SUBALPINE SENTINELS: UNDERSTANDING & MANAGING WHITEBARK PINE IN CALIFORNIA

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"The slender lash-like sprays of the Dwarf Pine stream out in wavering ripples, but the tallest and slenderest are far too unyielding to wave even in the heaviest gales."

–John Muir refers to whitebark as Dwarf Pine in *The Mountains of California*, 1894

A WIDESPREAD SPECIES AT RISK

A hardy inhabitant of the subalpine zone of western North America, whitebark pine (*Pinus albicaulis*) is a keystone tree species in California's subalpine forests, where it regularly defines the upper treeline in the Sierra Nevada, Cascade, Warner, and Klamath Mountains. Walking portions of the John Muir Trail in the southern Sierra Nevada, moving through extensive stands and mats of whitebark, one might wonder why such an apparently widespread and hardy species would be under consideration for listing as a federally endangered species.

Though whitebark is not uncommon in California, there is growing concern for its persistence, given recent observations of increased mortality, which may be exacerbated in coming decades due to the effects of climate change (Millar et al. 2012, Moore et al. 2017, Meyer and North *in press*). It is such concerns, in addition to dramatic and rapid declines throughout much of its range, that have led to proposals for listing this species under the federal Endangered Species Act (USFWS 2011). Indeed, as we go to press, status information related to listing is under review by the U.S. Fish and Wildlife Service (USFWS).

Figure 1. Whitebark pine cluster with basal sprouts on Table Mt., Bishop Creek, southern Sierra Nevada. *[U.S. Forest Service]*

In 2013, the U.S. Forest Service (USFS) placed whitebark pine on its Sensitive Species list in California. As a result, activities that could potentially affect the species must be evaluated under the National Environmental Policy Act. Nonetheless, there are relatively few studies that address the condition and health of whitebark pine in California, as distinct from elsewhere in western North America. Comprehensive management for whitebark pine was addressed in a recent range-wide restoration strategy (Keane et al. 2012), but this is largely focused on the Rocky Mountains and Pacific Northwest, due to relatively high impacts in these regions from threats such as mountain pine beetle outbreaks, white pine blister rust, climate change, and fire exclusion (Keane et al. 2012, Keane et al. 2017). So while these threats have caused precipitous declines of whitebark outside California, the southern Sierra population, for example, remains relatively healthy (Nesmith et al. 2019).

This means there is a high degree of interest among scientists, land managers, and stakeholders in gaining a better understanding of the potentially unique attributes of California's whitebark populations, which could serve a critical role in future management strategies. Even so, California is the only region that does not currently have an active genetic restoration program for whitebark. In other regions, these programs often include the collection, breeding, and planting of stock resistant to the non-native invasive pathogen, white pine blister rust. Current prospects for the development of such a restoration strategy and reforestation program in the state are promising, but these efforts will require considerable effort, cost, and coordination (Maloney et al. 2012). Here we review the most recent work evaluating whitebark health and status in California, and present the initial findings of a collaborative effort to establish a baseline of stand structure and health for continued monitoring.

A MAPPING CHALLENGE

At its highest elevations, whitebark often occurs in pure or nearly pure stands, resulting in geographically isolated stands on mountaintops. Most often found on windswept alpine and subalpine slopes and ridges, whitebark can either develop an upright stature or occur in krummholz (German for "twisted wood") cushions, or clumps, forming sometimes impenetrable islands that may exceed an acre in

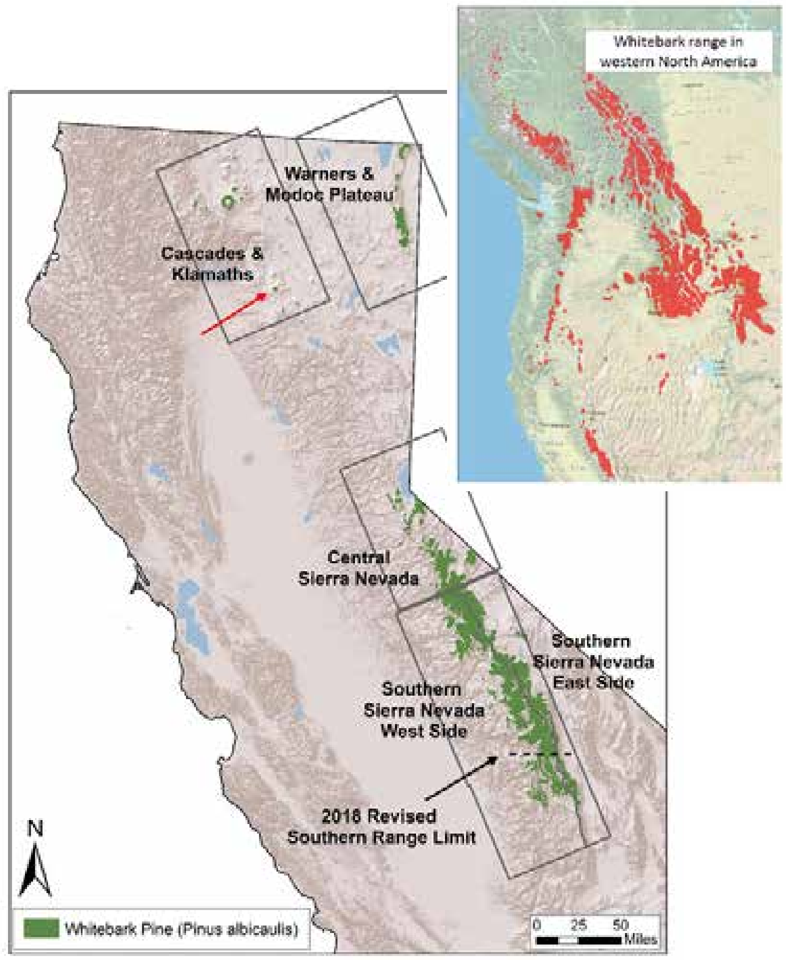

Figure 2. Distribution of whitebark in California, by geographic zone. Surveys revealed much more limited distribution at the southern range limit, with only two very small populations confirmed south of the revised boundary. Red arrow indicates highly isolated populations of Klamaths. Inset courtesy Whitebark Pine Foundation. *[http://whitebarkfound.org]*

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Figure 3. (a) Whitebark pine cones *[D. Pechurina]*, and (b) a cluster of seedlings and now empty seeds, cached in the soil by animals *[USFS]*.

size. Its success at high elevations can be attributed in part to tolerance of cold temperatures and adaptation to a short growing season, as well as to its structural ability to thrive near the ground surface, and thus remain protected from winter winds and desiccation under snow. Generally regarded as a disturbance-tolerant, early successional species, whitebark can be a first colonizer following a rockslide, avalanche, or stand-replacing fire. Yet on the harshest sites at or near treeline, it often forms "climax" communities where it is the dominant species (Arno and Weaver 1990).

Lower, stands are typically co-dominated by mountain hemlock, lodgepole pine, foxtail pine, western white pine, limber pine, and red or white fir (*Tsuga mertensiana, P. contorta* ssp. *murrayana, P. balfouriana, P. monticola, P. flexilis, Abies magnifica, A. concolor,* respectively).

Although whitebark has a broad geographic range, precise abundance and distribution information for California is limited. In 2014, the USFS compiled an updated map for whitebark-dominant stands, based on the CalVeg dataset (USDA Forest Service 2013a), 2012 National Insect and Disease Risk Maps (Krist et al. 2014), field visits, high resolution imagery, and aerial photography (Bokach 2014). Based on this effort, we estimated that there are 150,558 hectares (372,035 acres) of whitebark in stands greater than 0.4 hectares (one acre) in California.

Our more recent mapping and ground-truthing efforts in 2018 indicate that map improvements are still needed on over 20,000 acres, due to previous errors in interpretation of aerial photography and other imagery and also to the difficulty—even among experienced botanists—of determining species identity in situ if cones are absent. The two main look-alikes are western white pine and limber pine (*P. monticola* and *P. flexilis*, respectively). You can distinguish western white pine in the field with a hand lens by noting the fine serrations on its needle-like leaves. But limber and whitebark pine are virtually indistinguishable, especially when young, before whitebark acquires its namesake color and develops mature cones. Given that the distribution of whitebark pine in California represents the southernmost extent of the species (Arno and Hoff 1989), and risk for populations occurring at their range edge is elevated (Slaton 2015), continued study and mapping of these populations is needed to identify their potentially unique genetic make-up and take potential action, such as seed collection or restoration, to ensure their continued persistence (Syring et al. 2016).

DEMOGRAPHY OF A SUBALPINE TREE

The seeds of whitebark pines are wingless and rarely dispersed by wind. Instead they rely on dispersion by squirrels or birds, primarily Clark's nutcrackers (*Nucifraga columbiana*) (Arno and Hoff 1989, Tomback et al. 2001). These animals bury the seeds in the soil in small caches; if not reclaimed, the seeds may germinate and grow. Whitebark regeneration is therefore found most often in clumps, a form which can be accentuated by the tendency of lower branches to become pressed horizontally against moist ground from snow and then grow upright. Stems that do reach tree size (greater than 7.5 centimeters in diameter at breast height) are generally small compared to most other conifers, with height and diameter averaging 7 meters (23 feet) and 20 centimeters, respectively, in California (USFS, unpublished data).

Understanding the variability in stand structure and reproductive patterns between geographic regions can help to inform potential restoration strategies. For example, the relatively low tree density in the Warner Mountains, coupled with high proportions of conifers other than whitebark (namely, white fir) indicates that the sun-loving whitebark trees may be more vulnerable to being outcompeted by shade-tolerant species than in other regions of California. Also, whitebark's low reproductive success—sexual or asexual—in the Warner Mountains contrasts with the relatively high densities of young seedlings on the eastern side of the southern Sierra Nevada, perhaps indicating that success of planting efforts may vary by biogeographic region.

Finally, whereas previous studies have found increases in whitebark following disturbance in the southern Sierra Nevada (Meyer et al. 2016), we did not see this same correlation expressed at the scale of geographic regions—e.g. high recruitment rates in the Cascade and Klamath regions are coupled with relatively low disturbance rates. Such variable relationships emphasize how critical scale and ecological context are to understanding stand dynamics and planning restoration activities.

Given whitebark pine's broad geographic extent, consideration of genetic variation across regions is of utmost importance in developing potential conservation actions (Coutts et al. 2016). Studies are currently underway to assess regional genetic diversity and possible associations with climatic variables in central and southern Sierra Nevada whitebark pine populations (Elizabeth Milano, *personal communication*). In addition, we are finding whitebark stands at the edge of the tree's range in the southern Sierra Nevada undergoing proportional increases in recruitment of *other* conifer species, especially in the absence of disturbances that would create canopy openings and favor sun-loving whitebark (Slaton et al. *in review*). We did not observe this, however, in the interior part of its range. Thus, a revised southern distribution map may provide critical information on these vulnerable population segments.

A RESILIENT, YET VULNERABLE TREE

The USFWS designated whitebark pine as a candidate for listing under the Endangered Species Act in 2011 due to a suite of factors, including altered fire regimes; the introduced pathogen, white pine

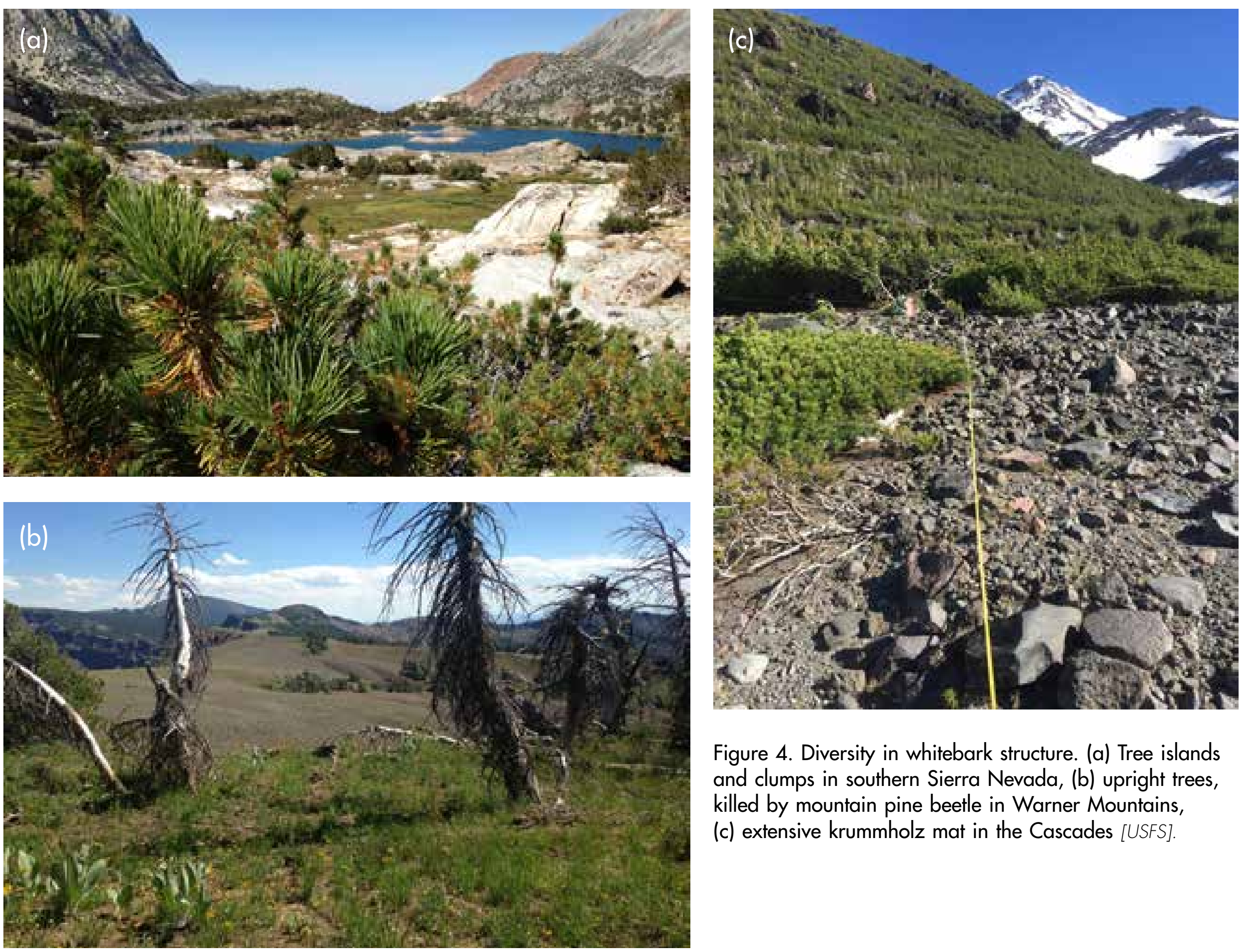


Figure 4. Diversity in whitebark structure. (a) Tree islands and clumps in southern Sierra Nevada, (b) upright trees, killed by mountain pine beetle in Warner Mountains, (c) extensive krummholz mat in the Cascades *[USFS]*.

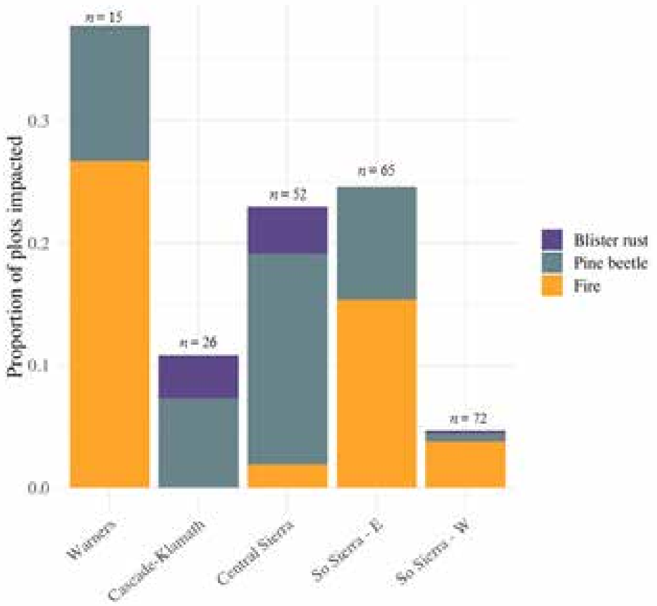


Figure 5. Geographic diversity in impacts of disturbance agents in whitebark ecosystems. Plot sample size indicated by n; data collected 2014-2018. Data combined from USFS and National Park Service protocols, plot size 0.12 - 0.62 acre (0.05 – 0.25 hectare). Other data sources indicate higher incidence of blister rust in central Sierra (Maloney et al., 2012); note USFS reports incidence by stem, whereas NPS reports by clump.

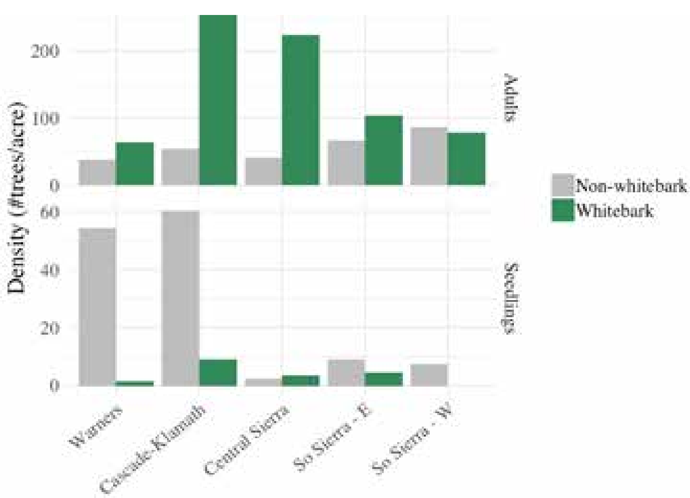


Figure 6. Variability in tree (> 7.5 centimeter diameter at breast height) and seedling (< 5 years old) density by geographic zone. Asexual regeneration is not accounted for here, although plots sampled in 2018 indicate highest basal sprout density in southern Sierra Nevada, and lowest in Warner Mountains. Sample sizes as in Figure 5; statistical analyses to be conducted following 2019 field campaign.

blister rust (*Cronartium ribicola*); mountain pine beetle (*Dendroctonus ponderosae*); and climate change (Tomback and Achuff 2010, USFWS 2011). These stressors have led to dramatic declines in whitebark across much of its range in the Rocky Mountains (Keane et al. 2012, Keane et al. 2017). Here we focus on how these threats are likely to affect whitebark populations in California in the future.

Changing fire regimes

Fire plays an important role in maintaining the health and resilience of whitebark pine forests throughout its geographic range. Historically, fires burned every 70 to 90 or more years in many upright (non-krummholz) stands, although researchers have documented shorter fire return intervals in other high-elevation forests (Murray and Siderius 2018, Meyer and North *in press*). Fire effects are variable, with some stands burning primarily at low severity (i.e., non-lethal surface fires) because of sparse surface and canopy fuels, and other stands burning at mixed severity (i.e., fire effects are highly variable over space and time) where trees are denser and fuels are spatially contiguous (Keane et al. 2012). Many areas in California are experiencing rapid shifts in fire severity, frequency, and extent, due to factors including warming temperatures, past fire suppression, and increased human ignitions (Keeley and Syphard 2016). We need more research and analysis to understand the current and projected changes in subalpine fire regimes in California.

Blister rust

Blister rust is an invasive pathogen native to northeastern Asia. It arrived in the United States around 1910 and spread through most of the range of whitebark pine and related five-needle (or white) pines, reaching the Sierra Nevada in 1968 (Kliejunas and Adams 2003). Whitebark is considered one of the most susceptible species of all the white pine hosts, including western white pine and limber pine (Kinloch and Dupper 2002).

Within the Sierra Nevada, blister rust occurrence and severity generally decline from north to south. For example, in Lassen National Park, Jules et al. (2017) found an average infection rate of 54% on whitebark pine. Maloney et al. (2012) found that, on average, 35% of individual whitebark pine trees showed symptoms of infection in the Tahoe basin, while Nesmith et al. (2019) and Dudney et al. (unpublished data) estimate that less than 1% of individual trees in the southern Sierra Nevada are infected. This trend is likely due to a combination of factors, including the relatively recent arrival of blister rust in the south, and the Sierra's relatively hot and dry climate. Although infections are still relatively low in the southern Sierra Nevada, Nesmith (2018a and 2018b) documents new observations of blister rust in Yosemite, Sequoia, and Kings Canyon National Parks.

Mountain pine beetle

The mountain pine beetle is native to western North America, including California, and is considered an important agent of disturbance in maintaining structural and compositional diversity of conifer forests (Weed et al. 2015). Recent warming trends have allowed the beetle to complete its seasonal life cycle at higher elevations, leading to increasingly common infestations in whitebark pine (Logan and Powell 2001, Mock et al. 2007, Kauffmann et al. 2014). It causes mortality by carving galleries through the xylem and phloem, and can be especially aggressive in drought-stressed trees. Although beetle outbreaks in California have been much lower compared to most other areas of its range, recent observations suggest this trend is changing and beetle populations are increasing (Millar et al. 2012, Meyer et al. 2016). Our data collection in 196 plots across the state from 2014 through 2018 indicated that mountain pine beetle is impacting 9% of whitebark pine trees. Many trees with symptoms of past attack have survived, and the chance of survival varies by region. For example, statewide, roughly one-half of attacked trees died; however, in the Warner Mountains, 100% of the attacked trees appear to have died.

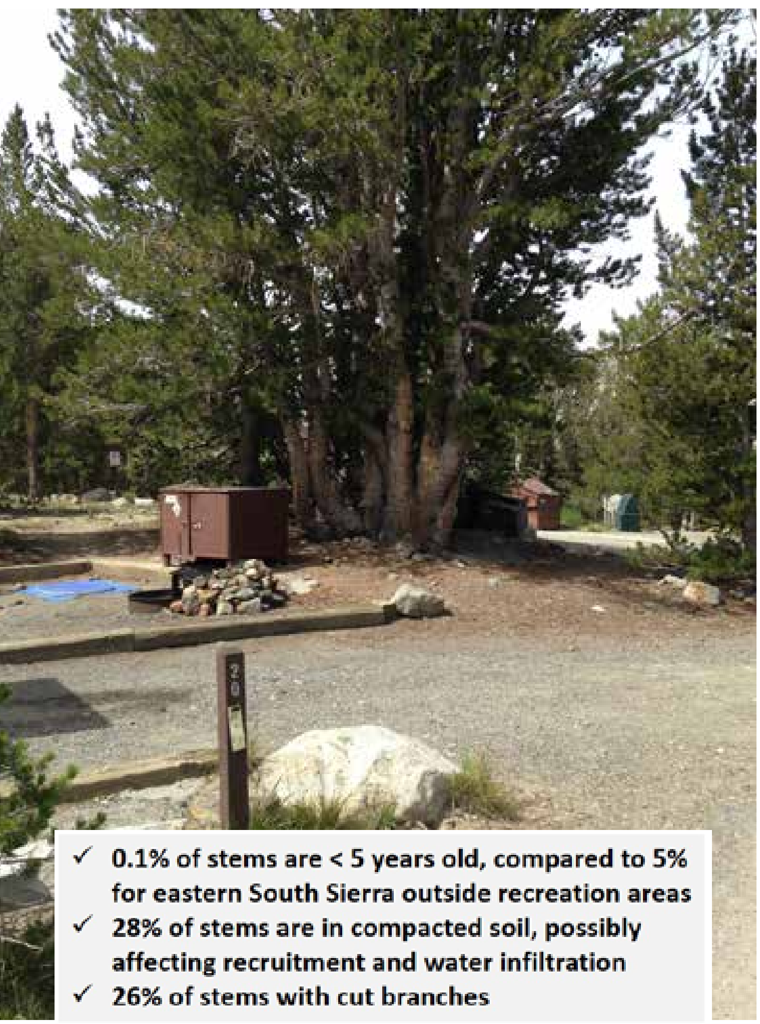
Climate change

Studies are currently underway to understand the impacts of warming temperatures, drought, and climatic water deficits on whitebark growth and survival in the Sierra Nevada. Dolance et al. (2013) has presented evidence that warming temperatures may increase recruitment and promote survival of small trees, leading to shifting stand structure weighted toward smaller, younger trees. However, temperature-induced increases in aridity may exacerbate physiological stress and susceptibility to mountain pine beetles (Logan et al. 2010, Millar et al. 2012, Moore et al. 2017). In addition, low minimum temperatures are known to control both beetle and blister rust spread (Weed et al. 2013). Thus, rising temperatures may facilitate an upward expansion of both blister rust and beetles to higher elevations, creating concern for the long-term outlook of whitebark pine.

Figure 7. Threats to whitebark pine: (a) Severe mountain pine beetle attack at June Mt. Ski Area, southern Sierra Nevada *[B. Oblinger]*; (b) mountain pine beetle galleries *[USFS]*; (c) pitch produced by whitebark to expel mountain pine beetles *[USFS]*; (d) white pine blister rust aeciospores on whitebark. *[USFS]*

FOREST MANAGEMENT: SCIENCE IN ACTION

Active forest management of California's whitebark stands has been exceedingly limited for several reasons. First of all, the stands, which are mostly located in wilderness or roadless areas, are relatively inaccessible. And secondly, they are found in more "natural" conditions that appear relatively unaltered from historic reference conditions, and therefore don't *need* much active management for restoration (Meyer and North *in press*). Nonetheless, prescribed fire (wildland fire managed for resource objectives) has been identified as an important resource management tool elsewhere in the western U.S. for restoring whitebark pine forests that may have experienced decades of fire exclusion (Keane et al. 2012). In addition, USFS has recently implemented several forest management projects in whitebark stands within ski resorts in the Sierra Nevada. These projects provide an opportunity for us to better understand the effects of forest management treatments and mitigation measures on whitebark in California.



One example is the 2018 initiative by the USFS Lake Tahoe Basin Management Unit and Heavenly Mountain Resort to develop a proactive whitebark management plan. The intent of this Whitebark Pine Partnership Action Plan is to minimize impacts from threats and to foster restoration by undertaking the following actions: (1) restore stands and increase resilience to stressors through mechanical thinning and prescribed burning; (2) reduce white pine blister rust where feasible by pruning and/or removing infected trees; (3) promote stand regeneration through canopy gap creation; and (4) collect viable seeds for genetic testing and planting.

Another example is the emerging partnership of the Inyo National Forest, Mammoth Mountain Ski Area, National Fish and Wildlife Foundation, and CalTrout to restore whitebark pine stands impacted by mountain pine beetle and drought in the June Mountain ski area. The project is designed to increase stand resilience to future bark beetle attack and climate change; promote and protect natural whitebark pine regeneration; reduce hazardous fuels associated with amplified tree mortality (which decreases wildfire risk to the nearby community of June Lake); and improve watershed function. In both examples, engaged partners will monitor the effectiveness of the treatments and evaluate long-term trends in ecosystem health.

Additional opportunities for restoration may exist in whitebark stands found in several accessible spectacular areas—with dramatic peaks and gorgeous subalpine lakes—that attract large numbers of recreational visitors. Potential impacts from recreational activities, such as trail system use and camping, are not well understood. So the Inyo National Forest recently undertook an assessment of impacts to whitebark pines in four major watersheds in the eastern Sierra Nevada where paved roads, campgrounds, and trailheads occur in whitebark habitat. Recruitment in these areas is extremely limited, and mature trees are affected by soil compaction and by branch and stem cutting. While these impacts occur in only a small portion of the whitebark's range, site accessibility and public visibility make these areas excellent candidates for potential restoration and educational activities related to whitebark pine health.

Figure 8. Results of a recreational impact study conducted by the Inyo National Forest for six popular recreation areas with campgrounds, trailheads, parking lots, and/or boat launches in whitebark habitat. Photo taken at Saddlebag Campground, Tioga Pass area. *[USFS]*

MONITORING

Recognition of the variability in whitebark pine among geographic regions has inspired our recent monitoring efforts in California, which we hope will provide guidance for appropriate restoration strategies. For example, we are studying the benefits of re-introducing fire in areas where it has apparently been long excluded (e.g. Cascades and Klamaths), whereas in the Sierra Nevada, we are identifying trees with genetic resistance to white pine blister rust to promote resilience in those populations.

As indicated above, there are relatively few long-term monitoring datasets for whitebark populations in California, due in part to the tree's low timber values and limited accessibility to its remote habitat and steep terrain. In addition, until recently, people have believed that conditions for the whitebark were stable. Just in the last decade, Millar et al. (2012) presented long-term trends based on tree-ring chronologies and USFS aerial detection surveys in which mappers estimated the extent and type of disturbance, finding localized, severe stand mortality in some portions of the southeastern Sierra Nevada and Warner Mountains. One of the very few examples of stand-level repeated measurements of whitebark pine is from a long-term U.S. Geological Survey study of a large (2.5 hectares) forest plot in Yosemite National Park, in which all trees have been censused annually since 1996. At this site, annual counts show that the newly dead trees generally outnumber newly established trees, suggesting a closer study of this site is needed (Das et al. 2013). This demographic trend has been occurring despite only recent and minor observations of white pine blister rust (Adrian Das, *personal communication*).

The National Park Service (NPS) Inventory & Monitoring program is another recent source for long-term monitoring data of whitebark pine. It began as a regional monitoring effort of high elevation white pines across several Pacific West Region parks in 2011. In Lassen, Yosemite, Sequoia, and Kings Canyon national parks, the researchers have established 94 of a planned 102 permanent plots (0.25 hectare) where trees are being individually tracked and assessed every three years (McKinney et al. 2012).

Implementing effective restoration requires an understanding of the ecological context of the target species (Keane et al. 2012). A broad-scale assessment of whitebark condition in California was initiated in 2014 by the USFS, complementing the existing network established on NPS lands. Such a monitoring network that adequately represents all geographic regions—regardless of land ownership—provides the ability to inventory and monitor patterns of mortality and regeneration, and to determine the rate and causes of mortality. In addition, such a network can contribute to the development of restoration and adaptive strategies and help identify where to prioritize management actions. The USFS campaign was substantially expanded in 2018 to 166 plots (0.08 hectare), and will be completed in 2019, after which it will serve as a baseline for future studies. Among the pressing questions under investigation are:

1) Are there areas where regeneration is not keeping up with mortality?
2) Where are stressors having the greatest impact, and are the impacts expanding?
3) Are other high elevation conifers outcompeting whitebark pine, and what role do disturbance regimes play in that interaction?
4) Are there additional range distribution surprises, similar to the revisions we found in the southern Sierra Nevada? Isolated populations in the northern Sierra Nevada and southern Great Basin in California are ripe for exploration.

CONCLUSIONS

Until recently, stressors such as blister rust and mountain pine beetle have had relatively small impacts in California, compared to their impacts in other parts of western North America, where they have largely decimated whitebark pine populations. However, the continued spread and intensification of these stressors and their interactions with a rapidly changing climate may portend future whitebark declines in this region. Clearly, the diversity of California's whitebark stands, with their many different ecological settings, and potentially unique genetic composition, points to the need for a strategy for monitoring, conservation, and restoration that is tailored to each unique zone.

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