knapp EE, Ramirez CM. 2012. Trends and causes of severity, size, and number of fires in northwestern California, USA. Ecological Applications **22**:184–203.

Ne'eman G, Fotheringham CJ, Keeley JE. 1999. Patch to landscape patterns in post fire recruitment of a serotinous conifer. Plant Ecology **145**:235–242.

O'Dell RE, Rajakaruna N. 2011. Intraspecific variation, adaptation, and evolution. Pages 97–137 in S. Harrison and N. Rajakaruna, editors. Serpentine: the evolution and ecology in a model system. University of California Press, Berkeley, CA.

Parks SA, Miller C, Abatzoglou JT, Holsinger LM, Parisien M-A, Dobrowski SZ. 2016. How will climate change affect wildland fire severity in the western US? Environmental Research Letters **11**:035002.

Parks SA, Miller C, Parisien M-A, Holsinger LM, Dobrowski SZ, Abatzoglou J. 2015. Wildland fire deficit and surplus in the western United States, 1984–2012. Ecosphere **6**:1–13.

Pierce DW, Kalansky JF, Cayan DR. 2018. Climate, drought, and sea level rise scenarios for the Fourth California Climate Assessment. California's Fourth Climate Change Assessment. Publication Number: CNRA-CEC-2018-006. California Energy Commission, Sacramento, CA.

Rapacciuolo G et al. 2014. Beyond a warming fingerprint: individualistic biogeographic responses to heterogeneous climate change in California. Global Change Biology **20**:2841–2855.

Reilly MJ, Monleon VJ, Jules ES, Butz RJ. 2019. Range-wide population structure and dynamics of a serotinous conifer, knobcone pine (*Pinus attenuata* L.), under an anthropogenically-altered disturbance regime. Forest Ecology and Management **441**:182–191.

Rentz E, Merriam KE. 2011. Restoration and management of Baker cypress in northern California and southern Oregon. Pages 282–289 in J. W. Willoughby, B. K. Orr, K. A. Schierenbeck, and N. J. Jensen, editors. Strategies and solutions: the 2009 CNPS Conservation Conference proceedings. California Native Plant Society, Sacramento, CA.

Rodríguez-Buriticá S, Suding K. 2013. Interactive effects of temporal and spatial fire characteristics on the population dynamics of a fire-dependent Cypress species. Journal of Applied Ecology **50**:929–938.

Safford HD, Van de Water KM. 2014. Using fire return interval departure (FRID) analysis to map spatial and temporal changes in fire frequency on national forest lands in California. Res. Pap. PSW-RP-266. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.

Schroeder MJ, Glovinsky M, Henricks VF, Hood FC, Hull MK. 1964. Synoptic weather types associated with critical fire weather. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Sharples JJ. 2009. An overview of mountain meteorological effects relevant to fire behaviour and bushfire risk. International Journal of Wildland Fire **18**:737–754.

Steel ZL, Safford HD, Viers JH. 2015. The fire frequency-severity relationship and the legacy of fire suppression in California forests. Ecosphere **6**:1–23.

Stephens SL, Martin RE, Clinton NE. 2007. Prehistoric fire area and emissions from California's forests, woodlands, shrublands, and grasslands. Forest Ecology and Management **251**:205–216.

Suba G. 2011. Outstanding environmental resources and values of the Walker Ridge public lands: a nomination to the U. S. Bureau of Land Management (Ukiah Field Office) for Area of Critical Environmental Concern (ACEC) status. California Native Plant Society, Sacramento, CA. Available from http://184.168.207.85/cnps/conservation/pdf/walker_ridge_petition-2011.pdf (accessed May 24, 2019).

Swain DL, Langenbrunner B, Neelin JD, Hall A. 2018. Increasing precipitation volatility in twenty-first-century California. Nature Climate Change **8**:427.

Syphard AD, Keeley JE, Pfaff AH, Ferschweiler K. 2017. Human presence diminishes the importance of climate in driving fire activity across the United States. Proceedings of the National Academy of Sciences **114**:13750–13755.

Taylor AH, Trouet V, Skinner CN, Stephens S. 2016. Socioecological transitions trigger fire regime shifts and modulate fire–climate interactions in the Sierra Nevada, USA, 1600–2015 CE. Proceedings of the National Academy of Sciences **113**:13684–13689.

Terry RG, Pyne MI, Bartel JA, Adams RP. 2016. A molecular biogeography of the New World cypresses (*Callitropsis*, *Hesperocyparis*; Cupressaceae). Plant Systematics and Evolution **302**:921–942.

Tonnabel J, Dooren TJMV, Midgley J, Haccou P, Mignot A, Ronce O, Olivieri I. 2012. Optimal resource allocation in a serotinous non-resprouting plant species under different fire regimes. Journal of Ecology **100**:1464–1474.

Van de Water KM, Safford HD. 2011. A summary of fire frequency estimates for California vegetation before Euro-American settlement. Fire Ecology **7**:26–58.

Vogl RJ. 1973. Ecology of knobcone pine in the Santa Ana Mountains, California. Ecological Monographs **43**:125–143.

Vogl RJ, White KL, Armstrong WP, Cole KL. 1977. The closed-cone pines and cypress (*Pinus*, *Cupressus*, plant communities). Pages 295–358 in M. G. Barbour and J. Major, editors. Terrestrial vegetation of California. John Wiley & Sons, New York, NY.

Wahl ER, Zorita E, Trouet V, Taylor AH. 2019. Jet stream dynamics, hydroclimate, and fire in California from 1600 CE to present. Proceedings of the National Academy of Sciences **116**:5393–5398.

Westerling AL. 2016. Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. Philosophical Transactions of the Royal Society B: Biological Sciences **371**:20150178.

Westerling AL. 2018. Wildfire simulations for California's Fourth Climate Change Assessment: projecting changes in extreme wildfire events with a warming climate. California's Fourth Climate Change Assessment. Publication Number: CCCA4-CEC-2018-014. California Energy Commission, Sacramento, CA.

Westerling AL, Bryant BP, Preisler HK, Holmes TP, Hidalgo HG, Das T, Shrestha SR. 2011. Climate change and growth scenarios for California wildfire. Climatic Change **109**:445–463.

Northern California Climate Adaptation Project:

Vulnerability Assessment Methods and Application

Defining Terms

Exposure: A measure of how much of a change in climate or climate-driven factors a resource is likely to experience (Glick et al. 2011).

Sensitivity: A measure of whether and how a resource is likely to be affected by a given change in climate or factors driven by climate (Glick et al. 2011).

Adaptive Capacity: The ability of a resource to accommodate or cope with climate change impacts with minimal disruption (Glick et al. 2011).

Vulnerability: A function of the sensitivity of a particular resource to climate changes, its exposure to those changes, and its capacity to adapt to those changes (IPCC 2007).

Vulnerability Assessment Model

The vulnerability assessment model applied in this process was developed by EcoAdapt (EcoAdapt 2014a; EcoAdapt 2014b; Kershner 2014; Hutto et al. 2015; Gregg 2018),[8] and includes evaluations of relative vulnerability by local and regional stakeholders who have detailed knowledge about and/or expertise in the ecology, management, and threats to focal habitats, species groups, individual species, and the ecosystem services that these resources provide. Stakeholders evaluated vulnerability for each resource by discussing and answering a series of questions for sensitivity and adaptive capacity. Exposure was evaluated by EcoAdapt using projected future climate changes from the scientific literature. Each vulnerability component (i.e., sensitivity, adaptive capacity, and exposure) was divided into specific elements. For example, habitats included three elements for assessing sensitivity and six elements for adaptive capacity. Elements for each vulnerability component are described in more detail below.

In-person workshops were held in Eureka, Redding, and Upper Lake between May and October 2017. Participants self-selected habitat and species group/species breakout groups and evaluated the vulnerability of each resource. Participants were first asked to describe the habitat and/or to list the species to be considered in the evaluation of an overarching species group. Due to limitations in workshop time and participant expertise, multiple resources were not assessed during these engagements. Evaluations for remaining habitats, species groups, and species were completed by contacting resource experts.[9]

[8] Sensitivity and adaptive capacity elements were informed by Lawler 2010, Glick et al. 2011, and Manomet Center for Conservation Sciences 2012.

[9] Resources evaluated by experts included: coastal bluff/scrub habitats, coastal conifer hardwood forest, true fir forest, lakes/ponds, freshwater marshes, vernal pools, seeps/springs, native insect pollinators, native ungulates, salamanders, frogs, native mussels, marbled murrelet, and northwestern pond turtle.

Stakeholders assigned one of five rankings (High, Moderate-High, Moderate, Low-Moderate, or Low) for sensitivity and adaptive capacity. EcoAdapt assigned rankings for projected future climate exposure. Rankings for each component were then converted into scores (High-5, Moderate-High-4, Moderate-3, Low-Moderate-2, or Low-1), and the scores were averaged (mean) to generate an overall score. For example, scores for each element of habitat sensitivity were averaged to generate an overall habitat sensitivity score. Scores for exposure were weighted less than scores for sensitivity and adaptive capacity because the uncertainty about the magnitude and rate of future change is greater. Sensitivity, adaptive capacity, and exposure scores were combined into an overall vulnerability score calculated as:

Vulnerability = [(Climate Exposure*0.5) x Sensitivity] - Adaptive Capacity

Elements for each component of vulnerability were also assigned one of three confidence rankings (High, Moderate, or Low). Confidence rankings were converted into scores (High-3, Moderate-2, or Low-1) and the scores averaged (mean) to generate an overall confidence score. These approximate confidence levels were based on the Manomet Center for Conservation Sciences (2012) 3-category scale, which collapsed the 5-category scale developed by Moss and Schneider (2000) for the IPCC Third Assessment Report. The vulnerability assessment model applied here assesses the confidence associated with individual element rankings and, from these rankings, estimates the overall level of confidence for each component of vulnerability and then for overall vulnerability.

Stakeholders and decision-makers can consider the rankings and scores presented as measures of relative vulnerability and confidence to compare the level of vulnerability among the focal resources evaluated in this project. Elements that received lower confidence rankings indicate knowledge gaps that applied scientific research could help address.

Vulnerability Assessment Model Elements

Sensitivity & Exposure (Applies to Habitats, Species Groups, Species)

- **Climate and Climate-Driven Factors:** e.g., air temperature, precipitation, freshwater temperature, soil moisture, snowpack, extreme events: drought, altered streamflows, etc.
- **Disturbance Regimes:** e.g., wildfire, flooding, drought, insect and disease outbreaks, wind
- **Future Climate Exposure:** e.g., consideration of projected future climate changes (e.g., temperature and precipitation) as well as climate-driven changes (e.g., altered fire regimes, altered water flow regimes, shifts in vegetation types)
- **Stressors Not Related to Climate:** e.g., tectonic and volcanic events; residential or commercial development; agriculture and/or aquaculture; roads, highways, trails; dams and water diversions; invasive and other problematic species; livestock grazing; fire suppression; timber harvest; mining; etc.

Sensitivity & Exposure (Applies to Species Groups and Species)

- **Dependencies:** e.g., dependencies on sensitive habitats, specific prey or forage species, and the timing of the appearance of these prey and forage species (concern for mismatch)

Sensitivity & Exposure (Applies to Species ONLY)

- **Life History:** e.g., species reproductive strategy, average length of time to reproductive maturity

Adaptive Capacity (Applies to Habitats, Species Groups, Species)

- **Extent, Integrity, and Continuity/Connectivity:** e.g., resources that are widespread vs. limited, structural and functional integrity (e.g., degraded or pristine) of a habitat or health and functional integrity of species (e.g., endangered), isolated vs. continuous distribution
- **Landscape Permeability:** e.g., barriers to dispersal and/or continuity (e.g., land-use conversion, energy production, roads, timber harvest, etc.)
- **Resistance and Recovery:** e.g., *resistance* refers to the stasis of a resource in the face of change, *recovery* refers to the ability to "bounce back" more quickly from the impact of stressors once they occur
- **Management Potential:** e.g., ability to alter the adaptive capacity and resilience of a resource to climatic and non-climate stressors (societal value, ability to alleviate impacts, capacity to cope with impacts)
- **Ecosystem Services:** e.g., provisioning, regulating, supporting, and/or cultural services that a resource produces for human well-being

Adaptive Capacity (Applies to Habitats ONLY)

- **Habitat Diversity:** e.g., diversity of physical/topographical characteristics, component native species and functional groups

Adaptive Capacity (Applies to Species Groups, Species)

- **Dispersal Ability**: i.e., ability of a species to shift its distribution across the landscape as the climate changes
- **Intraspecific/Life History Diversity:** e.g., life history diversity, genetic diversity, phenotypic and behavioral plasticity

---

Literature Cited

EcoAdapt. 2014a. A climate change vulnerability assessment for aquatic resources in the Tongass National Forest. EcoAdapt, Bainbridge Island, WA. 124 pp.

EcoAdapt. 2014b. A climate change vulnerability assessment for resources of Nez Perce-Clearwater National Forests. Version 3.0. EcoAdapt, Bainbridge Island, WA. 398 pp.

Glick P, Stein BA, Edelson NA. 2011. Scanning the conservation horizon: A guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

Gregg RM, editor. 2018. Hawaiian Islands climate vulnerability and adaptation synthesis. EcoAdapt, Bainbridge Island, WA. 284 pp.

Hutto SV, Higgason KD, Kershner JM, Reynier WA, Gregg DS. 2015. Climate change vulnerability assessment for the north-central California coast and ocean. Marine Sanctuaries Conservation Series ONMS-15-02. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. 473 pp.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Pages 617–652 in M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, editors. Cambridge University Press, Cambridge, UK.

Kershner JM, editor. 2014. A climate change vulnerability assessment for focal resources of the Sierra Nevada. Version 1.0. EcoAdapt, Bainbridge Island, WA. 418 pp.

Lawler J. 2010. Pacific Northwest Climate Change Vulnerability Assessment. From http://climatechangesensitivity.org

Manomet Center for Conservation Sciences and National Wildlife Federation. 2012. The vulnerabilities of fish and wildlife habitats in the Northeast to climate change. A report to the Northeastern Association of Fish and Wildlife Agencies and the North Atlantic Landscape Conservation Cooperative. Manomet Center for Conservation Sciences, Plymouth, MA.

Moss R, Schneider S. 2000. Towards consistent assessment and reporting of uncertainties in the IPCC TAR. In R. Pachauri and T. Taniguchi, editors. *Cross-Cutting Issues in the IPCC Third Assessment Report*. Global Industrial and Social Progress Research Institute (for IPCC), Tokyo.