An Interagency Conservation Strategy For *Pinus albicaulis* (Whitebark Pine) in California

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Cover Photo: Whitebark Pine in the Marble Mountain Wilderness of Northern California's Klamath Mountains. Michael E. Kauffmann.

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Executive Summary

Pinus albicaulis Engelm. (whitebark pine) is a keystone species of high elevation ecosystems across the west. The species is in decline across much of its range due to a variety of stressors, but information on the status and statewide health of whitebark pine in California is relatively unknown. Recent efforts in compiling data on the health of this species in California indicate that many of the causative reasons for decline are also present in California populations. White pine blister rust (*Cronartium ribicola* J.C. Fisch.) and the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) are altering whitebark pine ecosystems, with fire suppression and global climate change possibly exacerbating these interactions. Although white pine blister rust is present, its severity and effects have been limited in California relative to other regions. Up to this time, whitebark pine populations remain relatively free of white pine blister rust in most of its range in California. Mountain pine beetle infestations have been reported in multiple populations of whitebark pine in California, with wide variation in levels of mortality. Whitebark pine was listed as endangered in Canada under the Species at Risk Act in 2008 and it has been a candidate species under the Endangered Species Act since 2011.

Whitebark pines in California differ from populations across western North America by inhabiting a variety of parent materials – granitic, volcanic, ultramafic, and alluvial soils – and growing with different groups of associated tree and shrub species across the state. Numerous animal species are found with whitebark pine, as in other parts of its range, but several California endemic animal species are also present.

Most whitebark pines in California are found on public lands; 95% are found on NPS and USFS lands. The California Whitebark Pine Conservation Strategy is intended as a collaborative, coordinated multi-agency effort that includes managers, researchers, and the public to conserve and contribute to the species' persistence into the future. The conservation goals are: (1) conserve and protect existing diversity of whitebark pine; (2) reduce stressors and threats; (3) continue to build a strong scientific framework to inform science-based actions; (4) identify research needs and data gaps, and fund prioritized research to provide for science-based conservation and management of the species in California; and, (5) coordinate, communicate and educate. The conservation Categories and Actions for whitebark pine in California are to: (1) document its range and extent across the state; (2) understand its current health in California; (3) conserve and maintain genetic diversity; (4) identify, conserve, and protect blister rust resistant trees across its range; (5) coordinate and communicate whitebark pine information in California; (6) develop sub regional working groups to discuss topics at a local level; and, (7) continue to develop and implement the Conservation Action Plan (Appendix 1) as an iterative process to refine existing actions, track implementation, and identify new actions that will conserve whitebark pine.

The heart of this Strategy are the conservation goals and Conservation Action Plan, composed of prioritized tasks to conserve and manage the species in a coordinated effort across the state of California.

In signing the Strategy, the signatory agency indicates its agreement of the value in conserving whitebark pine in California. Signature indicates the agency's intent to support the implementation of priority actions identified in the Strategy, as feasible within individual agency budget and policy constraints. The USFWS and the USFS value the meaningful participation and technical and scientific expertise of agency staff, as available, to implement Strategy actions and identify potential funding sources; however it is understood that signature of the Strategy is not a commitment to providing staff resources. In certain cases, conservation actions are constrained by current ecological, logistical, or socio-political conditions and whitebark pine population status, and restoration options are limited. Final actions, commitments, and resource allocations will be determined by individual agencies. The Strategy does not propose conservation actions on privately-owned land, nor does it suggest management direction for privately-owned lands. Whitebark pine is not known to occur often on private lands in California. Private lands will not be discussed further in this Strategy.

Acknowledgements

We would like to thank the many scientists, Federal, State, and other agency staff and interested parties for contributing their time and expertise, sharing their experience and observations, and contributing to the project to develop this Strategy. We thank the Whitebark Experts Team, and all of the reviewers and participants who shared their expertise, ideas, and work to make this project possible.

This project builds on the work of whitebark pine practitioners in California as well as the Conservation Assessment prepared by the California Native Plant Society (CNPS)'s Vegetation Program (Julie Evens, Kendra Sikes, Michael Kauffmann, Jenell Jackson, Jennifer Buck and others) (Kauffmann et al. 2019).

We are grateful to the following individuals for providing reviews, suggestions and sharing expertise and advice throughout various phases of the project: (1) the Whitebark Pine Strategy Experts Team; (2) USFS reviewers and contributors: John Exline, Christina Boston, Beth Boyst, Phil Cannon, Togan Capozza, Arnaldo Ferreira, Mark Fenn, Chris Fettig, John Gleason, Marc Meyer, Leif Mortenson, Trent Procter, Hugh Safford, Don Schweizer, Joe Sherlock, Michele Slaton, Sheri Smith, Randy Striplin, Neil Sugihara, Det Vogler, and Jessica Wright; (3) USFWS reviewers and contributors: Stephanie Eyes, Amber Aguilera, and Josh Hull; (4) USGS reviewers and contributors: Amy Vandergast, Elizabeth Milano, and Diane Elam; (5) Signatory contacts: Chrissy Howell, Monica Buhler, Brent Johnson, and Kendal Young and, (6) the Whitebark Pine Strategy Core Team and others who have made this project possible.

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This project builds on the USFWS' 90-day finding (2010), USFWS' 12-month finding (USFWS 2011), and USFWS' draft Species Status Assessment (USFWS 2018).

This project also builds on other important whitebark work in other areas of the country. We are also grateful to the authors of four important strategies for whitebark pine restoration, for much of this Strategy is founded on their documents: "Conservation and Management of Whitebark Pine Ecosystems on Bureau of Land Management Lands in the Western United States" (Perkins et al. 2016); "A Range-Wide Restoration Strategy for Whitebark Pine (Pinus albicaulis)" (Keane et al. 2012); "Whitebark Pine Strategy for the Greater Yellowstone Area" (Greater Yellowstone Coordinating Committee - Whitebark Pine Subcommittee 2011); and, "Whitebark Pine Restoration Strategy for the Pacific Northwest Region 2009–2013" (Aubry et al. 2008). Aubry et al. (2008) is in the process of being updated.

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Introduction

Pinus albicaulis Engelm. (whitebark pine) is an important component species of high elevation ecosystems across the west. In California, the most extensive stands occur on high elevation, open ridges, and slopes of the central and southern portions of the Sierra Nevada mountain range. To the north, as the Sierra Nevada transitions to the Cascade Range in Lassen County, whitebark pine occurs on volcanic summits from Lassen Volcanic National Park to Mount Shasta (the two largest stands in the Cascades) as well as on other high elevation summits. Near the border of California to Nevada and Oregon, whitebark pine are found in high elevation areas of the Great Basin into the Warner Mountains to the east slopes and western portion of the Great Basin range including south to the Glass Mountains, Mono Craters, Bodie Mountains, Sweetwater Mountains, and Carson Range. Lastly, but importantly, there are isolated stands of whitebark in the Klamath Mountains – these sky islands are scattered across the diverse geological landscape of northwest California.

Since at least 1990, there has been a growing concern for whitebark pine across much of its range and in the northern Rocky Mountains and Canada in particular. Spread of white pine blister rust, a non-native pathogen, outbreaks of mountain pine beetle, climate change, and fire exclusion, led to a change in forest health and mortality throughout Canada and the Rocky Mountains. However, compared to populations in the rest of its range, whitebark pine populations in California are thought to be relatively healthy. Nonetheless, scientists and land managers have focused on inventory, mapping and monitoring, assessing forest health, and conducting studies to better understand whitebark pine, its habitat and its habitat needs. In an effort to protect and conserve whitebark pine in California, this conservation strategy provides an overview of: (1) biology and ecology, distribution, and genetic diversity; (2) threats; (3) historical and current condition of the species in California; and, (4) recommended goals and conservation actions to protect and conserve whitebark pine in California.

This Conservation Strategy for whitebark pine in California was prepared by an interagency team comprised of members of the USFWS Sacramento and Reno Fish and Wildlife Offices, USDA USFS Pacific Southwest Region and Pacific Southwest Research Station, NPS, CDFW, University of California, Davis, and species experts, under the guidance and direction of agency representatives from the USFWS Sacramento Office and USFS Pacific Southwest Region.

This Strategy provides a framework for the coordinated planning of ongoing and future restoration activities aimed at the conservation of whitebark pine in California. It provides a blueprint in the form of a Conservation Action Plan (Appendix 1) with options for conservation actions that individual agencies can implement as funding and other resources become available. In certain cases, conservation actions will be constrained by current ecological, logistical, or socio-political conditions and whitebark pine population status, and restoration options may be limited. Final actions, commitments, and resource allocations will be determined by individual agencies. The Strategy does not propose management actions on privately-owned land, nor does it suggest management direction for privately-owned lands.

The Strategy identifies five sub regions in California in which to focus conservation and management (Figure 1): The Klamath, Cascade, Modoc, Sierra Nevada North, and Sierra Nevada South sub regions. Although much of this document is based on the Conservation Assessment (Kauffmann et al. 2019), which identifies four sub regions, this Strategy uses five sub regions as the Sierra Nevada sub region was divided into north and south sub regions for management purposes. The Klamath sub region is the portion of whitebark pine habitat occurring on the Shasta-Trinity National Forest and the Klamath National Forest west of Interstate 5. The Cascade sub region includes the whitebark pine habitat occurring on the Shasta-Trinity and Klamath National Forests roughly east of Interstate 5, the Lassen National Forest, and the Lassen Volcanic National Park. The Modoc sub region includes the Warner Mountains and other areas of the Modoc National Forest. The Sierra Nevada North sub region includes the Stanislaus, Eldorado, Tahoe and Plumas National Forests along with the Lake Tahoe Basin Management Unit and portions of the Humboldt-Toiyabe National Forest that occur in California. The Sierra Nevada South sub region includes the Sierra, Inyo and Sequoia National Forests, and Yosemite and Sequoia & Kings Canyon National Parks.

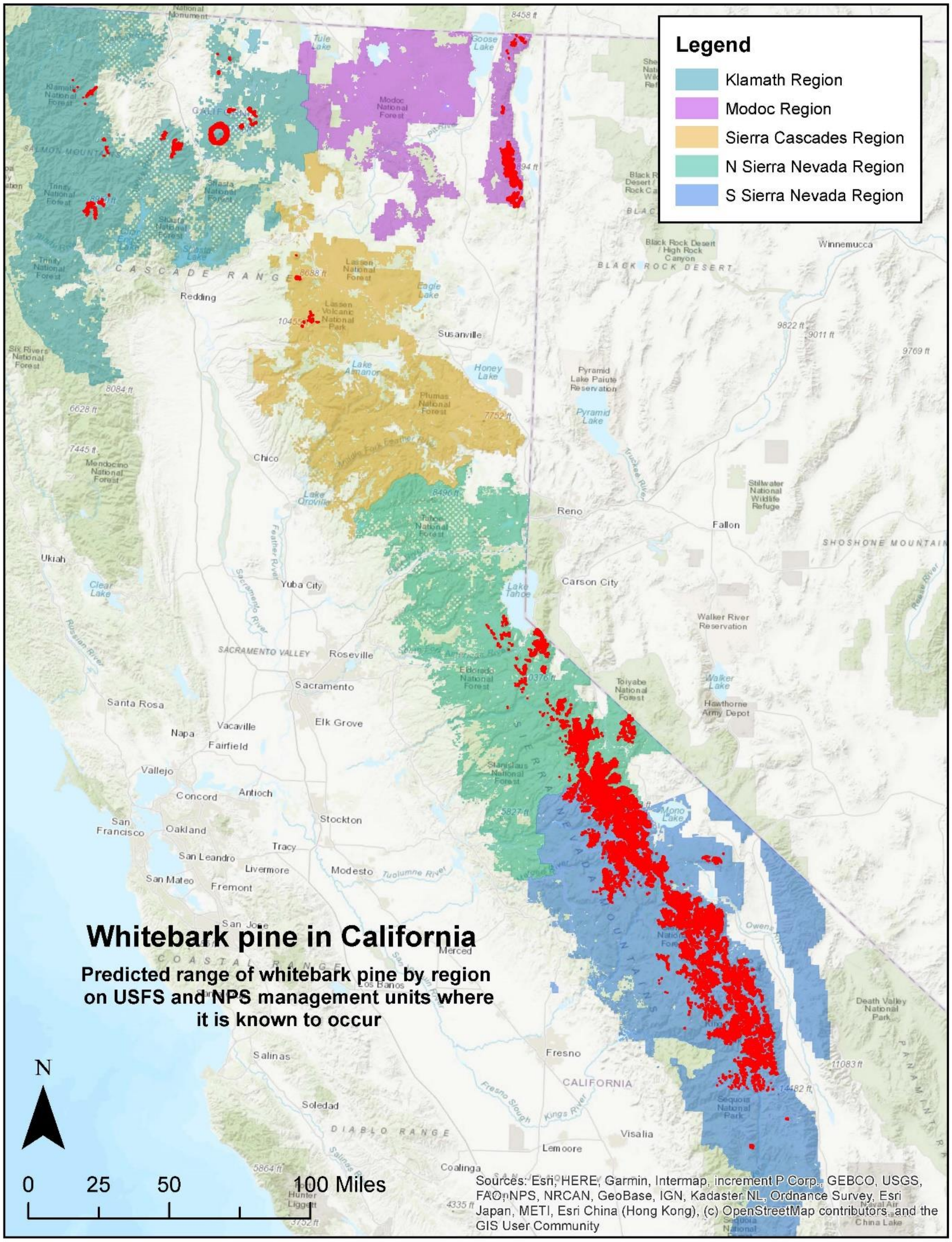

Figure 1. California predicted range map of *Pinus albicaulis* (whitebark pine) illustrated in dark red across the five sub regions (CNPS, unpublished).

Why Whitebark Pine is Special in California

Whitebark pine is a keystone species in high elevation ecosystems in North America. These high elevation areas are known worldwide for their natural beauty, plants, animals, and clean air, and are renowned for providing opportunities for recreation in all seasons. The snowpack and water generated in California's Sierra Nevada and southern Cascades are a critically important water source for the majority of the state, supporting both urban areas and agriculture. In addition, whitebark pine habitat supports important areas of biodiversity, and has unique ecology and species associations, which are representative of California. A summary of California whitebark pine soil, tree, and shrub associates, by sub region, are shown in Table 1. See Kauffmann et al. 2019 for a more detailed description of these associates throughout California.

One of the most unique aspects of California whitebark pine is its association with other co-occurring white pine species: six of the ten species of white pine (*Strobus* group) that occur in the North America are found in California. These include western white pine (*P. monticola* Douglas ex D. Don), sugar pine (*P. lambertiana* Douglas), limber pine (*P. flexilis* James), foxtail pine (*P. balfouriana* Balf.), Great Basin bristlecone pine (*P. longaeva* D.K. Bailey), and whitebark pine. California's complex geologic history and glaciations during the Pleistocene period have contributed to this rich heritage of five-needle white pine diversity in California (Schierenbeck 2014).

Approximately 91% of whitebark pine in California occurs in the Sierra Nevada (Meyer et al. 2020). Although genetic data at local scales are limited in California, local patterns in genetic diversity appear to be similar to those found at broader scales. However, Sierra Nevada populations appear to be genetically distinct from other regions, likely due to historical expansion from refugia in the Central Rocky Mountains, North Cascades and Northeastern Oregon (Zavarin et al. 2009, Yandell 2002, Richardson et al. 2002, Liu et al. 2016, Syring et al. 2016). Sierra Nevada populations are the most geographically isolated and they are also the most genetically distinct. This may reflect an adaptation to warmer, drier conditions, which may prevail in future climates, which highlights the importance of capturing California whitebark pine genetic diversity in gene conservation efforts (Syring et al. 2016). Additional genomic studies to determine local patterns of both neutral and adaptive genetic diversity within and among other sub regions in California could be useful in determining seed sourcing areas for future genetic restoration.

Table 1. Whitebark pine habitat and species associations in California (from USGS and CDMG 1966; Kauffmann et al. 2019).

Sub region	**Primary Soils**	**Trees**	**Shrubs**
Klamath	volcanic, sedimentary, ultramafic, granitic	western white pine, foxtail pine, white fir, Shasta fir, subalpine fir, mountain hemlock, Douglas-fir, common juniper, Sierra Nevada lodgepole pine*, Brewer spruce*, Pacific yew*	western moss heather, mahala mat, tobacco brush, Sierra laurel, huckleberry oak, curl leaf mountain mahogany, shrubby cinquefoil, Greene's goldenbush, rubber rabbitbrush, wideleaf rabbitbrush, Oregon boxwood, dwarf bilberry
Cascade	volcanic	western white pine, Sierra Nevada lodgepole pine, white fir, Shasta fir, mountain hemlock	Rocky Mountain maple, pine mat manzanita, greenleaf manzanita, mahala mat, tobacco brush, Sierra chinquapin, rubber rabbitbrush, marum leaved buckwheat, western blueberry
Modoc	volcanic	western white pine, Sierra Nevada lodgepole pine, white fir, lodgepole pine, western hemlock	pine mat manzanita, low sagebrush, mountain sagebrush, rayless goldenbush, Greene's goldenbush, rock spiraea, tobacco brush, antelope bush, snowberry
Sierra Nevada North	volcanic and granitic	western white pine, Sierra Nevada lodgepole pine, mountain hemlock, Jeffrey pine, Sierra juniper, quaking aspen, red fir	sagebrush, ocean spray, wax currant, mountain currant, mountain snowberry, low sagebrush, interior goldenbush
Sierra Nevada South	granitic	western white pine, Sierra Nevada lodgepole pine, mountain hemlock, Jeffrey pine, Sierra juniper, quaking aspen, foxtail pine, limber pine	granite prickly phlox, Brewer's mountain heather, ocean spray, wax currant, dwarf bilberry, shrubby willow, shrubby cinquefoil, Sierra chinquapin

*Not common

Biology and Ecology

Whitebark pine is a member of the Pinaceae (Pine Family), Genus *Pinus*, and is in the subgenus Strobus or white pine group. There are about 45 species in this group worldwide. White pines include the five-needle pines and pinyon pines (FNA 1993, Price et al. 1998), and whitebark pine is one of six species of five-needle pines in California. These pines are characterized by leaf anatomy of one vascular bundle per needle with needles occurring five to a sheath; hence the term five-needle pine. Whitebark pine has pale gray bark with cones that do not open in maturity.

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The species occurs in thin, rocky, cold, and weakly developed soils at or near the upper limit of treeline in the southern part of its range and at lower elevations, in a wider elevational band below treeline, in its northern range. Whitebark pine is cold-tolerant, somewhat drought-tolerant and shade-intolerant. It often grows in pure stands, but is also found in mixed stands of other high elevation trees such as red fir (*Abies magnifica* A, Murray bis), mountain hemlock (*Tsuga mertensiana* (Bong.) Carrière), Sierra juniper (*Juniperus grandis* R.P. Adams), Sierra lodgepole pine (*Pinus contorta Douglas* ex London var. *murrayana* (Balf.) Engelm.), and several additional five-needle white pine species: foxtail, limber and western white pine (Kauffmann et al. 2019).

Within California, whitebark pine grows in cold, windy snow zones. In wetter areas like the Klamath and Cascades, it is most abundant on the warmer and drier sites, though is also occurs regularly on the north side of Mount Shasta. In the more arid Warner Mountains and in the Sierra Nevada, the species is more commonly found on the cooler, more mesic north-facing slopes as well as south-facing slopes. However, some of these patterns are shifting. In the last 50 years, whitebark pines have been able to colonize new habitat including north-facing slopes that are now snow-free earlier in the year due to warming temperatures (Millar et al. 2012).

At tree-line and at exposed sites, whitebark pine will often adopt a stunted, mat-like dwarf form known as krummholz (or “twisted wood” in German) that can withstand cold, desiccating winter winds. Occasionally, branches can be seen growing above the tree mats, however, these upright limbs are often killed by frost in the next cold season. In more favorable sites, whitebark pine will grow in an upright tree form up to 26 meters (85 feet) tall (Baldwin et al. 2012).

The largest whitebark pine recorded in California to date was found in the Humboldt-Toiyabe National Forest in 2011 with a trunk circumference of approximately 597 centimeters (235 inches) (Big Tree Registry, 2020). The oldest whitebark pine trees in the state are in excess of 1,700 years old and likely as much as 2,000 years old (krummholz individuals, King and Graumlich 1998). Whitebark pine is a slow growing pine and typically does not begin to produce cones until it reaches 40- 60 years (Arno and Hoff 1990). Full cone production occurs as trees approach 200 years of age (Arno and Hoff 1990). These life history traits mean that whitebark pine generation time (average time to produce a viable seedling/offspring) is at least 60 years (Arno and Hoff 1990).

Clark's nutcracker (*Nucifraga columbiana* Wilson) is one of whitebark pine's most well-known associates. Whitebark pine is dependent on this large grey, black and white bird in the crow family for seed dispersal (Tomback 1978, 1982). Whitebark pine cones do not open at maturity; Clark's nutcracker break open the cones and collect the seed. Some seeds are consumed immediately, but many are buried by nutcrackers in multi-seed caches, often nearby, for later retrieval in the early spring. Seed in unretrieved caches often germinate together, resulting in stems from multiple trees growing adjacent to one another and often fusing together at the base and forming tree clusters. For a comprehensive review of Clark's nutcracker and whitebark pine, please see Keane et al. (2012).

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There are several ecological consequences for whitebark pine that are due to its symbiotic (mutual benefit) relationship with Clark's nutcracker. Multi-trunk and or tree cluster individuals are closely related genetically due to Clark's nutcracker seed caching behavior (Tomback 1982, Hutchins and Lanner 1982, Tomback and Linhart 1990). As with other pine species, whitebark pine pollen is wind-dispersed; the spatial distribution of trees in tree clusters means that trees are mostly pollinated by their immediate neighbors. Due to this clumped seed caching and wind-driven pollination, trees in close proximity can have high genetic similarity. However, information is lacking regarding differences related to tree versus krummholz forms and more research is needed.

Additional ecological consequences of this relationship are associated with differences in year-to-year seed dispersal. Whitebark pine is a masting[1] species and seed dispersal by Clark's nutcrackers in a given year is a function of the cone crop size in that year. In order for birds to be attracted to whitebark pine trees, a stand of whitebark pine needs to produce over a certain threshold of cone crop production and of cone density (McLane et al. 2017, McKinney et al. 2009).

In poor cone crop years, whitebark pine cones are often not harvested by nutcrackers, as the birds are able to switch to other seed sources such as foxtail pine (Ray et al. 2020). Therefore, seed that is produced in low production years has either low dispersal or, if nutcrackers do forage on the seeds, they are largely consumed, which means that less whitebark pine seeds are cached or produce viable seedlings. Lastly, in most cases, whitebark pine seed dispersal distance is limited to how far nutcrackers fly to cache seed.

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[1] To preclude widespread predation of seeds by animals many species of pine, including whitebark pine, have evolved a strategy called masting in which populations synchronize their reproductive activity (Lorenz et al. 2008). In masting trees, synchronized, heavy reproductive events are thought to deplete stored resources and to impose a replenishment period before subsequent masting. However, direct evidence of resource depletion in wild, masting trees is very rare (Sala et al. 2012).

Distribution

Whitebark pine is the most widespread of the nine five-needle white pine species in North America. It grows in montane to upper tree-line elevations, 6,560 feet to 12,139 feet, in the Rocky Mountains (Alberta, British Columbia, Montana, Idaho and Wyoming), in the Coast Mountains of British Columbia, in the Cascade Mountains (California, Oregon, and Washington), the Klamath Mountains, the Sierra Nevada, and in a few isolated intermountain ranges of Nevada and eastern California (Figure 2).

In California, whitebark pine grows along the crest of the Sierra Nevada range northward into the Cascade Range in Northern California, Oregon and Washington (Figure 1, Baldwin et al. 2012). There are known whitebark pine stands in the Warner Mountains in northeastern California and eastward from the Sierra Nevada in the Humboldt-Toiyabe National Forest. The most southerly known location in California *and* for the entire species, is the Kern Plateau. Disjunct stands also occur on the isolated, geologically diverse "sky islands" of the Klamath Mountains. Whitebark pine is also known from a few isolated stands clustered around Glass Mountain northeast of Lake Crowley in Mono County, the Mono Craters, Bodie Mountains and Sweetwater Mountains, and the northern White Mountains.[2] There are likely other isolated scattered stands across the state, as not all potential locations have been documented. Since outlier and isolated populations in range margins have important characteristics relating to genetic diversity and white pine blister rust resistance, refining our current knowledge of distribution may inform conservation efforts in these areas.

The majority of whitebark pines in California grow along the contiguous high-elevation crest of the Sierra Nevada, where they often form pure stands. Distribution in the northern part of the state is much more heterogeneous; sky islands supporting whitebark pine are relatively small in area and are broken up by vast river valleys. These islands in the sky include various volcanoes in the Cascades and isolated peaks in the geologically complex Klamath Mountains. The Warner Mountains offer homogeneous high elevation stands in the South Warner Wilderness, while whitebark pine stands in the northern Warner Mountains are more heterogeneously distributed across smaller, high elevation pockets (Kauffmann et al. 2019).

[2] Based on a single herbarium specimen collected by D. W. Taylor in 1986. Locality description: "White Mountains; Headwaters of easternmost branch of southern fork of upper Middle Creek" RSA359936, Consortium of California Herbaria, accessed 14 May 14, 2020.

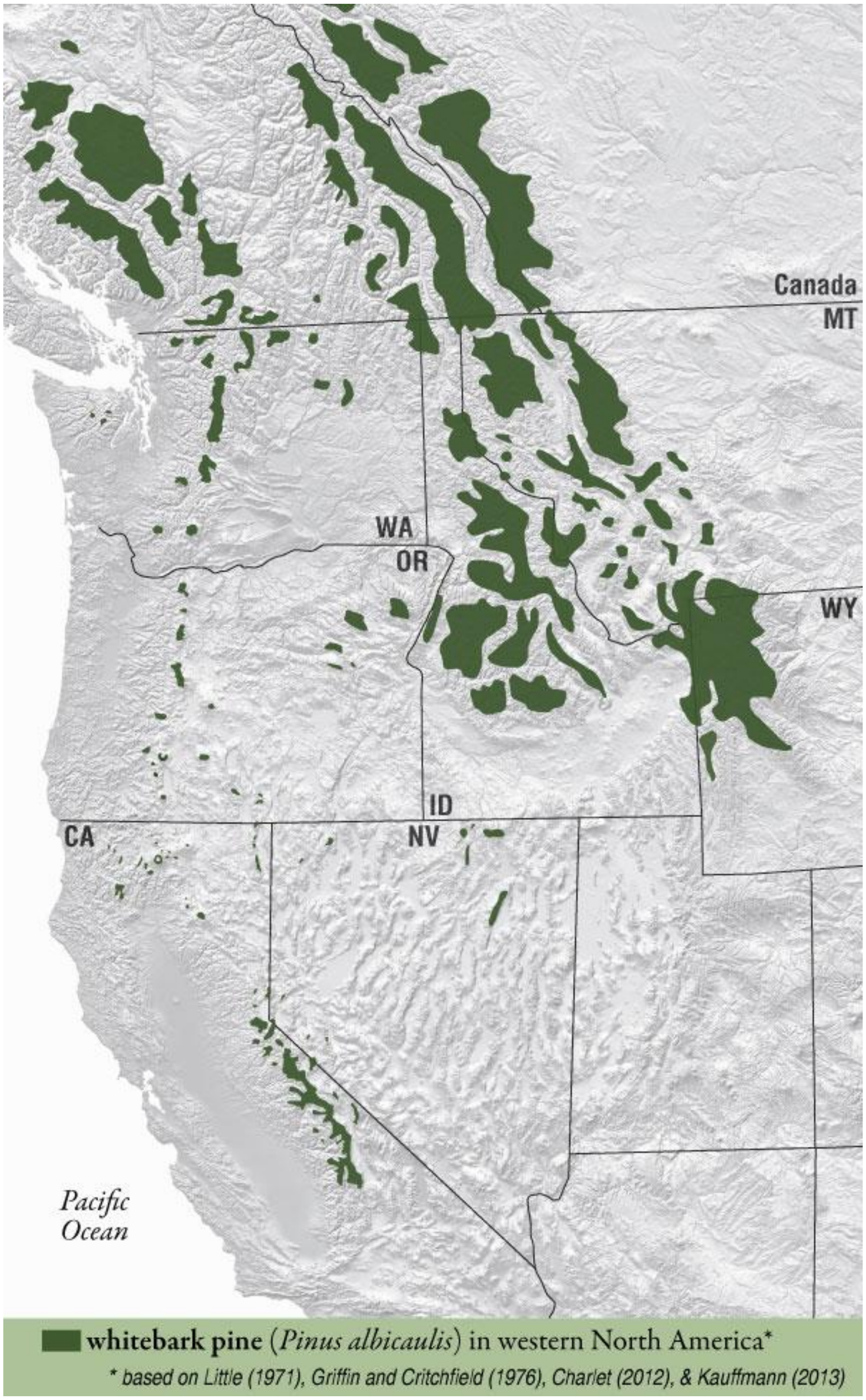

Figure 2. Western North American range map for *Pinus albicaulis* (whitebark pine). This figure appears in the *Conservation Assessment for Pinus albicaulis on National Forest Lands in California with Management Considerations* (Kauffmann et al. 2019) as well as *Conifers of the Pacific Slope* (Kauffmann 2013).

Various entities have attempted to map the distribution of whitebark pine across California using different datasets and assumptions (e.g., Griffin and Critchfield (1976), CALVEG (1997-2016)). One of the more recent efforts is the distribution map provided in the Conservation Assessment (Kauffmann et al. 2019). Most recently the USFS, Pacific Southwest Region, Remote Sensing Lab (RSL) produced a map of the species' distribution in California (Figure 3, RSL 2020) that is a composite of sources and field validation. Not all areas mapped as whitebark pine habitat in the RSL map have been ground-truthed and not every area containing whitebark has been included; some "typically low elevation settings may contain ecologically important segments of the population" that have been excluded and may potentially be impacted by management or recreation uses (RSL 2020). During field surveys, in some areas previously mapped as whitebark pine, none was present: this may be due to errors in the original mapping or, more ominously, unknown shifts in species distribution. Although some of the data represented in the RSL map may be included in the Kauffmann et al. (2019) analyses, the RSL map was created more recently and the data represented here may differ from the Kauffmann et al. (2019) analysis. The Conservation Assessment (Kauffmann et al. 2019) provides an analysis of regional and vegetation patterns of whitebark pine across California. A summary of visual examples of vegetation patterns are presented in Appendix 3.

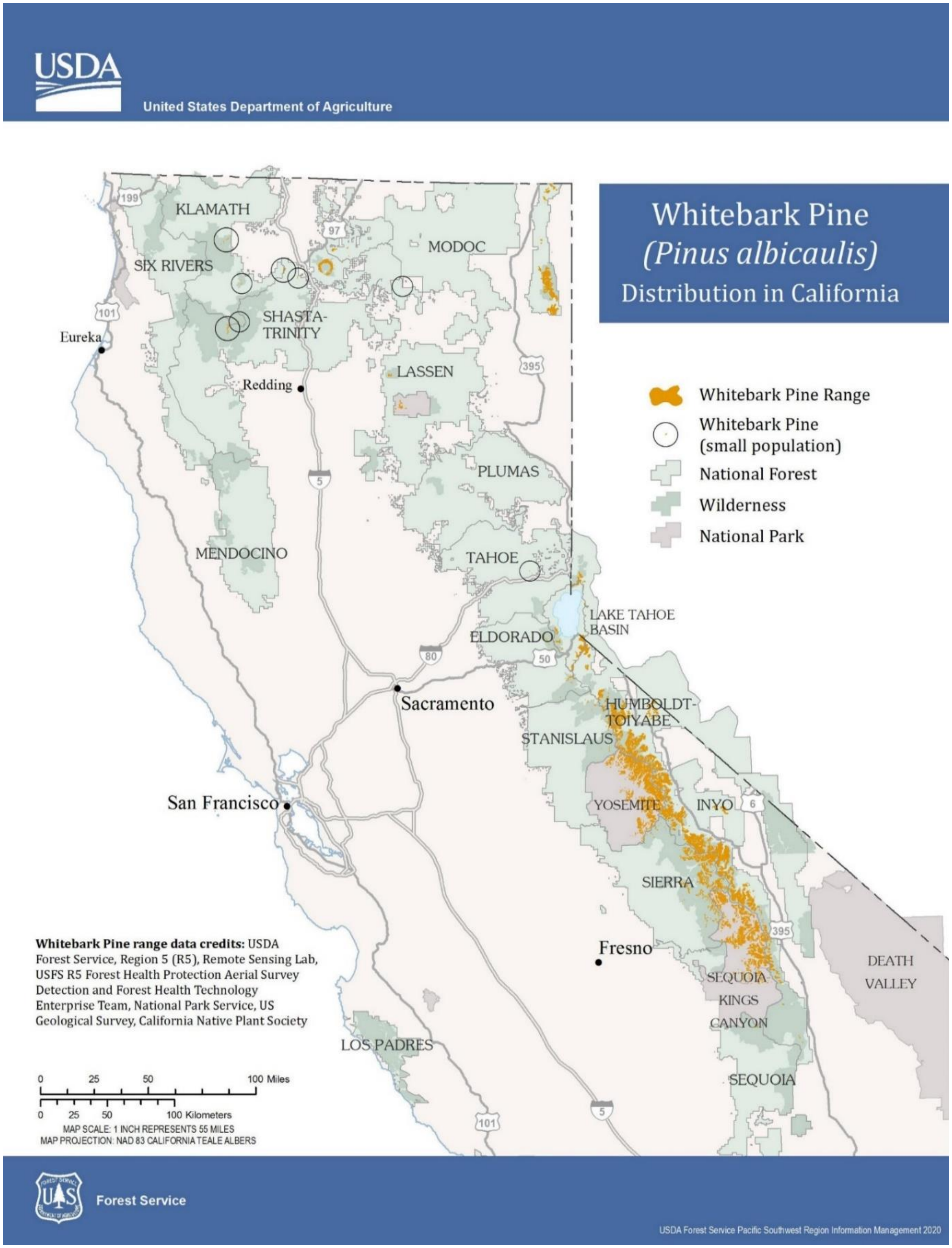

Figure 3. Whitebark pine (*Pinus albicaulis*) distribution in California (RSL 2020).

Genetic Diversity

Conservation of a species' genetic diversity is essential to ensure the long term viability of populations and their ability to adapt to current stressors and future conditions. This requires an understanding of the amount and distribution of genetic variation among individuals, populations, and regions. As mentioned above, Sierra Nevada populations appear to be genetically distinct from other regions, and the possibility that this reflects adaptation to warmer, drier conditions, highlights the importance of capturing this genetic diversity in gene conservation efforts (Syring et al. 2016).

Range-wide Genetic Considerations

Range-wide studies using neutral molecular markers show low genetic diversity in whitebark pine, with levels comparable to or lower than those of other widespread conifers in western North America (Aubry et al. 2008, Bower et al. 2011, Keane et al. 2012, Syring et al. 2016). Patterns of diversity and signatures of population expansion in allozymes, organelle DNA, and targeted genomic markers suggest a history of bottlenecks from glacial refugia and re-expansion into limited subalpine habitat (Jorgensen and Hamrick 1997, Richardson et al. 2002, Krakowski et al 2003, Syring et al. 2016).

Populations in different geographic regions are genetically distinct, likely due to historical expansion in different directions from refugia in the Central Rocky Mountains, North Cascades and Northeastern Oregon (Zavarin et al. 2009, Yandell 2002, Richardson et al. 2002, Liu et al. 2016, Syring et al. 2016). Sierra Nevada populations are the most geographically isolated of these and they are also the most genetically distinct, harboring unique variation that may be adaptive in southern, high-elevation habitats (Syring et al. 2016).

Like many wind-pollinated pines, whitebark pine populations within a region show low differentiation in neutral molecular markers, with only four to five percent of variation due to differences among populations, and the vast majority of variation residing within populations (Bruederle et al 2001; Krakowski et al 2003; Bower and Aitken 2008). However, significant clinal patterns in quantitative phenotypic traits indicates adaptive genetic differences have evolved among populations despite high levels of gene flow demonstrated by neutral molecular markers. Regional studies have documented adaptive genetic differentiation among populations for cold hardiness, growth, phenology, stem form, and blister rust resistance (Bower and Aitken 2006; Mahalovich et al. 2006; Hamlin et al. 2007; Lind et al. 2017; Sniezko et al. 2018). Seed sourced from populations throughout the entire range and grown in a common environment revealed low levels of population differentiation for growth related traits, but moderate to strong differentiation for traits related to cold adaptation (Bower and Aitken 2008).

Selection pressures appeared to differ depending on the region. While growing season length and temperature were important in other regions, water availability appeared to drive adaptation in southern populations, including California, because survival and date of needle flush were both associated with rainfall patterns. This finding is supported by strong evidence for adaptation to soil water availability at fine spatial scales in the Lake Tahoe Basin (Lind et al. 2017). Levels of resistance to blister rust infection differ regionally, with populations from California having relatively low genetic resistance (Sniezko et al. 2018). A more comprehensive evaluation of blister rust resistance is California is needed and is currently underway (Maloney 2020, pers. comm.). Tradeoffs between growth and physiological defense against blister rust demonstrate the importance of conserving genetic variability to allow adaptive responses to complex biophysical and biological stressors that may challenge the species in unpredictable ways in future climates (Kichas et al. 2020).

Genetic Considerations within California Sub Regions

Although genetic data at local scales are more limited in California, local patterns in genetic diversity appear to be similar to those found at broader scales. For example, genetic surveys within the Sierra Nevada North population found high levels of genetic similarity among sampled sites in allozyme loci (Jorgensen and Hamrick 1997; Rogers et al. 1999) and decreasing genetic diversity with decreasing latitude (Jorgensen and Hamrick 1997). Despite a background of high gene flow, as mentioned in the paragraph above, associations between genotypes and soil water availability suggest adaptive genetic differences at very fine spatial scales in the Lake Tahoe Basin (Lind et al. 2017). Additional genomic studies to determine local patterns of both neutral and adaptive genetic diversity within and among other sub regions in California could be useful in determining seed selection strategies for future genetic restoration.

Developing Genetic Conservation and Restoration Strategies

California is the only region that does not currently have an active genetic restoration program for whitebark pine (Slaton et al. 2019). In other regions, these programs often include the collection, breeding, and planting of stock resistant to blister rust. It may be important to invest in such a restoration strategy and reforestation program despite considerable effort, cost, and coordination (Maloney et al. 2012), if the relatively healthy populations in California begin to show declines similar to those in other parts of the region. However, this type of proactive intervention is likely to achieve the best results at significantly less cost when conducted prior to significant declines (Schoettle and Sniezko 2007, Schoettle et al. 2019). Development of seed sourcing guidelines is critical for such an effort, and patterns of local adaptation in response to unique selection pressures in different regions suggest the need for tailored guidelines (Bower and Aitken 2008). Tailored guidelines have been proposed for each region, and the lack of correspondence between quantitative genetic variation and climatic variables suggests seed can be moved freely within the southern region (including California), but transfer between mountain ranges (Sierra Nevada and Cascades) should be avoided. Because only four populations were sampled from California in this study, further research is needed to delineate seed sourcing guidelines.

The University of California, Davis, Forest and Conservation Biology lab is working with the USFS Placerville Nursery to establish a common garden study and white pine blister rust resistance testing for 180 source families of whitebark pine from over 40 locations in California and Nevada (Figure 4). Collections are range wide in California throughout the Sierra Nevada, Southern Cascades, Klamath, Warner Mountains, and Great Basin. Seed for the common garden were sown in May 2020 and seed for rust resistance testing will be sown in 2021 and 2022 (Maloney 2020 pers. comm.).

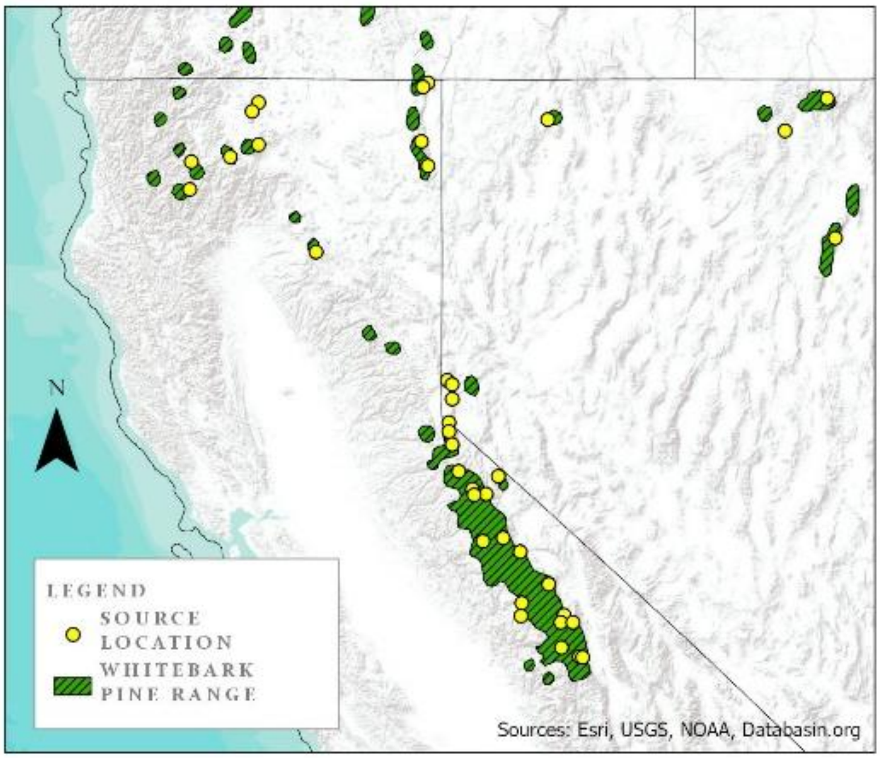

Figure 4. Map of University of California, Davis, seed collection locations for 180 source families of whitebark pine in California (Maloney 2020 pers. comm.).

Efforts are currently underway to identify trees with genetic resistance to white pine blister rust in California, assess genetic diversity, and identify possible associations with climatic variables in central and southern Sierra Nevada whitebark pine populations (Slaton et al. 2019b). The diversity of ecological settings of whitebark pine and their potentially unique genetic composition, points to the need for a strategy for monitoring, conservation, and restoration that is tailored to each unique zone (Slaton et al. 2019b).

Threats to Whitebark Pine with a Focus on California

The decline of whitebark pine across its range in North America is the result of multiple interacting, recent human-caused and natural events (Arno 1986, Kendall 1995, Kendall and Keane 2001, Tomback et al. 2001, Tomback and Achuff 2010, Tomback et al. 2011). In

California, the primary threats impacting whitebark pine populations are believed to be white pine blister rust, mountain pine beetle, climate change, fire, and drought. The effects of these threats on whitebark pine are not currently synthesized since much of the work is unpublished. The major threats identified by the USFWS for whitebark pine in its 12-month finding include white pine blister rust, mountain pine beetle, changing fire regimes, and changing climate (USFWS 2011).

White Pine Blister Rust

The non-native fungal pathogen white pine blister rust is a primary concern in all five-needle white pine ecosystems in western North America. *C. ribicola* (cause of white pine blister rust) was introduced into British Columbia around 1910 and arrived in northern California around 1929 and the southern Sierra Nevada by 1961 (Smith 1996). White pine blister rust wave years (i.e., infection periods) in the Mediterranean climate of California, particularly in lower-elevation forests of the Sierra Nevada on the western slopes, have a frequency of 7 to 14 years, and in some favorable microclimates possibly less than 7 years (Kinloch et al. 1996, Maloney 2020 pers. comm.). In high-elevation forests of California the current white pine blister rust - infection observed is likely the result of initial infection approximately 25 to 40 years ago (Smith and Hoffman 2000, Duriscoe and Duriscoe 2002). Although in the southern Sierra Nevada, previously undocumented infections have been observed in the last several years in whitebark pine at low incidence (Nesmith et al. 2019, Dudney et al. 2020).

C. ribicola is a heteroecious rust with five spore stages that require > 90% relative humidity and temperatures ranging between 2-18°C for infection to occur (McDonald and Hoff 2001), that must alternately infect both white pines and *Ribes* or other non-*Ribes* alternate hosts to complete its life cycle (Geils et al. 2010). The primary alternate hosts, currants and gooseberries (*Ribes spp.*), are widely distributed across the western United States, with approximately 30 species in California (Baldwin et al. 2012). *Ribes* spp. occur in a wide range of habitats and elevations, and most are susceptible to white pine blister rust, but different species vary in their susceptibility (Zambino 2010). Two non-*Ribes* alternate hosts (i.e., *Castilleja* and *Pedicularis*) (McDonald et al. 2006) are common forbs throughout California; also distributed across a wide habitat and elevational range (Baldwin et al. 2012). During the spring, spores from infected pine boles and branches are dispersed to infect leaves of the alternate hosts. These spores have long-distance dispersal capabilities and can sometimes travel as far as 1,000 km or more (Smith 1996, Frank et al. 2008). During the summer months, spores on infected host *Ribes* leaves spread to uninfected *Ribes* leaves, and this cycle repeats throughout the growing season (Scharpf 1993, Kliejunas and Adams 2003). In late summer and early fall, lesions on *Ribes* leaves give rise to short-lived spores that locally disperse, traveling < 2 km to infect white pine (Geils et al. 2010).

Negative effects of the pathogen occur mainly on the pine host, in which branch infections are perennial (Kinloch et al. 1996, Geils et al. 2010) and the cankers girdle main stems and branches and subsequently restrict water and nutrient transfer. In California and other regions, white pine blister rust can adversely affect reproductive output (female cone production) by infecting and killing cone-bearing branches (McKinney et al. 2009, Maloney et. al 2012). This species-level effect can have negative consequences on important community-level interactions, such as resource availability (e.g., cones and seeds), dispersal of whitebark pine, and regeneration (Tomback et al. 2001, McKinney et al. 2009, Maloney et al. 2012). Observations of greater white pine blister rust activity from south to north in California whitebark pine stands suggest that the more northerly regions in California at times may have favorable conditions for white pine blister rust infection to occur (e.g., Maloney et al. 2011, 2012; Dunlap 2012 *in* Meyer et al. 2020).

Throughout the range, early efforts aimed at controlling white pine blister rust were unsuccessful. This work was mainly focused on eradicating the alternate host *Ribes* species and was found to be impractical due to a copious persistent seed bank often present in sensitive riparian habitats.

White pine blister rust resistance is potentially present in low levels in natural whitebark pine populations (Hoff et al. 2001, Sniezko et al. 2012). Seedlings grown from healthy trees in stands that are heavily infected and damaged by blister rust may have the highest probability of resistance (McDonald and Hoff 2001).

Current management efforts are focused on locating and protecting individual trees resistant to white pine blister rust (when identified), collecting their seed, assessing their disease resistance and other adaptive traits. Given the negative impact of white pine blister rust throughout many parts of the range of whitebark pine, increasing the proportion of white pine blister rust-resistant individuals in the population and a diverse seedbank may represent some effective strategies for ensuring the future for the species (Keane et al. 2012).

Mountain Pine Beetle

Native bark beetles within the genus *Dendroctonus* are major drivers of ecological change in western forest ecosystems. Mountain pine beetle in particular has been a significant cause of tree mortality historically (Evenden 1944, Perkins and Swetnam 1996, Taylor et al. 2006, Brunelle et al. 2008), with the severity of outbreaks reaching unprecedented levels in recent years (Gibson et al. 2008, Raffa et al. 2008, Bentz et al. 2010, Meddens et al. 2012, Hick et al. 2016, Fettig et al. in press). These insects can exist at endemic population levels in most forest ecosystems (Gibson et al. 2008, Bentz et al. 2014) and are considered important biotic disturbance agents that maintain structural and compositional diversity of western forests (Weed et al. 2015). In western North America, mountain pine beetle mainly infests and reproduces in live trees in the genus *Pinus*, and successful brood production often results in host death (Amman and Cole 1983, Safranyik and Caroll 2006). Whitebark pine, a host of mountain pine beetle, has been found to be especially susceptible to infestation and/or death (Logan and Powell 2001).

Mountain pine beetles are small insects (3.7 to 7.5 mm in length) that spend their entire life cycle under the bark of host pine trees except during flight periods when adults emerge to mate and seek new host trees for brood production. Bark beetles damage host trees by feeding on the phloem tissue located just under the bark. Both developing larvae and adults feed on the tree's phloem and make channels or "galleries" in host tissue, interrupting the flow of water and nutrients. Mountain pine beetle dynamics are complex and involve interactions between the defense mechanism of pine hosts and the bark beetles' microbial associates. For a review of mountain pine beetle dynamics in coniferous forests, refer to Negron and Fettig 2014.

Bentz et al. (2014) found that mountain pine beetle in whitebark pine stands in the northern Sierra Nevada had a mostly semivoltine life cycle with a generation time ranging between 385 and 695 days. Voltinism refers to the number of broods or generations an organism has in a year and semivoltine requires more than a year to complete a life cycle or produce a brood.

Mountain pine beetles produce an "anti-aggregation" pheromone to prevent overcrowding that repels attacks from additional beetles. This pheromone has been identified, is synthesized commercially and is available as verbenone. Verbenone does not appear as effective in preventing mountain pine beetle infestation in whitebark pine as compared to other pines. USFS researchers are also looking at combining tree volatiles with verbenone to improve efficacy (Fettig et al. 2012). Various formulations have been used or are in development (Fettig et al. 2012, Progar et al. 2014). The application process is labor intensive and must be done annually prior to beetle flight season (i.e., applied in spring), but may be useful to protect specific high value trees or populations that demonstrate resistance to white pine blister rust.

Mountain pine beetle has been evolving in western pine forest ecosystems for millennia. However, warming temperatures in the alpine and subalpine zones are of great concern as temperature plays a key role in mountain pine beetle success, particularly development rate and life cycle timing (aka phenology) (Bentz et al. 1991, Bentz et al. 2014, Safranyik and Linton 1998, Bentz and Mullins 1999). Rising global temperatures may decrease the amount of time required for the beetle to complete its life cycle and increase the length of the flight season, likely exacerbating bark beetle impacts on whitebark pine and other high elevation tree species in California (Bentz et al. 2010). Although effects of mountain pine beetle infestation together with global climate change effects may be complex and difficult to predict, there is a need to plan and implement conservation measures (Hobbs and Cramer 2008, Perkins et al. 2016). These include continued protection of high value stands and blister rust-resistant cone-bearing trees, and the evaluation of host defense chemistry. Additionally, intensified and annual monitoring of beetle infestations and impacts across the California range of whitebark pine is needed, both to provide current species status and to provide insight and information for research and management efforts.

Climate Change

Effects of climate change are being documented and modelled across the range of whitebark pine. The range-wide whitebark pine restoration strategy (Keane et al. 2012) was recently updated to address climate change through modelling (Keane et al. 2017). Habitats and ecology of whitebark pine in California differ from the Rocky Mountains and Cascade Mountain populations, so a separate regional modeling exercise may be warranted.

Several studies have addressed climate change impacts to whitebark pine in California. Millar et al. (2004) found that climate change effects to whitebark pine over the past 120 years were complex and, in some cases, often counter-intuitive. Changes in four ecological responses of whitebark pine were examined (snowfield invasion, branch growth, meadow invasion and vertical branch release in krummolz trees) and found to correlate with either periods of minimum temperatures or a North American specific climate modality related to El Niño (Pacific Decadal Oscillation indices). Under certain conditions, whitebark pine was found to have expanded into formerly persistent snowfields and into meadows. The expectation that whitebark pine distributions will shift upwards in elevation with climatic warming has not borne out to date; patterns from past warming periods are more complicated (Millar et al. 2004; Millar et al. 2020).

Species besides whitebark pine will respond to a changing climate (e.g., foxtail pine, *Pinus balfouriana*) (Moore et al. 2017), and potentially allowing pests and pathogens (e.g., bark beetles and white pine blister rust) to become more active. There are well documented instances of increased beetle activity in British Columbia, where historically beetles were temperature limited; however, it unclear if this applies to the Sierra Nevada. In the Sierra Nevada, bark-beetle-killed stands of whitebark pine had lower incidence of fire-caused mortality, perhaps due to reduced continuity of fuels so remaining trees escaped crown fire(Millar and Delany 2019).

Dolanc et al. (2013) found that warming temperatures over the past century increased recruitment and promoted survival of small trees, leading to a shifting stand structure weighted toward smaller, younger trees, densification of existing stands, and no evidence for establishment above current treeline. Meyer and North (2019) also documented this shift to smaller younger trees in subalpine forests, including whitebark pine. They also modelled future impacts to subalpine forests, including whitebark pine and found that most models predicted an 82 to 100 percent reduction in pines which may affect the entire geographical range of whitebark in California (Meyer and North 2019).

The effects of climate change on various whitebark pine disturbance processes have been studied, including bark beetle outbreaks (Millar et al. 2012), fire (Millar and Delany 2019) and "mega-droughts". Other work has focused on Californian subalpine forests more generally but they do not call out whitebark pine specifically (Hayhoe et al. 2004). Changing climate will likely affect many aspects of whitebark pine ecology, but so far direct changes from climate change appear to be slow and lagged due to the longevity of the species and ability to persist under varied climate.

Fire

Whitebark pine is well-suited as a pioneer species in high elevation communities. Its cold tolerance combined with its nutcracker seed dispersal "system" allow it to colonize disturbed sites exposed to harsh conditions. Competition from shade-tolerant species may confine it to the narrow strip of habitat at the upper limit of trees. Thus, fire is one of several kinds of ecological disturbance that can open up habitat for whitebark pine regeneration (Perkins 2015).

High-elevation subalpine forests in the Sierra Nevada are sparse and open-canopied, with shallow fuel beds and frequent rock outcrops that restrict the frequency and severity of fire (van Wagtendonk and Fites-Kaufman 2006, Fites-Kaufman et al. 2007). Natural fire return intervals in Sierra Nevada subalpine forests have been estimated at between 100 and 420 years, depending on the site, with a mean fire return interval of 133 years (van Wagtendonk et al. 2018). Human efforts at fire suppression within the subalpine zone (which are already relaxed due to wildland fire use policies in many wilderness areas, as well as the great distances to human population centers) have had little to no effect on forest composition or structure, as these efforts began only 75–100 years ago, a shorter time period than the natural mean fire-free period in Sierra Nevada subalpine forests. As a result, unlike the lower-elevation forests where human fire suppression has caused major shifts in the fire regime, modern recent fires in high-elevation forests of the Sierra Nevada are burning well within the historical range of variation for fire severity (Miller and Safford 2008).

California's forests, in general, are experiencing shifts in fire severity, frequency, and extent due to warming temperatures, fire suppression, and human ignitions (Keeley and Syphard 2016), and there is evidence for increasing elevation extent of fires in the Sierra Nevada (Schwartz et al. 2015). More information is needed to better understand the relationship of fire to whitebark pine sustainability in California, particularly as other stressors become more important. Also, on USFS lands, revised forest plans may provide for managed wildfire to meet resource objectives, including whitebark pine restoration. Much of the whitebark pine habitat in National Forests occurs in what will be designated as wildfire maintenance zones, where using fire will be highly encouraged (USFS 2019).

The Conservation Assessment (Kauffmann et al. 2019) examined fire evidence across the range of whitebark pine in California; these impacts were found to vary by region. For example, the assessment found that more than 50% of whitebark pine stands sampled in the Modoc region showed evidence of fire impacts. Slaton et al. (2019a), indicated about 25% of 15 compiled plots sampled in the Warner Mountains (in the Modoc region) showed fire impacts, with no impacts in the Cascade-Klamath range (n=26). Slaton et al. (2019b) also compiled fire impact data across the Sierra Nevada (n= 189), with impacts as low as 1-2% in the central Sierra and up to 15% in the eastern slope of the southern Sierra. From these plot data, there appears to be some variation in fire activity in whitebark pine stands across California. Based on an analysis by the writer-editor of fire perimeter records from 1928-2018 and whitebark pine distribution, fire in California has burned only 1.4% of currently known whitebark habitat (FRAP 2020, RSL 2020). These data do not include the small (less than 1 acre), lightning-strike single-tree fires.

In mixed-species stands, fire may be especially important in maintaining whitebark pine. Red fir, mountain hemlock, Sierra white fir (*Abies lowiana* (Gordon & Glend.) A. Murray bis), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.)can all outcompete whitebark pine in California (Burns and Honkala 1990). Unlike whitebark pine, these species are shade tolerant, at least in the seedling and establishment phase (Burns and Honkala 1990), and are able to grow under the canopies of other species. Whitebark pine requires light and does not regenerate under the canopies of other tree species; when other species are removed, whitebark pine can survive. Fire eliminates competitive shade-tolerant trees, and leaves the open habitat preferred for caching whitebark pine seed by Clark's nutcracker in the Rocky Mountains (Keane et al. 2012, Perkins 2015); this dynamic could occur in California populations as well. More research is needed to understand the role of fire in whitebark pine dynamics in California.

Drought

The recent California drought resulted in extreme moisture stress on forest trees and high tree mortality. Drought-related tree mortality was not spatially uniform. The highest mortality was observed in low-elevation yellow pine forests in the southern Sierra Nevada. Much of the mortality was associated with bark beetle attack. It is unclear how high-elevation species, such as whitebark pine, respond to drought events (Cailleret et al. 2019, Fettig et al. 2019, Millar et al. 2012, Stephenson et al. 2019).

Little information on drought effects to California whitebark pine is available. Response of whitebark pine in the Sierra Nevada to the recent drought is currently under investigation. These studies are documenting how environmental and genetic variability contributed to recent patterns of stem growth and proxies of photosynthesis across the range of whitebark pine in the Sierra Nevada (Cailleret et al. 2019, Fettig et al. 2019, Millar et al. 2012, Stephenson et al. 2019).

Air Quality, Nitrogen Deposition and Ozone

The air pollutants of primary ecological concern in the Sierra Nevada include ozone, nitrogen deposition and possibly sulfur deposition (Bytnerowicz et al. 2016, Fenn et al. 2020). Nitrogen deposition, the addition of nitrogen deposited from the air, acts as a fertilizer or eutrophying agent in many wild places. The Sierra Nevada receives nitrogen and other pollutants, particularly in summer months, from the Central Valley via air currents (Fenn et al. 2003, Heard et al. 2014). There is no recent information on rates of nitrogen deposition in high elevation whitebark pine habitat. No air pollution effects studies have focused specifically on whitebark pine, although a recent study using Forest Inventory and Analysis data reports effects of ozone, and nitrogen and sulfur deposition on common high-elevation conifers in the Sierra Nevada (Fenn et al. 2020). Air pollution monitoring studies indicate that the levels of nitrogen deposition and ozone in the Sierra Nevada and the White Mountains may be high enough to impact these ecosystems (Bytnerowicz et al. 2019, Fenn et al. 2020).

Nitrogen and sulfur deposition are difficult to quantify, especially in remote subalpine regions (Fenn et al. 2009). Limited empirical nitrogen deposition data are available for the high-elevation Sierra Nevada (Bytnerowicz et al. 1992, Fenn et al. 2009), in addition to simulation model estimates of atmospheric deposition of nitrogen and sulfur (Fenn et al. 2020). Dry deposition of nitrogen to whitebark and lodgepole pines at Eastern Brook Lakes (Inyo County) in the early 1990s was estimated to be 0.4 kg ha^{-1} yr^{-1} (Bytnerowicz et al. 1992) and wet deposition in high elevation catchments in the Sierra Nevada ranged from 1.2 – 1.5 kg ha^{-1} yr^{-1} (Fenn et al. 2009), yielding estimated annual total nitrogen deposition of 1.6 – 1.9 kg ha^{-1} yr^{-1}. Simulation model estimates of total nitrogen deposition for high-elevation sites in the Sierra Nevada were somewhat higher, ranging from 2.5 – 3.1 kg ha^{-1} yr^{-1} (Bytnerowicz et al. 2019). It should be noted that the modelled deposition estimates also include inputs of organic nitrogen from the atmosphere. In the eastern Sierra Nevada, sulfur deposition in California is lower than nitrogen deposition, with simulated values ranging from 0.3 – 1.5 kg sulfur ha^{-1} yr^{-1} across many sites, with values on the lower end of this range likely more common in remote forests (Fenn et al. 2020). These estimated levels of nitrogen and sulfur deposition expected in most whitebark pine habitats are on the lower end of the range for areas influenced by air pollution emissions in California. Statewide findings from the spatially extensive USFS' Forest Inventory Analysis data base suggest that, in high-elevation forests, at least for some species, nitrogen and sulfur deposition can positively affect growth (Fenn et al. 2020). Further research to clarify what effects these relatively low-level air pollution inputs may have on sensitive ecosystem components is warranted.

The response of coniferous species to ozone varies, but the sensitivity of whitebark pine to ozone is not known, although several pine species are known to be sensitive to ozone (Miller et al. 1983). Seasonal average ozone concentrations were similar at eastern high elevation sites in the Sierra Nevada as concentrations on the western portion of the range (Bytnerowicz et al. 2019). Species such as California red fir and lodgepole pine responded with increased growth to increasing ozone exposures (Fenn et al. 2020), suggesting that in some whitebark pine stands, ozone levels likely occur at biologically relevant concentrations, although the sensitivity of whitebark pine to ozone will require further study.

Ozone and nitrogen deposition have been shown to affect forest health in mid-elevation California forests by increasing susceptibility to fungal diseases (Fenn et al. 1990) and bark beetle attack and beetle-induced mortality (Grulke et al. 2009, Jones et al. 2004). Such interactive effects between air pollution and forest pests and diseases are particularly strong during extended droughts, and could hypothetically also occur in whitebark pine, although such relationships have not been investigated.

In summary, little research has been done on air pollution effects on whitebark pine. Air pollution exposures are thought to be relatively moderate in whitebark pine habitats, but previous studies have found such high-elevation forests and watersheds to be sensitive to even low levels of atmospheric deposition (Fenn et al. 1998). Nonetheless, more research is needed on the direct effects of ozone and nitrogen and sulfur deposition on whitebark pine.

Other Threats

In addition to the threats discussed above, members of the Interagency Conservation Strategy Team identified two other threats to whitebark pine that may be of particular concern in California but for which information is lacking: seed and cone insects, and mistletoe species. Available information on these threats is provided below and the Conservation Action Plan (see the *Conservation Goals and Conservation Actions for Whitebark Pine in California* section) includes actions focused on collecting data on these threat so that we will be able to proactively respond if they become more of a conservation concern.

Seed and Cone Insects

Little is known about insect cone predation and its possible effects on whitebark pine reproduction, although several studies suggest insect seed predation may be significant. Kegley et al. (2001) examined the impact of cone and seed insects at seven study sites selected from the geographical range of whitebark pine in Idaho, Montana, Washington, Oregon, and California. Ten different insect species were found affecting various reproductive structures of whitebark pine, with the fir cone worm (*Dioryctria abietivorella*) and western conifer seed bug (*Leptoglossus occidentalis*) having the greatest impact across most sites. Cone worms infested up to 68% of the total cones collected across all seven study sites, destroying up to 13% of the seed extracted. Seed bugs damaged up to 27% of the seeds. For California in particular, cone worms infested 43% of the cones sampled, destroying 1.6% of the seed extracted. Seed bugs destroyed up to 2.7% of the seed extracted. Impacts to reproduction prior to mature cone and seed production was also documented at the California study site, with 17% of the originally selected study flowers and 3% of first-year conelets aborting. Additional research on the frequency and severity of seed and cone insect predation on whitebark pine throughout California is needed.

Mistletoe Species

Whitebark pine mortality from dwarf mistletoe infestations was noted in 1989. Whitebark pine forests on the northwest slopes of Mt. Shasta killed by dwarf mistletoe were reported by Cooke as early as 1955 (Cooke 1955). Whitebark pine is a primary host for limber pine dwarf mistletoe (*Arceuthobium cyanocarpum*) (Fryer 2020, Hawksworth and Wiens 1996) and an alternate host for lodgepole pine dwarf mistletoe (*A. americanum*) (Agne 2020) and mountain hemlock dwarf mistletoe (*A. tsugense*) (Mathiasen and Daugherty 2009). No dwarf mistletoe has been observed in ongoing NPS monitoring of whitebark pine in Lassen, Yosemite, or Sequoia & Kings Canyon national parks (Jules et al. 2017, Nesmith et al. 2019). Information on the effects of *Arceuthobium* species on whitebark pine in California is lacking and additional studies are needed in order to understand the extent and magnitude of this potential threat.

Current Status and Trends in California

Effective conservation of this species and its habitat is challenging given there are information gaps regarding species status and trends. At a minimum, we need additional information regarding whitebark pine distribution in California, how much genetic variation exists within the species, the demographic trends of populations, and how threats are impacting whitebark pine in California.

According to Kauffman et al. (2019), there are approximately 153,129 hectares (378,390 acres) of whitebark pine in California, with about 72% of whitebark pine occurring on USFS lands (60% Pacific Southwest Region, 12% Intermountain Region; including the Sequoia, Sierra, Inyo, Stanislaus, Eldorado, Tahoe, Lassen, Modoc, Klamath, Shasta-Trinity and Humboldt-Toiyabe National Forests, and the Lake Tahoe Basin Management Unit. A few herbarium sources showed plant collections from the San Bernardino and the Six Rivers National Forests but after additional examination, the specimens were confirmed as another species), about 27% on NPS lands (including the Sequoia, Kings Canyon, Yosemite, and Lassen Volcanic National Parks and Devils Postpile National Monument), and about 1% on other lands. These numbers are estimates of species distribution and based on various data sources from 1976-2019. The Conservation Assessment (Kauffmann et al. 2019) shows a side-by-side comparison of whitebark acreage analysis and mapping over time.

Meyer et al. (2020) reports that approximately 94% of whitebark pine in California occurs in protected areas, including 81% in wilderness, 13% in inventoried and roadless areas (outside of those areas that overlap with wilderness), and 0.5% in research natural areas.

Inventory, mapping, and monitoring efforts to assess the range and extent of the species are under way in California and, numerous inventory, mapping and monitoring, forest health, and research efforts on whitebark pine have occurred in various areas throughout California. Despite these efforts, continued inventory, mapping, and monitoring is needed in order to determine acres by ownership, such as Bureau of Land Management, California State Parks, Department of Defense, University of California Reserve System, and other Federal, State, Tribal, local, and private lands and to understand changes in population health and the effects of threats on whitebark pine in California.

Information regarding the prevalence of white pine blister rust and mountain pine beetle within the range of whitebark pine in California continues to be gathered by scientists, land managers, and interested parties. A preliminary summary of average infection rates of white pine blister rust on whitebark pine in California by sub region is presented in Table 2 and the estimated impact of white pine blister rust on whitebark pine throughout California is shown in Figure 5. A preliminary summary of mountain pine beetle impacts on whitebark pine trees in California, by sub region, is presented in Table 3 below and the estimated impact of mountain pine beetle on whitebark pine in California is shown in Figure 6. A recent study by Meyer et al (2020) indicated that white pine blister rust activity was infrequent to rare in many parts of the state, with greater frequencies of detection in the Cascade-Klamath and Central Sierra Nevada.

Table 2. Initial data on whitebark pine white pine blister rust average infection rates by sub region, in California.

Sub Region	**Average Infection Rate**	**Source**
Cascades Sub region	54% (2012-2014) (Lassen Volcanic National Park (LAVO)) 16% (2015) (LAVO) 11% (2016) (LAVO) 6% (2017) (LAVO) 1.3%	Jules et al. (2017) Smith and Chung-MacCoubrey (2016) Smith (2017) Smith (2018) Maloney (2011)
Warner Mountains	Less than 1% (2012)	Figura (2014, unpublished data)
Sierra Nevada North	24.2%	Maloney (2011)
Sierra Nevada South	Less than 1% (Yosemite and Sequoia & Kings Canyon National Parks) 0.5%	Nesmith et al. (2019), Dudney et al. (2020) Maloney (2011)

Sub Region	Average Infection Rate	Source
Statewide	5.44% 11.7% (2002)	Maloney (2011) Maloney et al. (2002) Kauffmann et al. (2019)[3]
Klamath[s] (includes areas outside of California)	15.18%	USFWS (2018), by analysis unit
Sierra Nevada	2.26%	USFWS (2018), by analysis unit
Basin and Range (includes areas outside of California)	17.96%	USFWS (2018), by analysis unit

[3] The Kauffman et al. (2019) Conservation Assessment (Figure 7 graphs, 429 plots, 2013-2018) also provides a compilation, analysis and maps for both white pine blister rust and mountain pine beetles effects to whitebark pine in California. However, all data sources were not available for the Assessment so number may vary. A preliminary analysis shows 45.1% statewide with 18.7% in the southern Sierra and 85% in the Sierra Cascades.

Table 3. Preliminary information regarding mountain pine beetle impacts to whitebark pine, by Sub region, in California.

Sub Region	**Estimated Mortality Rates**	**Source**
Cascades Sub region	4% 0% 0% 0%	Jules et al. (2017) Smith and Chung-MacCoubrey (2016) Smith (2017) Smith (2018)
Warner Mountains Sub region	5.4% mountain pine beetle mortality or infection (green infested) 38%	Figura (2014) for 2006-2012 Millar et al. 2012
Sierra Nevada South	Less than 1% (Yosemite and Sequoia & Kings Canyon National Parks) 5%	Nesmith et al. (2019) Dudney et al. (2020) Millar et al. 2012
Statewide	9%	RSL (2020), 196 USFS plots, 2014-2018, through crown mortality; Kauffmann et al. (2019)[4]
Statewide	20%	Meyer et al. (2020)
Klamath[s] (includes areas outside of California)	7%	USFWS (2018), by analysis unit
Sierras (includes areas outside of California)	5%	USFWS (2018), by analysis unit

[4] Kaufmann et al. (2019) beetle mortality: 54.5%, Upon compiling data from CNPS, NPS, Maloney et al. 2012, and other sources, 352 plots/samples across the state, 2013-2018; Kaufmann et al. (2019, Figure 6, incidence of mountain pine beetle across five geographic areas): 14% (Sierra-Cascades), 29% (Klamath-Cascades), 60% or greater (Modoc and Sierra Nevada).

<u>**Sub Region**</u>	<u>**Estimated Mortality Rates**</u>	<u>**Source**</u>
Basin and Range (includes areas outside of California)	22%	USFWS (2018), by analysis unit

Other studies [Bentz et al. (2014), Bentz et al. (1991), Safranyik and Linton (1998), Bentz and Mullins (1999)] also report incidence of mountain pine beetle on whitebark pine in California.

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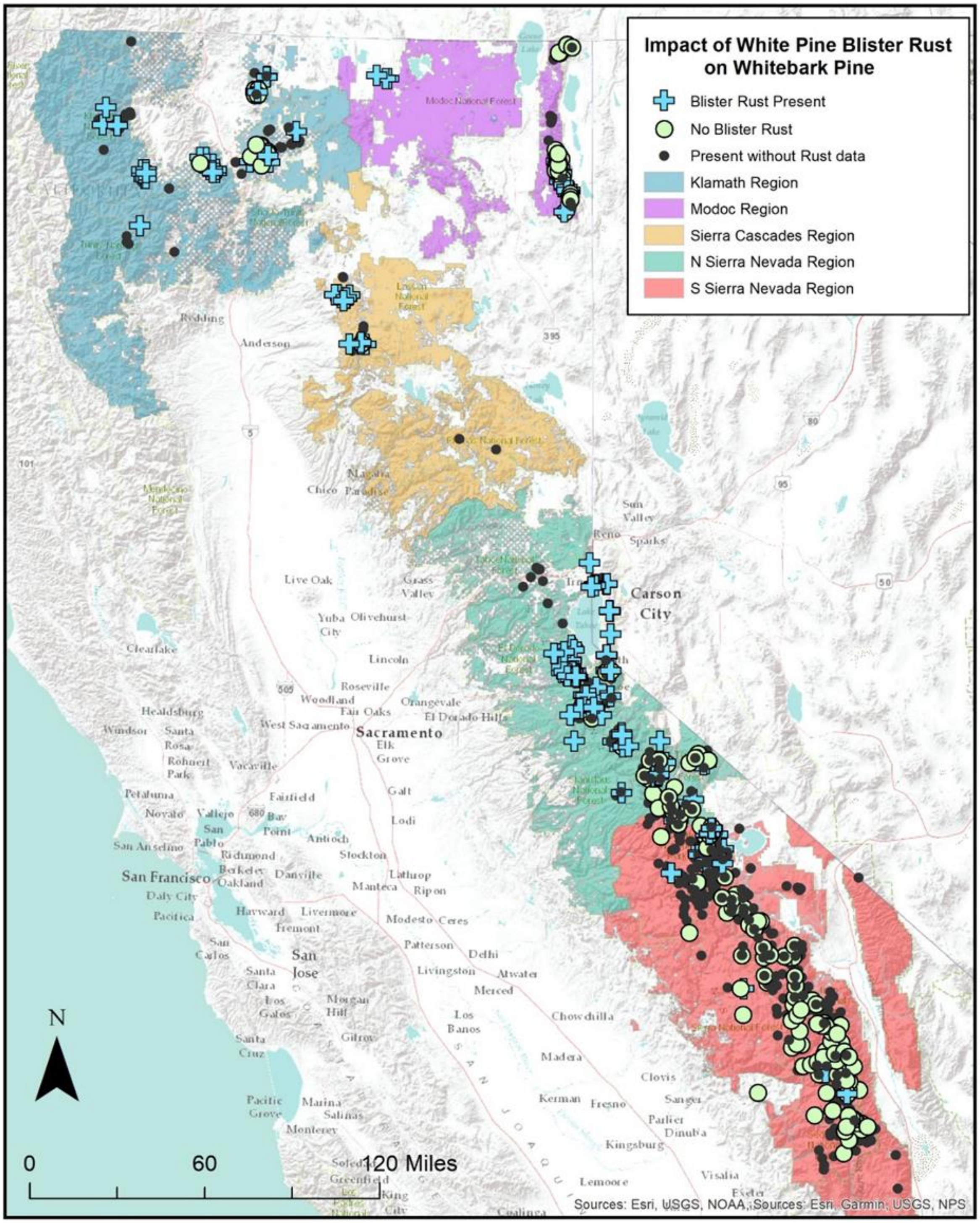

Figure 5. Estimated impact of white pine blister rust on whitebark pine in California. This map is from Kauffmann et al. (2019) and summarizes the most current statewide impacts of white pine blister rust. This information does not represent a coordinated sampling effort but rather a compilation of available sources researchers and land managers were able to share at the time this Strategy was completed.

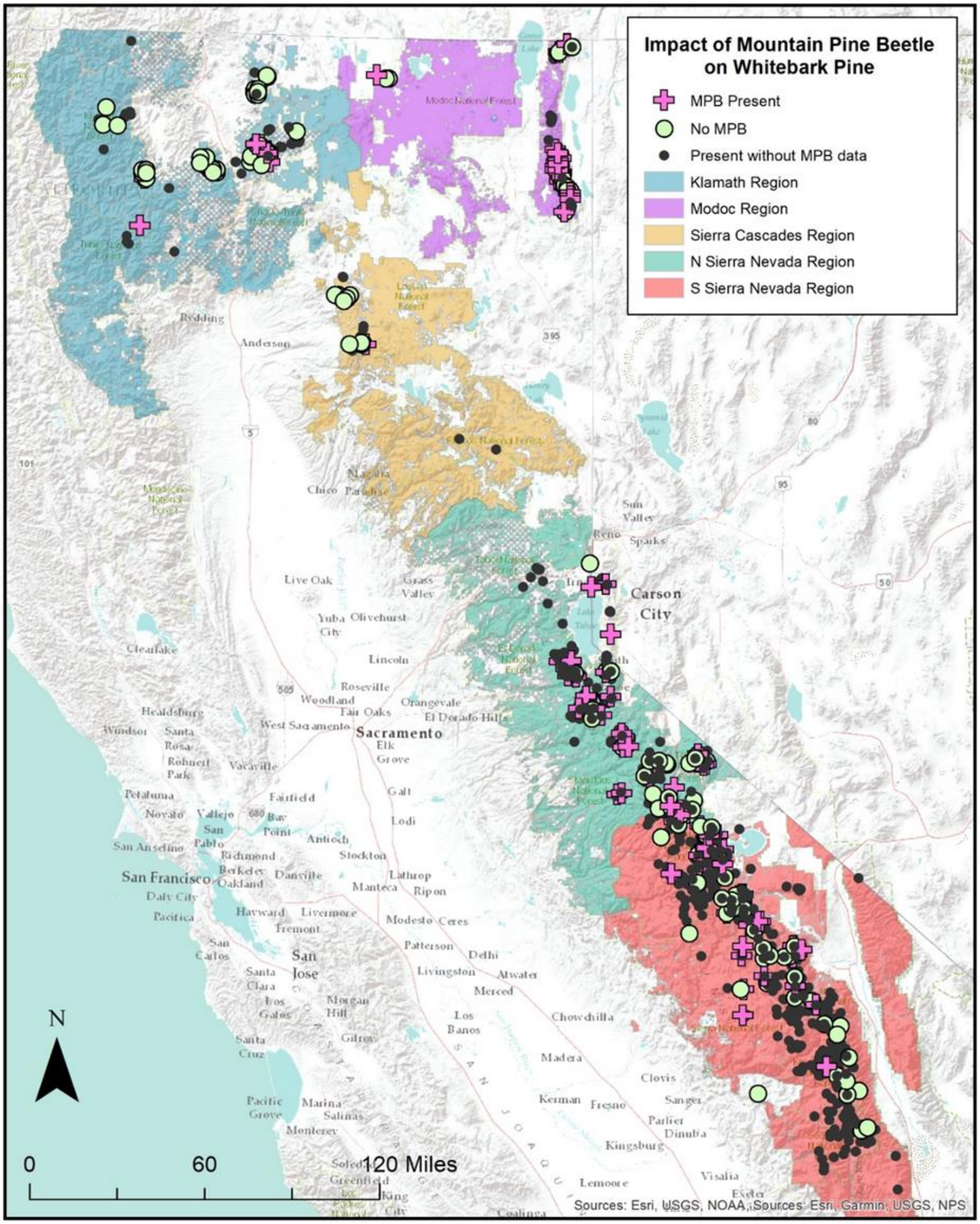

Figure 6. Estimated impact of mountain pine beetle on whitebark pine in California. This map is from Kauffmann et al. (2019) and summarizes the most current statewide impacts of mountain pine beetle in California. This information does not represent a coordinated sampling effort but rather a compilation of available sources researchers and land managers were able to share at the time this Strategy was completed. *MPB = mountain pine beetle.

Sub Region Status

The following is a description of the current, known distribution and status of whitebark pine in each of the sub regions. The text in this subsection is copied directly, with some modification for brevity, from Kauffmann et al. 2019.

California's Klamath Mountains

In California's Klamath Mountains, whitebark pines are true summit trees that survive in only the highest subalpine conditions where they define the limits of timber line between 7,000-9,000 feet (2,000-2,700 meters) on localized mountain tops, or sky islands. Trees are often sparingly scattered across xeric serpentine savannahs or found in meager soil deposits between granite outcrops. In the lower extent of the range, whitebark pines form complex vegetation communities in peripheral areas—including edges of lakes or meadows where they are less likely to be impacted by competition from other species.

Whitebark pine has been surveyed and mapped in the Big Bar Ranger District of the Shasta-Trinity National Forest and the Scott River Ranger District of the Klamath National Forest. Because of the average lower elevation of Klamath Mountain whitebark pine stands compared to the rest of California, there are unusual distribution patterns that emerge. Most whitebark pine grows on south-facing slopes due to competition from firs and hemlocks on north-slopes.

A recent study by Meyer et al. (2020) found that white pine blister rust activity was higher in whitebark pine stands of the Cascade and Klamath, information that is corroborated by other recent surveys in these sub regions (e.g., Maloney et al. 2011, 2012).

California's Cascade Range

In the Cascade Range, whitebark pine occurs in a narrow belt from the north-central part of California from the California-Oregon border east of Interstate-5 southward in small, disjunct populations on the summit of volcanoes to Lassen Volcanic National Park. Across the Cascades they grow at elevations between 7,500-12,000 feet (2,300-3,700 meters). In the lower elevations, trees become quite large (2-4 feet [0.5-1.2 meters] diameter at breast height) and tall (60-80 feet [18-24 meters]). At the upper elevational limits, krummholz individuals approach true alpine on Mount Shasta and extreme subalpine on Mount Lassen.

In California's Cascades, whitebark pines occur on the Shasta-Trinity, Klamath, and Lassen National Forests, with the largest population on Mount Shasta. North of Mount Shasta the species occurs above 7,000 feet (2,133 meters) on the summits of volcanoes and along ridgelines between certain summits. In the Cascades (east of Interstate 5) whitebark occurs between 6,500-8,500 feet (1,980-2,590 meters). The upper elevational limits are restricted by the height of the peaks, except for the flanks of Mount Shasta where the trees range from 7,000-10,000 feet (2,135-3,000 meters) where the species may be expanding upslope. Whitebark pine was reported on Black Butte (a satellite cone of Mt. Shasta) at 6,300 feet (1,920 meters) (Griffin and Critchfield 1976).

In the Lassen area, there are three separate populations of whitebark pine, isolated on the highest peaks and subalpine landscapes where they range from approximately 7,000-10,000 feet (2,133-3,000 meters). One of these populations is located around the Lassen Peak highlands within Lassen Volcanic National Park. Two other populations occur in the Lassen National Forest. One is within the Thousand Lakes Wilderness around Magee and Crater Peaks. This stand occurs along the rim of the ancient Thousand Lakes Volcano which has since eroded away. The other is a scattered stand of approximately 40 trees across 15 acres on the summit of Burney Mountain.

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While white pine blister rust is present at varying degrees across the three population centers (see *California's Klamath Mountains*, above), mortality by mountain pine beetles is generally absent. The lack of mountain pine beetle infestation might be explained by lower cover of lodgepole pine within these populations of whitebark (compared to more arid regions of the West) which could mitigate the vectoring of beetles into the area; whitebark pine often inhabited xeric ridgelines on south slopes rather than the north slopes; mountain pine beetles have not yet "found" these trees in large numbers.

Other conifers, including mountain hemlocks are known to encroach within, or adjacent to, stands of whitebark pine. This pattern is seen in Lassen Volcanic National Park along the Bumpass Hell Trail. In the swales carved out by erosion, decreased snowpack (and early season melting) has led to novel habitat in which hemlocks are rapidly pioneering. This is allowing encroachment into whitebark pine habitat on the ridges above these swales. Another interesting pattern seen in the upper reaches of treeline on Mount Shasta is the ecological release whitebark pines are experiencing. Formerly krummholz trees are now sending out leaders skyward. This is most likely occurring due to decreased snowpack and early season melting.

California's Warner Mountains

In northern California's Great Basin, whitebark pine only occurs in the Warner Mountains. This fault block range runs north to south for approximately 80 miles (180 km). The highest average elevation is in the south, mostly protected within the South Warner Wilderness. North of Highway 299, small stands of whitebark pine persist sporadically, with the largest stands near the Oregon border along Mount Bidwell's extensive ridgeline.

The northern Warner Mountains, between Mount Vida (8,240 feet,[2,512 meters]) north to Mount Bidwell (8,266 feet [2,507 meters]), hosts scattered stands of whitebark pine. Large swaths of conifers, including lodgepole, western white, and whitebark pine, were devastated by mountain pine beetles in the mid- to late-2000s. While many of the larger trees died, sapling and seedling regeneration is vigorous, and the short-term future of pines appears promising. The small populations of whitebark pine in the central Warner Mountains exhibit excellent health on and around Bald Mountain (8,274 feet [2522 meters]) and Cedar Mountain (8,152 feet [2,458 meters]). Stand size is small, and the trees are geographically isolated, thus, bark beetles were not present during the outbreaks between 2005 and 2009.

Large and extensive stands of whitebark pine exist in the southern Warner Mountains. Much of this is protected within the South Warner Wilderness highlighted by Eagle Peak (9,892 feet [3,015 meters]). Across this high elevation escarpment whitebark pine dominates the highest elevations and mixes with lodgepole pine in the mid- to upper elevations. Large pockets of lodgepole pine and smaller pockets of whitebark were killed by mountain pine beetles in the 2005-2009 outbreak. North-facing slopes of the highest elevations are being pioneered by young seedlings due to decreased snowpack. The seedlings began recruiting 20-40 years ago and are rapidly expanding in this novel environment. A smaller, somewhat disjunct stand defines the southern limit of whitebark in the Warner Mountains around Emerson Peak (8,989 feet [2,740 meters). Whitebark pine is common here on north-facing slopes where patterns of beetle mortality and recruitment are similar to that seen in the Northern Warner Mountains near Mount Bidwell. The species is expanding into the lower elevations in grazed areas most likely due to decreased competition from shrubs which are consumed by herds of grazing sheep.

California's Sierra Nevada Mountains

[This section includes descriptions of the status of both the Sierra Nevada North and Sierra Nevada South sub regions]

The northern National Forests of the Sierra Nevada include the Stanislaus, Eldorado, Tahoe, and Humboldt-Toiyabe National Forests, and Lake Tahoe Basin Management Unit. From the high country of Humboldt-Toiyabe National Forest, whitebark pine extends northwards to Freel Peak with patchy occurrences north and west of Lake Tahoe, becoming more disjunct to the north and at lower elevations. In the northern portion of the Sierra Nevada, whitebark pine is presumed present on approximately 47,000 acres across an elevation range of 7,200 to 11,400 feet (2,200 - 3,500 meters) with an average elevation of 9,500 feet (2,900 meters).

The southern National Forests of the Sierra Nevada include the Sequoia, Sierra, and Inyo National Forests; Sequoia & Kings Canyon National Parks, and Yosemite National Park also occur in the southern Sierra Nevada. The southernmost whitebark pines within California are found in small, disjunct populations beginning around the Coyote Peaks of Sequoia National Forest and continuing north in scattered patches on mountain tops. Around the Kings Kern Divide, whitebark pine occurs continuously across the peaks and ridges of the Sierra crest through Yosemite National Park. The largest stands of whitebark pine in California exist in the southern portion of the Sierra Nevada where average elevation is much higher than other parts of the state. Whitebark pine is estimated to be present on 107,808 hectares (266,400 acres). This acreage spans elevations ranging from 7,150 to 13,500 feet (2,200 - 4,120 meters) with an average elevation of 10,430 feet (3,180 meters).

Whitebark pine blister rust has been documented to occur at low frequencies (Maloney et al. 2011, Nesmith et al. 2019, Dudney et al. 2020), although Meyer et al. (2020) plot and aerial detection survey data failed to detect this introduced pathogen in the Southern Sierra West portion of their study area. During a statewide survey, Meyer et al. (2020) found 0.9-6.7% of WBP was attacked by mountain pine beetle, with the highest percentage in the Warner Mountains.

Species Conservation and Management

In 1991, whitebark pine was petitioned for Endangered Species Act listing but the USFWS determined that listing was not warranted. In 2008, USFWS received a petition to list whitebark pine as endangered throughout its range and to designate critical habitat. In 2011, the USFWS published a 12-month finding that determined the species warrants protection under the Endangered Species Act, but adding the species to the Federal List of Endangered and Threatened Wildlife and Plants was precluded by the need to address other listing actions of a higher priority. In 2011 and 2013, the International Union for Conservation of Nature assessed whitebark pine as Endangered. In 2018, the USFWS developed a Species Status Assessment and shared for agency review.

Managers face multiple challenges related to conservation and management of whitebark pine in California. Given the broad suite of threats and efforts to conserve whitebark pine, we need to acknowledge complex dynamics when developing conservation and restoration plans within National Forests, National Parks, and other ownerships across California. Ultimately, addressing threats will occur at the local level, and therefore, conservation and management activities may best serve populations of whitebark pine when local stressors are acknowledged (Diggins et al. 2010). The presence and severity of these threats may vary with the differences in climate and topography across the sub regions in California. Regional effectiveness monitoring and research of forest management actions (e.g., Retzlaff et al. 2019 *in* Meyer et al. 2020) and focused monitoring in stands with significant mortality (e.g., Meyer et al. 2016 *in* Meyer et al. 2020) will also aid in the development of effective restoration and adaptation approaches in California's whitebark pine forest ecosystems.

The history of whitebark pine site-specific protection and activities in California varies by landowner and agency. Appendix 2 (Laws, Regulations and Policies Relating to Whitebark Pine in California) provides a selected description of land management agency processes that guide whitebark pine conservation on NPS and USFS lands, including the Wilderness Act of 1964 and Forest Plans. A summary of whitebark pine management and conservation on these lands, as well as at a broader regional and nationwide level, is presented below.

Management on National Park Service Lands in California

In Lassen Volcanic National Park, Yosemite National Park and Sequoia & Kings Canyon National Parks, whitebark pine is inventoried, and monitored on a three to four year cycle as part of the Sierra Nevada and Klamath Inventory and Monitoring Networks (McKinney et al. 2012). Whitebark pine is assessed for white pine blister rust and other insect and pathogen damage each year in permanent plots. A separate survey of white pine blister rust among all white pine species in Sequoia & Kings Canyon National Parks was conducted in the late 1990's (Duriscoe and Duriscoe 2002) and recently resurveyed (Dudney et al. 2020). A status assessment of all five-needle pine species within Sequoia & Kings Canyon National Parks was also completed in 2013 (Eschtruth et al. 2013) as part of the Park's Natural Resource Condition Assessment. One important management consideration is that within the southern Sierra national parks, all whitebark pine occurs within Designated Wilderness. The Lassen Volcanic National Park is also working on a management strategy and is pursuing funding to support broader understanding of the genetic makeup of satellite populations found in northeastern California. Additional inventory and monitoring of whitebark pine may occur in association with site-specific management activities within each park.

Management on US Forest Service Lands in California

Forest plans, sensitive species status (1982 planning rule), species of conservation concern status (2012 planning rule), and other existing plans (Sierra Nevada Forest Plan Amendment, Northwest Forest Plan, Columbia Basin Plan, etc.) provide direction to protect, conserve and manage whitebark pine areas on USFS lands in California. In 2013, the USFS Pacific Southwest Region added whitebark pine to the Regional Forester's sensitive plant species list as part of an amendment (partial list update). The forests analyze this species as part of their National Environmental Policy Act review and analysis. Whitebark pine is also on the Regional Forester's sensitive plant species list for the USFS Intermountain Region.

The management of National Forests within the Sierra Nevada is primarily governed by the 2004 Sierra Nevada Forest Plan Amendment. However, in 2016, the Lake Tahoe Basin Management Unit Forest Plan was revised under the 1982 planning rule, and in 2019, the Inyo National Forest revised their forest plan under the 2012 planning rule. Within forest plans, certain Special Areas are identified, with specific direction, which can be important for whitebark pine management. These areas include Wilderness, Wild and Scenic Rivers, Pacific Crest Trail, Research Natural Areas, and Botanical Special Areas. Current uses and activities occurring in whitebark habitat on USFS lands in California include recreation (over-snow vehicle use, ski areas, backcountry skiing, hiking trails, camping, and pack stock use), grazing, mining, fire suppression and fuels reduction, and special uses (utilities and other special uses).

Other Lands in California

Suitable habitat has been identified on Bureau of Land Management lands in California in the Warner Mountains (Applegate Field Office), Monitor Pass area (Motherlode and Bishop Field Offices), Cowtrack Mountain (Bishop Field Office), and Bodie Hills (Bishop Field Office). However, no confirmed whitebark pine populations occur on these lands in California.

Whitebark pine is also found on Tribal lands and University of California Natural Reserve (Lassen Field Station). There are some areas where suitable habitat for whitebark pine may occur on California State Park lands and perhaps other areas under other ownership in California. However, we are not aware of additional information for these lands.

Rangewide Conservation Efforts

Plans, Strategies and Guiding Documents

Due to the broad distribution of whitebark pine in the United States, management of this species falls under numerous jurisdictions encompassing local and regional ecological, climatic, and management conditions and needs. Several management and restoration plans have been developed for specific regions or jurisdictions to address the task of conserving and restoring this widespread, long-lived species; the plans will vary in how they apply to California. In addition, some plans overlap in their respective regions of concern, and can often be duplicative in their guidance. Conversely, some areas within the range of whitebark pine do not have a specific management plan for whitebark pine; this was the case for California prior to the development of this Strategy. In addition to these species-specific management and restoration plans, management actions generally follow established forest or vegetation management plans developed under the National Forest Management Act of 1976 or 2012 or other similar policies (e.g., USFS forest plans, NPS vegetation management plans).

The following are some of the most prominent guidance documents related to whitebark pine published or in development to-date. These documents provide useful context for whitebark pine conservation in California. However, it should be noted that only a small portion of the whitebark pine's range is in California, and it is at the edge of the species' range. As described in the sections above, whitebark pine in California has unique elements. Conservation of whitebark pine in California will therefore need to consider these unique elements and utilize local knowledge in order to be successful.

National Whitebark Pine Restoration Plan (in development; anticipated completion in 2021 or early 2022)

This comprehensive and consensus-based strategic restoration plan is currently being developed to address the significant logistical and financial constraints inherent to whitebark pine restoration activities. This collaborative effort is being led by the USFS National Office, the Whitebark Pine Ecosystem Foundation, and American Forests, with participation and input solicited from all vested agencies, non-governmental organizations, tribes, and individuals. This plan will designate priority core areas within broader administrative units (e.g., National Forests, National Parks, etc.), to comprise of 20-30% of the total whitebark pine distribution within each unit. Specific restoration protocols will then be developed for each priority core area, allowing for flexibility to accommodate specific physical conditions, resource needs and constraints inherent to each.

For example, several National Parks in California have already nominated core areas covering a total of 53,355 hectares (131,844 acres) in Sequoia & Kings Canyon National Parks, with an additional 640,363 hectares (158,304 acres) of core areas nominated in Yosemite National Park. The core areas include 72% and 50% of the current whitebark pine habitat within Sequoia and Kings Canyon National Park and Yosemite National Park, respectively, and can serve as focal points for conservation for whitebark pine in the southern Sierra Nevada. Additional core areas are in the process of being identified on other National Parks, as well as on Bureau of Land Management (BLM) and USFS lands.

U.S. Forest Service Restoring Whitebark Pine Ecosystems in the Face of Climate Change (Keane et al. 2017)

This is a companion document for the earlier-published Range-wide Strategy for Whitebark Pine (Keane et al. 2012) outlined below, which did not address climate change effects on whitebark pine communities and restoration strategies. This document utilizes the same concepts described in the Range-wide Strategy, and applies those concepts to modeled future climate-impacted scenarios. Guidelines for developing adaptation strategies for restoration were developed from a comprehensive literature review, as well as a spatially explicit, ecological process model that simulated future climate change, management, and fire behavior and treatment scenarios. Strategies developed in this document are intended to be implemented at fine scales (e.g., stand-level) of management.

Conservation and Management of Whitebark Pine Ecosystems on Bureau of Land Management Lands in the Western United States (Perkins et al. 2016)

This document is adapted and developed from the Range-wide Strategy (Keane et al. 2012), the Whitebark Pine Strategy for the Greater Yellowstone Area (Greater Yellowstone Coordinating Committee Whitebark Pine Subcommittee 2011), and the USFS Pacific Northwest Region Strategy (Aubry et al. 2008), and provides general guidance for whitebark pine restoration on BLM-administered lands. This plan acknowledges and accounts for the uniqueness of whitebark pine communities that occur on BLM lands, which often occur on the periphery of major core areas, on the margins of the species' range, at lower elevations, and in isolated stands.

U.S. Forest Service Range-wide Restoration Strategy for Whitebark Pine (Keane et al. 2012)

This reference document provides a top-down, multi-scale approach for prioritizing, designing, implementing, and assessing whitebark pine restoration strategies across its range in the U.S. and Canada. The goal of this guide is to promote inter- and intra-agency coordination to improve efficiency of whitebark pine restoration activities. Four main principles are applied to each spatial scale under consideration: (1) promote white pine blister rust resistance; (2) conserve genetic diversity; (3) save seed sources; and (4) employ restoration treatments. Strategic plans are presented for broad-scale strategies, and real-world examples are provided for finer scale situations (e.g., tree or stand level).

Actions

Described below are the general conservation actions occurring in portions of the range outside of California; some of the actions are similar and/or applicable to California, as described in the Strategy; others are not as pertinent in California and are not addressed in detail in this strategy. Throughout other portions of the range, most current management and research focuses on producing whitebark pine with genetic resistance to white pine blister rust, as well as implementing mechanical treatments and prescribed fire as conservation tools. Additional research investigates natural regeneration and silvicultural treatments, such as appropriate site selection and preparation, pruning, and thinning in order to protect high-value genetic resources, increase reproduction, reduce white pine blister rust damage, and increase stand volume (Zeglen et al. 2010). Conservation measures for whitebark pine can generally be categorized as either protection of existing healthy trees and stands or restoration of damaged, unhealthy, or extirpated trees and stands. Inventory, monitoring, and mapping of whitebark pine stands are critical for assessing the current status and implementing conservation activities.

<u>Protection</u>

Protection measures can be employed at various scales, including individual tree level, stand-level, and sub-population and population scales. Protection of important individual trees and healthy stands/populations at all scales is important across the range of whitebark pine, including in California. Protection is much broader than protecting "plus" trees – those with demonstrated resistance to white pine blister rust, and this strategy for California will further define and look at these factors.

At the individual tree scale, protection measures are usually employed to guard critical sources of rust-resistant genotypes (i.e., plus trees) from the threats of white pine blister rust, mountain pine beetles, seed predation, and wildfire. While no measures are known to protect against white pine blister rust infection, infected branches (flagging) can be pruned from the tree to delay or prevent further infection or mortality of the tree. High-value trees can be protected from mountain pine beetle attack by application of insecticides or anti-aggregation pheromones. Carbaryl is a highly effective insecticide that is sometimes used for this purpose, but requires either locations with vehicle access, or pack animals to access more difficult to reach locations. Verbenone can offer short-term effectiveness for preventing mass beetle attacks on and around high-value trees, and has multiple delivery methods for both tree and stand level applications. However, its effectiveness can be overwhelmed during extreme epidemics (Progar 2005, Progar et al. 2013).

Cones slated for collection from plus trees are routinely protected from seed predation by wrapping cone bundles in wire mesh (hardware cloth) cages early in the growing season. These must be installed by certified tree climbers, or if feasible, by a boom and bucket truck, and thus this activity can be costly and time-consuming, yet it remains highly effective and the only proven method to protect valuable natural sources of rust-resistant seed. Protecting individual trees from wildfire involves removal of ladder fuels from a specified distance around the tree (daylighting). In the past, attempts to protect individual trees by wrapping them in fire shelter material proved ineffective (Keane and Parsons 2010, Keane et al. 2012). 47

Due to the inherent challenges involved in utilizing carbaryl insecticide, it has not been widely used. Verbenone has been used much more extensively by the USFS, BLM, and NPS due to its relative ease of use and ability to be deployed in wilderness areas (if allowed by local management guidelines). Most plus trees are treated with verbenone to protect the important cone crops from loss to mountain pine beetles.

See the Conservation Action Plan (Appendix 1) for examples of actions related to protection at sub-population and population scales.

Restoration

Restoration strategies are multi-faceted but employed consistently throughout other portions of the species' range and across most management agencies. These strategies are broadly defined by three actions: propagation, screening and planting of seedlings from genetically rust-resistant parent trees; mechanical treatments (e.g., daylighting (cutting of shade-tolerant competing species in a circle around whitebark pine trees), thinning) of competing conifers in seral mixed-species stands; and using prescribed fire to mimic natural fire processes.

See the Conservation Action Plan (Appendix 1) for examples of priority actions related to restoration in California; the elements of restoration will be further defined during the implementation phase.

Propagation, Screening and Planting

In other portions of the species range where white pine blister rust infection rates are high, ensuring future generations of whitebark pine are genetically resistant to white pine blister rust is the most critical action for achieving long-term recovery in those areas (Mahalovich and Dickerson 2004, Perkins et al. 2016). Genetic management of white pine blister rust is actively conducted for whitebark pine, including the USFS white pine blister rust resistance screening programs (Mahalovich 2016, Sniezko 2016). Seeds and pollen sourced from "plus" trees (those with presumed (i.e., phenotypic) rust resistance) or "elite" trees (those with proven (i.e., genotypic) rust resistance) are used for screening and selective breeding for white pine blister rust resistance (not immunity), molecular genetics studies, assessing levels of inbreeding, growing compatible rootstock for grafting in seed orchards, clone banking and gene conservation, and identifying genetic macro-refugium (Mahalovich 2016, Perkins et al. 2016, Sniezko 2016).

Eventually, the long-term goal is to establish whitebark pine seed orchards across the spectrum of whitebark pine habitat to provide reliable and accessible sources of genetically-resistant seed (Mahalovich 2017). Scions (e.g., living branches) taken from trees with proven genetic resistance to white pine blister rust are grafted onto established root stocks, enabling them to develop the capability to produce cones much sooner than the time required for outplanted seedlings to reach reproductive maturity (approximately 60 years). Four seed orchards have recently been established or are currently being developed in whitebark pine habitat representing distinct breeding zones, with current overall establishment level at approximately 60% (Mahalovich 2017). These seed orchards are located on the Custer-Gallatin, Helena-Lewis and Clark, and Lolo National Forests in Montana, and the Nez Perce-Clearwater National Forest in Idaho, with another proposed by the Salish Kootenai Tribe on the Flathead Indian Reservation in Montana. Another seed orchard is in the early stages of development at the Dorena Genetic Resource Center in western Oregon, while another has been established at the Coeur d'Alene Nursery in Idaho to develop full-sibling crosses to monitor changes in behavior of white pine blister rust. Once established, these orchards will reduce the need for more costly and time-intensive field-based cone collections, and provide a reliable and validated source of genetically resistant seed stock.

In California, development of a summary of available restoration options, ongoing restoration efforts to minimize rust resistance, and lessons learned (e.g., effectiveness monitoring) has been identified as an Objective for this Strategy. This includes the development of a rust resistance screening program, by sub region, including but not limited to: identifying cone collection of plus trees, nursery sowing, common garden studies, and seed source guidelines, as needed. An important issue that is generally overlooked in regions where active whitebark pine restoration is occurring, is that any seed sourcing strategies in California should include local, diverse, with a percentage rust resistant seed sources (the amount deployed will depend on the level of "WBPR risk" associated with each population). Whitebark pine in California is genetically distinct from other regions and that unique genetic diversity needs to be maintained when designing restoration strategies. Specific associated actions can be found in Appendix 1.

Mechanical Treatment

Silvicultural practices such as mechanical cutting and thinning are frequently employed to treat existing stands of whitebark pine where evidence of insect, disease, and advanced succession is apparent, in order to restore them to an early-successional stage and improve their chances of surviving fire. Most are designed to mimic non-lethal mixed-severity fire (Keane and Arno 2001), reduce or eliminate competition from other conifer species such as subalpine fir, and to increase regeneration space for potentially rust-resistant seedlings.

Approaches include creating "nutcracker" openings (i.e., caching habitat) wherein all trees except healthy whitebark pines are cut within a 1-5 acre opening (Keane and Arno 2001, Keane and Parsons 2010); thinning of all non-whitebark trees below a certain diameter (Chew 1990); and fuel enhancement treatments where other competing trees are directionally felled to increase and distribute fuel loadings to better carry subsequent prescribed fire (Keane and Arno 2001, Keane and Parsons 2010). Thinning and prescribed burning of whitebark pine stands on suitable sites may result in increased vigor (e.g., growth rate) of remaining sapling to mature-class trees (Keane et al. 2007, Retzlaff et al. 2018), and reduce the likelihood of mountain pine beetle attacks (Keane et al. 2012).

Mechanical treatments to achieve protection and restoration have also been identified as a priority in California (e.g., see Appendix 1).

Prescribed Fire

Whitebark pine is a fire-adapted species that gains a competitive advantage when its main competitors (e.g. subalpine fir, Englemann spruce, or mountain hemlock) are reduced or eliminated after fire (Arno 1986, Arno 2001). Prescribed fire can therefore be used to create openings for Clark's nutcracker cache habitat, prepare sites for planting, and reduce competition (Arno 2001, Perkins et al. 2016). There are three types of prescribed fire that can be used to achieve varying conservation objectives. Low-severity ground fires retain the overstory but reduce surface fuel loadings and competing conifer seedlings and saplings, while enhancing the seed bed by exposing soil and helping to cycle nutrients back into the soil. Mixed-severity prescribed fire can create openings by reducing the amount and density of over-grown stands, and reducing or eliminating competing species that are less adapted to fire. High-severity prescribed fires, though possible, are generally not implemented due to the high risk involved in managing this type of fire (Perkins et al. 2016). However, prescribed fire that mimics high-severity stand replacing fires, particularly when preceded by fuel enhancement cuttings, can be useful for creating abundant Clark's nutcracker caching habitat (Keane and Parsons 2010). Successive low or medium-severity fires can also achieve similar results of a high-severity fire while reducing the overall management risk.

In California, more research is needed to understand the role of fire in whitebark pine dynamics. Evaluating fuel treatment methods, including prescribed fire, to achieve protection and restoration has been identified as a priority in California (e.g., see Appendix 1).

Proactive Intervention

As described above, most restoration approaches target stands that have already experienced high impacts from the primary stressors. However, in stands where white pine blister rust has yet to take a strong hold, proactive management may offer a means to prepare and protect existing healthy stands from impending impacts of white pine blister rust and other stressors. This approach is premised on the concept of actively facilitating evolutionary change in whitebark pine to improve its resiliency on the landscape in the persistent presence of white pine blister rust (Schoettle and Sniezko 2007). Strategies to prepare healthy stands of whitebark pine include managing stand composition, diversifying age class structures, increasing tree vigor, promoting natural regeneration, and introducing rust-resistant stock onto the landscape in existing healthy stands, utilizing some of the techniques described above (thinning, burning, etc.) (Schoettle and Sniezko 2007). Healthy stands of whitebark pine are more responsive to management actions, thereby increasing the available management options in a proactive approach (Keane and Schoettle 2011). This proactive approach has been implemented recently in the southern Rocky Mountains within the range of other high-elevation five-needled pines that are also susceptible to white pine blister rust (Keane and Schoettle 2011). More recently, a framework has been developed to help guide implementation of the National Restoration Strategy in remaining healthy stands of whitebark pine, particularly in the southern and southwestern portions of its range (Schoettle et al. 2018). As whitebark pine has declined precipitously throughout much of its range, it will be important to implement proactive intervention in remaining healthy stands to retain the resiliency of the species.

In California, proactive intervention has not been identified as a high priority action, although it may be useful in specific, local situations. Site-specific plans should be developed by sub regional working groups to develop a framework to capture local knowledge. Local knowledge will be used to identify triggers and thresholds to document when proactive intervention is necessary, along with documenting lessons learned (e.g., effectiveness monitoring).

Challenges to Restoration

Wilderness

A separate, important challenge to actively restoring whitebark pine is the fact that a significant portion of its range in the U.S. lies within designated and de facto wilderness areas (USFWS 2011). Currently, the Wilderness Act of 1964 (16 U.S.C. 1131 1136) generally requires additional justification for many direct restoration activities to occur in designated or recommended wilderness areas (GYCC 2015). However, section 4(c) of the Wilderness Act (the minimum requirement tool) may be utilized to accomplish certain management objectives such as prescribed fire, planting seedlings or application of verbenone, while still maintaining the wilderness character (GYCC 2011, GYCC 2015, USFWS 2018). How the Wilderness Act is implemented can vary between agencies, regions, or even between species.

Limited Access

In concert with more restricted management options, the remote and challenging terrain in which whitebark pine frequently exists presents numerous logistical challenges for accessing sites for restoration. In non-wilderness roadless areas, much effort and/or costs may be required to transport equipment, seedlings, and personnel to work sites, whether by foot, livestock, or aerial means. Seasonal access to many sites is likely to be brief due to abbreviated snow-free conditions at high elevations, which often coincides with summer wildfire seasons. As the level of accessibility to whitebark pine stands decreases, so does the number of available restoration options (Keane et al. 2012), meaning fewer options to treat impacted stands in more difficult-to-access sites.

<u>Conservation Goals and Conservation Actions for Whitebark Pine in California</u>

This Conservation Strategy identifies the following five goals for whitebark pine conservation in California. These conservation goals are designed to conserve the habitat and ecosystems upon which whitebark pine depend to provide for healthy populations of whitebark pine across its range in California.

1) Conserve and protect the existing diversity of whitebark pine in California's sub regions,
2) Reduce stressors and threats,
3) Continue to build a strong scientific framework of science-based actions,
4) Identify research needs and data gaps and fund prioritized research to provide for science-based conservation and management of whitebark pine in California, and
5) Coordinate, communicate and educate.

In order to meet these five goals, the Strategy identifies the following specific, measurable conservation objectives and associated categories of conservation actions ('Conservation Categories') that will be needed to achieve the objectives. The Conservation Categories serve to group together discrete actions detailed in the Conservation Action Plan table (Appendix 1). In turn, the Conservation Action Plan table details specific conservation actions for each Conservation Category. Accomplishment of these actions will contribute to achieving the Goals described above. The Conservation Action Plan table also serves as a tracking tool to document the implementation progress of conservation actions. This table is considered a "living" document, and will be updated periodically as existing actions are undertaken and new actions are identified.

The Objectives and associated Conservation Categories are listed below. The goals that each objective will help meet are also identified.

Objective 1. Establish an inventory and monitoring network and strategy, by sub region, to target and fund work in the highest priority areas; (Goals 1, 3, 4)

- <u>Conservation Category</u>: **Develop a baseline map of whitebark pine in California.** This is necessary to provide required baseline information for identification of information gaps and to geographically focus needed conservation actions.
- <u>Conservation Category</u>: **Inventory and document current condition of whitebark pine across California.** This is necessary to identify and prioritize needed conservation actions, including identifying where restoration is needed and where conservation of healthy populations can be a focus.

- **<u>Conservation Category</u>: Monitor whitebark pine health for current and developing threats in California.** This is necessary to track success of conservation efforts and to enable us to address emerging threats early.

Objective 2. Better understand whitebark pine genetics in California and develop a gene conservation plan, with cost estimates, for the purpose of biodiversity and long-term cone storage (including protocols, repositories, seed testing, cone collection list, etc.). (Goals 1, 3, 4)

- **<u>Conservation Category:</u> Document patterns of genetic diversity in California.** This is necessary to understand where genetics are unique and may be in need of gene conservation.

Objective 3. Develop a summary of current rust resistance and restoration efforts, restoration options, and lessons learned/effectiveness monitoring; this can include development of a rust resistance screening program, by sub region, including but not limited to: identify plus trees and continue cone collection, nursery sowing, common garden studies, seed transfer zones, as needed. (Goals 1, 2, 3)

- **<u>Conservation Category</u>: Document patterns of white pine blister rust resistance.** This is necessary to understand monitoring and screening program needs.

Objective 4. Continue to support and fund science to inform management, including prioritizing needs, and consider developing best management practices guide. (Goals 3, 4).

- **<u>Conservation Category</u>: Protect whitebark pine.** This is necessary to identify and maintain healthy populations where they exist.

- **<u>Conservation Category</u>: Restore whitebark pine.** This is necessary to increase healthy populations.

Objective 5. Develop a vision to "protect the best, restore the rest," by identifying locations of the biggest/best, unique, high quality whitebark areas, clusters of rare elements, genetically unique populations, and/or habitat available for acquisition. As declines happen and as needed, develop plans and associated restoration effectiveness monitoring to restore whitebark pine, by sub region. (Goals 1, 2, 3)

- **<u>Conservation Category</u>: Protect Whitebark Pine.** This is necessary to maintain healthy populations where they exist.

- **<u>Conservation Category</u>: Restore Whitebark Pine.** This is necessary to increase healthy populations.

Objective 6. Develop, coordinate, and implement education and outreach by developing communication tools, prioritizing and coordinating education and outreach efforts, and developing public outreach plan(s) for support and participation. (Goal 5)

- **Conservation Category: Education, Outreach and Coordination.** It is necessary to facilitate education, outreach, and coordination opportunities in order to encourage collaboration among land managers and species experts when proposing or implementing management and conservation actions in whitebark pine habitat, and educate public stakeholders on the value of the species, the need for conservation, and possible ways the public can contribute to whitebark pine conservation.

Next Steps: Strategy Implementation

Implementation of this strategy is focused on accomplishment of the Conservation Action Plan detailed in Appendix 1. The conservation actions within the Conservation Action Plan were identified as priority needs by species experts during the development of this Strategy.

The effective implementation of this Strategy will require involvement of and coordination among all parties interested in whitebark pine conservation in California, including Federal and State agencies, university and other researchers, and other interested partners. The Core Team will work with the Experts Team to broadly reach out to interested partners to form an Implementation Team. This Team will be an ad hoc group, open to anyone interested in whitebark pine conservation in California, and will be led by an Implementation Committee of representatives from the signatory agencies.

The Implementation Team will meet annually to assess implementation status of, and update as needed, the Conservation Action Plan. In addition, this annual meeting will provide focused time for participants to identify additional needs, share data and other information, and coordinate among partners. If needed, the Implementation Committee will meet separately to review progress to date, discuss new actions items, and prioritize and coordinate future work.

This Strategy also recognizes that much of the work needed for whitebark pine conservation in California will be accomplished at the sub regional level. The Implementation Team will strive to establish Sub regional Working Groups where there is partner interest and need. The purpose of the sub regional working groups would be coordination within the sub region, including data management development, information sharing, site visits at the local level, and working together on site-specific plans, as needed.

Additional coordination among the Implementation Team, Implementation Committee, or Sub Regional Working Groups will occur as needed to address more urgent conservation actions or specific coordination topics such as inventory, mapping and monitoring, gene conservation for long-term storage, white pine blister rust work, site-specific management plan development, and/or field visits.

Implementation of the Strategy will occur within an adaptive management framework in which the Conservation Strategy and Conservation Actions are revised as needed based on science and newly acquired information. This Strategy and its associated attachments are living documents, and the overall effort will need to adapt to funding constraints, natural events, and through further research, implementation of the Strategy, and monitoring of results. Regular updates of the Conservation Action Plan will serve as the primary tracking tool to document the implementation progress of conservation actions, and will be accomplished primarily during the annual meeting of the Implementation Team. In addition, if needed, periodic status reports will be developed by the Implementation Team, to provide the Strategy signatories with more detailed information on the status and results of the various implemented actions.

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Appendix 1: Whitebark Pine Conservation Action Plan

This Appendix to the Interagency Conservation Strategy for *Pinus albicaulis* (Whitebark Pine) in California (Strategy) details the conservation actions identified by species experts during the development of the Strategy as priority needs, as outlined in the Conservation Action Plan (CAP) Table, below. Actions are presented by Conservation Category, as outlined in the Strategy. This CAP table also serves as a tracking tool to document the implementation progress of conservation actions. This table is considered a "living" document, and will be updated periodically as described in the Conservation Strategy. 70

Table 1. Conservation Action Plan for Whitebark Pine in California.

Conservation Category/Action	Additional Action Description (if needed)
Develop a Baseline Map of Whitebark Pine in California	
Develop one consolidated map of whitebark pine occurrences in California	
Inventory the Current Condition of Whitebark Pine Across California	
Conduct a comprehensive review of currently available spatial layers	Highlight/categorize outlier populations in particular, treeline delineations.
Survey additional habitat in California that likely contains occurrences of whitebark pine; some of this work could happen as part of sub regional working groups	Include the Middle Creek in White Mountains, Bodie Mountains, Ball Mountain, Goosenest; Devil's Postpile National Monument; and Plumas NF. Evaluate the need for surveys on Bureau of Land Management lands on Applegate, Bishop, Motherlode Field Office areas.
Validate (through surveys) areas in California where whitebark pine is assumed to be absent	
Repeat photo surveys of whitebark pine sites for which historical photos are available	
Identify existing climate vulnerability modeling of the California whitebark pine range. If no appropriate modeling exists, conduct climate vulnerability modeling.	Include assessment of the Marcus Warwell and Gerry Rehfeldt bioclimatic model. Consider inclusion of more comprehensive biological (population dynamics, genetics, etc.) and environmental (soil, climate, geography, topography, etc.) parameters.
Continue inventory, mapping and monitoring discussions within the Implementation Team and as part of sub regional working groups.	
Evaluate the potential for using citizen science platforms to validate the range of whitebark pine in California	For example: iNaturalist

Conservation Category/Action	Additional Action Description (if needed)
Monitor Whitebark Pine Health for Current and Developing Threats	
Create a subcommittee to address monitoring tasks	Several ongoing or historical monitoring efforts exist across agencies; however, a coordinated approach to facilitate data sharing, analyses, and consistency among sampling methods is needed.
Solidify coordination and establish subcommittee between land management agencies (e.g., NPS, USFS) and interested parties with regards to monitoring approaches and efforts to establish state-wide monitoring plots with a common set of goals and data-collection protocols.	Similar to Greater Yellowstone Coordinating Committee's Whitebark Pine Subcommittee
Continue surveys of established monitoring plots (inherent funding issues with this)	Coordinated by the aforementioned monitoring subcommittee.
Create a single/comprehensive system of plots that are monitored for the long-term to evaluate whitebark pine population dynamics, vulnerability, and condition	Coordinated by the aforementioned monitoring subcommittee.
Design and document a monitoring protocol and training requirements	Coordinated by the aforementioned subcommittee.
Continue forest health monitoring aerial surveys	
Examine the potential of refugia for whitebark pine in California	Specifically the krummholz zone - describe the alpine tundra treeline; evaluate the viability of the seeds; conduct photo monitoring; examine the type and extent of predation on cones.
Monitor mistletoe	Coordinated by the aforementioned monitoring subcommittee.
Describe and monitor patters of hydrology (timing, amount, variability) in whitebark pine-dominated ecosystems	Assess whether using airborne snow observatory data to look at snowmelt patterns is feasible and, if so, implement.
Identify additional data sources that can be used to evaluate current status and trends of whitebark pine in California	For example: NASA databases (e.g., ECOSTRESS), https://ecostress.jpl.nasa.gov.
Support research to better understand the role of fire in California whitebark pine regeneration	

Conservation Category/Action	Additional Action Description (if needed)
Conduct research to better understand the historical and current fire regime at treeline	Consider wilderness areas data as proxy for subalpine - determine whether this data has been compiled. Some potential data sources include CalFire Fire and Resource Assessment Program (FRAP) database and Monitoring Trends in Burn Severity MTBS.
Conduct research on the impacts of changing climate, and particularly drought on California whitebark pine	For example: Phil van Mangtem et al.'s ongoing work (https://www.researchgate.net/scientific-contributions/Phillip-J-van-Mantgem-2115756444).
Conduct research to understand population dynamics of Clark's nutcracker in the Sierra Nevada and other vertebrates (e.g., Douglas squirrels) as well as cone/seed predation (e.g., cone/seed insects)	Including examining any relationships between Clark's nutcracker occurrence and areas of high white pine blister rust.
Monitor the effects of atmospheric stressors/deposition, including air pollution, ozone, and nitrogen	Monitor as an aspect of general health of these stands
Document Patterns of Genetic Diversity	
Evaluate existing genetic diversity data and identify data gaps	Conduct a literature review of existing information on whitebark pine genetics in California and how this relates to the larger population.
Continue to conduct research to address genetic information data gaps	
Conduct studies to understand the genetics of outlier populations	
Conduct experimental research with plantings from southern populations (genetic diversity studies) to help understand/manage for climate change	
Continue work to establish common gardens and pair with field studies and population genetics	
Conduct trials (also outside of range) for assisted migration studies	
Leverage current and novel technology to develop more advanced methods of white pine blister rust screening.	Including a review of what technology is being applied to other species (e.g., sugar pine).

Conservation Category/Action	Additional Action Description (if needed)
Continue to present results of climate work on seed transfer zones (need to consider other environmental datasets besides climate, e.g., soil, geography, topography, as well as genetic datasets)	
Develop seed transfer zone guidelines	
Document Patterns of White Pine Blister Rust Resistance	
Conduct screening for white pine blister rust resistance, followed by establishment of a seed orchard, if feasible	
Work with the USFS Pacific Southwest genetics program establish seed orchards and develop strategies to increase capacity for screening	
Screen outlier populations for white pine blister rust resistance	Once outlier populations have been identified.
Test current markers for resistance mechanisms in sugar pine/limber pine in whitebark to see if worth pursuing further.	
Conduct research on *Ribes* spp. to understand the distribution of white pine blister rust in these species as well as their whitebark pine blister rust susceptibility	
Develop hazard/risk models of disease spread and severity (look into other models that have been done (e.g. USFS National Insect & Disease Risk and Hazard Maps)	
Conduct research to understand epidemiology, infection periods, dynamics of disease spread in the different regions within California	
Conduct research to understand to what extent white pines at lower elevations that are infected with white pine blister rust may pose a threat to whitebark pine	
Conduct research to understand how climate changes influence white pine blister rust disease cycles in California	

Conservation Category/Action	Additional Action Description (if needed)
Deploy spore traps to monitor for the presence of white pine blister rust	
Protect Whitebark Pine	
Identify priority areas for conservation/Identify high risk sites for restoration through implementation of population studies (demography), genetic/genome, resistance, vertebrate studies, epidemiological studies, etc.	Define "high-value" as it applies to whitebark pine and then identify high value stands and individual trees (for example, krummholz populations and rare outlier populations); High priority areas to protect may include: krummholz and outlier populations, populations that are vulnerable or resilient to white pine blister rust and mountain pine beetle.
Review existing research on the different methods of protection against mountain pine beetle and evaluate benefits and costs of each method	
Identify and protect high value trees and stands against mountain pine beetle	Consider this as a goal with specifics (e.g. verbenone) as activities; consider a flow chart of work. Steps/Approaches can include: Evaluate the feasibility of using verbenone to protect individual high-value trees and implement, if appropriate.
Protect high-value individual trees and stands against high severity fires	Potential protective actions include local thinning and fuels reduction, as well as targeted fuel treatments outside of whitebark pine stands to reduce the risk of high severity fire spreading into those areas. These efforts should be informed by fire spread models and other available tools to predict fire behavior.
Identify and implement methods for building resilience of California whitebark pine stands to a variety of stressors, including changing climate.	Define "resilience" as it applies to California whitebark pine.
Identify/map California whitebark pine areas that may require protection from fire and develop guidance for managers and responders on whether/how to implement protective measures	This will serve as an educational tool for fire responders and resource advisors.
Conduct research to understand fire return intervals in California Whitebark pine habitat	

Conservation Category/Action	Additional Action Description (if needed)
Restore Whitebark Pine	
Conduct research to determine whether direct seeding is a useful tool for restoration and conservation of California whitebark pine	
Identify high risk sites (create thresholds and trigger points) for potential restoration actions	
Develop and test a seeding and planting protocol	Consider local and diverse sources when conducting planting and directing conservation actions.
Develop a land management strategy regarding planting white pine blister rust resistant seedlings. Determine levels of resistance to deploy but always plant a diversity of seed sources.	
Assess current seed collections and fill in gaps for gene conservation. USFS, Pacific Southwest Region Forest and the Institute for Forest Genetics have done an extensive collection of whitebark pine; however, there are still gaps (i.e., 4-5 populations) in the collection. The next step is to build the seedbank for whitebark pine, as is done with other forest tree species in the Pacific Southwest Region of the USFS.	
Proactively identify sites to allow for opportunistic management and/or experimentation.	The site identification process should include consideration of not only where the species currently is present but where it may occur in the future. One example of opportunistic management/experimentation would be managing fire dynamics in sites immediately downhill of whitebark pine populations - for example, fire in red fir below a whitebark pine stand might allow for some experimentation.
Conduct research to address data gaps in temporal/spatial information on cone crops and on seed predation	

Conservation Category/Action	Additional Action Description (if needed)
Evaluate fuel treatment methods and land management needs	There is a need to think more broadly and include management decisions that occur downslope and may impact whitebark pine; in particular with increasing prescribed fire, are there particular things that should be considered, such as whether downslope fuel treatments of other host species could be used as a method to protect the species from white pine blister rust.
Evaluate and conduct silvicultural treatments	When and if warranted, on a case-by-case basis
Evaluate ski areas as areas to implement management actions	
Create a list of specific restoration activities and reference other programs, such as Keane et al. (2017)	Review lessons learned from other programs.
Education, Outreach, and Coordination	
Conduct meetings that provide opportunities for coordination, data-sharing, and tracking the implementation of conservation actions	Meetings should occur on an annual (or otherwise appropriate interval) basis.
Develop a flow chart to guide the implementation of conservation actions	Some actions require the implementation of others before they can be addressed.
Monitor the effectiveness of conservation actions	
Identify opportunities for collaboration on data collection across monitoring programs	For example, there is the potential to collaborate with Sierra Nevada red fox research/monitoring efforts as this species' range overlaps with that of whitebark pine.
Coordinate and increase communication among different research groups and efforts associated with whitebark pine genetics work in California	
Coordinate with Nevada on their ongoing efforts to map blister rust	

Appendix 2: Laws, Regulations and Policies Relating to Whitebark Pine in California

NPS Policies

1. NPS Wilderness: The National Park Service policy under National Park Service Management Policy 2006 is as follows: (a) 6.3.1—General Policy. “The National Park Service will take no action that would diminish the wilderness eligibility of an area possessing wilderness character until that wilderness designation has been completed. All management decisions affecting wilderness will further apply the concept of “minimum requirement” for the administration of the area regardless of wilderness category.” (b) 6.3.6—Scientific Activities in Wilderness. “The statutory purpose of wilderness includes scientific activities, and these activities are encouraged and permitted when consistent with the Services responsibilities to preserve and manage wilderness.” (c) 6.3.6.2—Monitoring Wilderness Resources. “As appropriate, wilderness monitoring programs may assess physical, biological, and cultural resources and social impacts. Monitoring programs may also need to assess potential problems that may originate outside of wilderness to determine the nature, magnitude, and probable source of those impacts.” (d) 6.3.7—Natural Resource Management. “The National Park Service recognizes that wilderness is a composite of resources with interrelated parts. Without natural resources, especially indigenous and endemic species, a wilderness experience would not be possible. Natural resources management in wilderness will include and be guided by a coordinated program of scientific inventory, monitoring, and research. The principle of non-degradation will be applied to wilderness management, and each wilderness area’s condition will be measured and assessed against its own unimpaired standard. Natural process will be allowed, insofar as possible, to shape and control wilderness ecosystems. Management actions, including the restoration of extirpated native species, the alteration of natural fire regimes, the control of invasive alien species, the management of endangered species, and the protection of air and water quality, should be attempted only when knowledge and tools exist to accomplish clearly articulated goals.”

USFS Policies

1. In 2016, the Lake Tahoe Basin Management Unit Forest Plan completed under the 1982 planning rule. Forest Plan language relating to whitebark pine

    a. Work collaboratively with partners to identify and implement efforts to conserve and, as necessary, restore whitebark pine stands.

    b. Assess management activities for the risk of establishment or spread of white pine blister rust among whitebark pine stands.

c. Conserve whitebark pine genetic diversity by collecting and archiving seeds and growing and planting genetically diverse seedlings. Identify and collect seed from trees that exhibit some level of white pine blister rust resistance. Where possible, protect valuable rust-resistant, seed-producing trees from future mortality caused by disturbance, climate change, and competition.

d. Proactively manage whitebark pine stands of high conservation or restoration priority to improve resilience after disturbance and resistance to pathogens. Actions may include: precautions to limit the spread of blister rust; use of fire or silvicultural treatments; or reforestation with white pine blister rust resistant seedlings.

e. Identify whitebark pine stands of conservation and, as necessary, restoration priority. Develop spatially explicit species habitat areas.

f. Develop a unit-wide whitebark pine conservation strategy.

g. Develop and maintain spatial data of known whitebark pine stands and potential habitat.

2. In 2019, the Inyo National Forest revised their forest plan under the 2012 planning rule. It replaces the 1988 land management plan and its amendment. The plan went into effect on November 24, 2019. Under the 2012 planning rule, sensitive species are replaced by a species of conservation concern (SCC), and there are differences in terms of how species are analyzed for projects. In the Inyo Plan, however, whitebark pine is not included as a SCC due to its Endangered Species Act candidate species status. Inyo Forest Plan language relating to whitebark pine

a. Desired Conditions (TERR-ALPN-DC)

b. Subalpine woodlands are highly variable in structure and composition. Diverse patch types vary from open woodlands with scattered trees to small, dense groves.

c. Fires occur infrequently, are mostly very small, and burn with mixed severity. Fire intensity is highly variable, but crown fires are usually limited in size.

d. Subalpine woodlands are resilient to insects, diseases, fire, wind, and climate change. High-elevation white pines (whitebark pine, Great Basin bristlecone pine, limber pine, and foxtail pine) are healthy and vigorous, with a low incidence of white pine blister rust, and resilient to moisture stress and drought. White pine blister rust-resistant trees are regenerating and populations of high elevation white pines have the potential to expand above the treeline.

e. Mature cone-bearing whitebark pine trees are spatially well distributed to produce and protect natural regeneration and conserve genetic diversity.

f. Alpine ecosystems are resilient to climate change, and fires are small and occur infrequently.

3. The Sequoia and Sierra National Forests forest plans are in the process of being revised. Additional information is found here: **https://www.fs.usda.gov/detail/r5/landmanagement/planning/?cid=stelprdb5444003**

4. The Research Natural Areas with whitebark pine in California are: Klamath (Antelope Creek Lakes Candidate RNA, Crater Creek RNA, Sugar Ridge Candidate RNA); Shasta-Trinity (Mt. Eddy RNA, Red Butte-Red Fir Ridge RNA); Modoc (Raider Basin Recommended RNA); Eldorado: (Snow Canyon Candidate RNA); Tahoe: (Lyon Peak/Needle Lake RNA); Inyo (Harvey Monroe RNA, Sentinel Meadow RNA); and Stanislaus (Highland Lakes (Dropped) RNA, Clark Fork Candidate RNA). Plots are mentioned for Snow Canyon Candidate, Sentinel Meadow, Crater Creek, Mt. Eddy, Red Butte-Red Fir Ridge, Highland Lakes Dropped, and Clark Fork Candidate RNAs.

5. The USFS uses the term "conservation strategy" to include, but is not limited to, "… a document that establishes conservation objectives and identifies management actions necessary to conserve a species, species group or ecosystem." The strategy will be incorporated into USFS plans through the National Environmental Policy Act process with appropriate line officers approval.

6. Wilderness: In A Range-Wide Restoration Strategy for Whitebark Pine (Rocky Mountain Research Station, General Technical Report RMRS-GTR-279, June 2012, pages 30-33), please see summary of relevant agency policies related to wilderness.

7. Wilderness: In Supplement to Minimum Requirements Analysis/Decision Guide (MRA/MRDG): Evaluating Proposals for Ecological Intervention in Wilderness (Aldo Leopold Wilderness Research Institute, 2017), please see a comprehensive set of questions to guide the evaluation of proposals for ecological intervention in wilderness.

8. Wilderness: Passages from the Forest Service Manual (Policy) that relate to the topic of whitebark pine restoration:

a. FSM 2320—Introduction. “Manage wilderness to ensure that human influence does not impede the free play of natural forces or interfere with natural successions in the ecosystem.”

b. FSM 2320.2—Objectives. 2. “Maintain wilderness in such a manner that ecosystems are unaffected by human manipulation and influences so that plants and animals develop and respond to natural forces.”

c. 2323.5—Management of Forest Cover. “Manage forest cover to retain the primeval character of the environment and to allow natural ecological processes to operate freely.”

d. 2323.54—Reforestation. “Allow reforestation only if a loss of the wilderness resource has occurred, due to human influence, and there is no reasonable expectation of natural reforestation.”

e. 2323.04b states that the Chief has the authority to approve vegetative cover manipulation or any reforestation activities.

f. 2324.2—Management of Fire. Objectives. 1. “Permit lightning caused fires to play, as nearly as possible, their natural ecological role within wilderness.”

g. 2324.22—Policy. 7. “Do not use prescribed fire in wilderness to benefit wildlife, maintain vegetative types, improve forage production, or enhance other resource values.”

h. 2323.3—Management of Wildlife and Fish. Objectives. 3. “Provide protection for known populations and aid in recovery in areas of previous habitation, of Federally-listed threatened or endangered species and their habitats.”

i. 2323.32—Policy. 4. “Manage wilderness to protect known populations of Federally-listed threatened or endangered species where necessary for their perpetuation and aid in their recovery in areas of previous habitation. When alternative areas outside of wilderness offer equal or better protection, take actions to recover threatened or endangered species outside of wilderness areas first.”

9. *Pacific Crest Trail:* The National Trails System Act (P.L. 90-543) directs in Section 7(a) that “Development and management of each segment of the National Trails System shall be *designed to harmonize* with and complement any established multiple-use plans for the specific area in order to insure continued maximum benefits from the land. Section 7(c) further directs that “other uses along the trail, which will not substantially interfere with the nature and purposes of the trail, may be permitted by the Secretary charged with the administration of the trail. Reasonable efforts shall be made to provide sufficient access opportunities to such trails and, to the extent practicable, efforts be made to avoid activities incompatible with the purposes for which such trails were established.”

10. *Pacific Crest Trail:* The PCT Comprehensive Management Plan (1982) further acknowledges that the trail must co-exist in harmony with all other resource uses and activities of the land as determined through the land management planning process…."even though some resource activities may occur immediately adjacent to or across the trail, the agencies will protect the integrity of the trail proper by modifying management practices as needed" (page 21).

Appendix 3: Representative Photos - Sub Regional Vegetation Patterns

Klamath Sub Region

Figure A3-1. Whitebark pine near the summit of Mount Hilton in the Trinity Alps Wilderness, Shasta-Trinity National Forest, California. Photo by Michael E. Kauffmann.

Figure A3-2. Whitebark pine from Boulder Peak in the Marble Mountain Wilderness, Klamath National Forest, California. Photo by Michael E. Kauffmann.

Figure A3-3. Whitebark pine on South China Mountain in the Klamath National Forest, California. Photo by Michael E. Kauffmann.

Cascade Sub Region

Figure A3-4. Whitebark pine from the summit of Ash Creek Butte, looking west toward Mount Shasta, Klamath National Forest, California. Photo by Michael E. Kauffmann.

Figure A3-5. Whitebark pine from the steep ridgelines of the Antelope Creek Research Natural Area, California. Mountain pine beetle kill was common (approximately50% of trees). Here looking west to Ash Creek Butte and Mount Shasta. Photo by Michael E. Kauffmann.

Figure A3-6. Extensive stand of whitebark pine spread through the basin between Haight Mountain (back left) and West Haight on the Klamath National Forest, California. Photo by Michael E. Kauffmann.

Modoc Sub Region

Figure A3-7. Whitebark pine on Yellow Mountain in the northern Warner Mountains, California. Here *Pinus albicaulis* is restricted to the west slopes. Photo by Michael E. Kauffmann.

Figure A3-8. Small stands of whitebark pine on Bald Mountain in the central Warner Mountains, California. Photo by Michael E. Kauffmann.

Figure A3-9. Old growth whitebark pine frame the Surprise Valley near the summit of Eagle Peak, Warner Mountain Wilderness, California. Photo by Michael E. Kauffmann.

Sierra Nevada North Sub Region

Figure A3-10. Whitebark pine on Little Round Top on the Eldorado National Forest, California. Photo by CNPS.

Figure A3-11. Stunted whitebark pine on Lookout Peak on the Stanislaus National Forest, California. Photo by CNPS.

Sierra Nevada South Sub Region

Figure A3-12. Krummholz whitebark pine stand on a ridge south of Depressed Lake, John Muir Wilderness, Sierra National Forest, California. Photo by CNPS.

Figure A3-13. Clumped whitebark pine on the upper slope of Goddard Canyon, Kings Canyon National Park, California. Photo by NPS.


Figure A3-14. Large whitebark pine near Windy Ridge, Kings Canyon National Park, California. Photo by NPS.

Figure A3-15. Small stand of whitebark pine near northern Goddard Creek, Kings Canyon National Park, California. Photo by NPS.