CHAPTER 8.

Investigating Causes of Bishop Pine Decline on California's North Coast

(Project WC-B-16-02)

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INTRODUCTION

This project seeks to understand the causes of a dramatic decline of bishop pine (*Pinus muricata*) stands on the northern California coast in Mendocino and Sonoma Counties. The northern bishop pine forest is designated by the State of California as a sensitive vegetation type with a global rank of G2 (endangered) and a State rank of S2.2 (threatened) (Sawyer and others 2009). Stand decline and high mortality levels have been reported, especially in mid- to northern Mendocino County, since the early to mid-2000s; a drive along U.S. Highway 1 through these two counties or even a cursory examination of Google Earth imagery confirms the severity of the problem. Coupled with reported declines of bishop pine in the southern part of its California range, this northern decline may imperil the future not only of the species, but also of the unusual forest ecosystems it supports and the people who depend on them.[1] However, this decline is not yet represented in the scientific literature, nor does it show up in aerial survey records or Forest Inventory and Analysis (FIA) plots because of its coastal position. Our project proposed to remedy this need by collecting a set of systematic observations throughout the range of the decline. We investigated the decline using a twofold approach: (1) the application of dendroecological methods to a subset of trees in several stands to determine stand age structure, growth, and regeneration trends within the past century; and (2) an inventory of pest (pathogen and insect) problems present in these stands to gauge their prevalence and identify any that appear to be primary causes of the decline.

METHODS

Locations containing both healthy and declining stands were selected in 2015. Locations (fig. 8.1) included a northern cluster of sites near the towns of Fort Bragg and Mendocino (MCK, RG, HQ, and WS) and a southern cluster south of the town of Gualala (SR, FMC, SALT, and SPP). WS and SPP were pygmy/oligotrophic forest sites, while the others comprised stands with full-sized, mature bishop pines as dominants or codominants. Some soils were also collected from a limited number of sites with 100 percent bishop pine mortality. At each site with living pines remaining, one to three 0.1-ha plots were established. In each plot, each standing stem of any species >5 cm diameter was inventoried. Heights of selected living bishop pines were recorded using a laser rangefinder. Percent crown density (relative to 100 percent density, in which all visible space within the crown is occupied by living foliage) and percent branch dieback within the crown were recorded for each bishop pine. All observable insect pests and pathogens were recorded on plot bishop pines, and dwarf mistletoe and western gall

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[1] For example, in 2010, tourism—much of which is focused along the coast where bishop pine grows—accounted for 38.8 percent of total local taxes generated in Mendocino County as well as >$300 million in total local spending and >$6 million in transient occupancy taxes (County of Mendocino 2010); additionally, the Kashia Band of Pomo Indians attach enormous cultural importance to forest lands, including bishop pine stands, along the coast (Moore 2017).

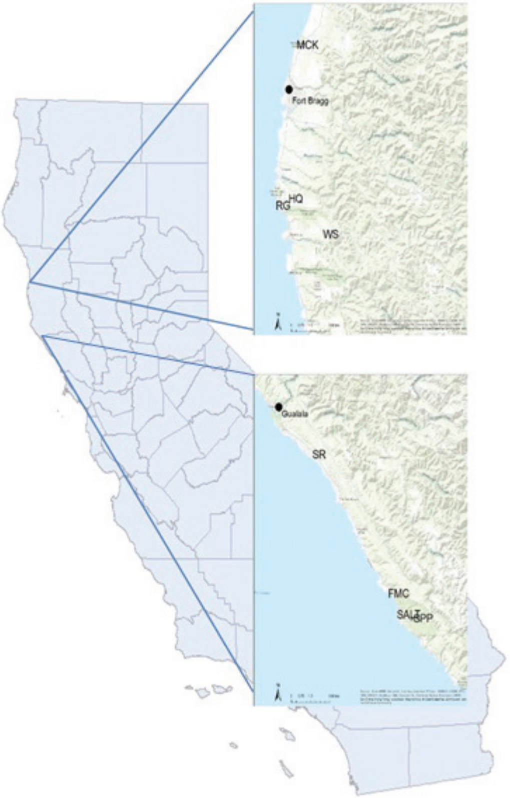

Figure 8.1—Study site locations.

rust incidence within the crown were recorded on a 0 (no infection) to 6 (greatest infection) scale, following the rating system presented in Hawksworth (1977). Some pest identifications required sampling of infected tree tissues followed by surface sterilization in 10-percent sodium hypochlorite (NaOCl) solution and plating on half-strength potato dextrose agar amended with 1 mL/L 85-percent lactic acid solution (Wick 2013); resulting cultures were sent to the California Department of Food and Agriculture (CDFA), Sacramento, CA, for DNA extraction, polymerase chain reaction (PCR)-based genomic amplification, sequencing of the amplicon, and identification based on homology of the amplicon to ones curated on the general biological database GenBank or the *Phytophthora*-specific databases *Phytophthora*-ID (http://phytophthora-id.org) and Phytophthora Database (http://phytophthoradb.org) (Martin and others 2012). On each plot, 8–12 living and dead bishop pines were cored (two orthogonal cores taken for each pine). Cores were dried and sanded to reveal growth ring fine features and the rings measured at Utah State University. Soils were characterized at each site by digging soil pits to 100-cm depth, collecting samples from each clearly discernible horizon, and recording a complete suite of physical characteristics for each horizon, including but not limited to pH, texture, coarse and fine root presence, color, and presence of redox features. Mineral soil was collected from the upper 10 cm of the profile at least twice from each plot in fall and spring to bait for oomycete pathogens. The baiting procedure involved flooding approximately 300 g of soil with distilled water, adding whole pears to the top of the flooded soil as well as floating Port Orford-cedar leaflets on the water, and plating the leaflets or lesioned portions of the pears on PARPNH-V8 agar, a growth medium selective for *Phytophthora* species (Bernhardt and Swiecki 2015, Schmitthenner and Bhat 1994). Resulting cultures of oomycetes were sent to the CDFA lab for PCR, sequencing, and identification.

RESULTS

Tree Statistics

Patterns of dieback varied from dramatic mortality of entire patches to more diffuse and gradual crown dieback within stands (fig. 8.2). Mean diameter at breast height (d.b.h.) for all trees on plots ranged from 19.7–56.7 cm, whereas mean d.b.h. for bishop pines alone was generally larger (range: 21.8–76.6 cm). Stem densities for all trees varied from 210 stems/ha (at WS10) to 890 stems/ha (at MCK); stem densities for bishop pines alone varied from 120 stems/ha (at RG5) to 510 stems/ha (at SALT2). Basal area of all trees ranged from 8 m^2/ha (at WS10) to 113 m^2/ha (at HQ); basal area of bishop pines alone ranged from 5.2 m^2/ha (at WS9) to 90.1 m^2/ha (at HQ). Although mean crown density for bishop pines varied little among sites, it was relatively low at all sites, with most sites averaging 55- to 75-percent density (fig. 8.3). Bishop pine branch dieback within the crown was significantly lower at sites with some of the greatest mean crown density (HQ and RG) than at other sites (fig. 8.3). Basal area increment (BAI) began to decline across all sites beginning mid-1990s according to our bishop pine tree core data (fig. 8.4; minimum mean BAI 8 cm^2/year; maximum mean BAI 23 cm^2/year). Of the trees cored, 20 percent established between 1850–1930, 66 percent established between 1935–1960, and 14 percent established since 1960 (fig. 8.5).

Figure 8.2—Bishop pine decline in northern Sonoma County. (A) Wide-scale, synchronous mortality; (B) gradual decline in crown conditions. (Photos by Christopher Lee, California Department of Forestry and Fire Protection)

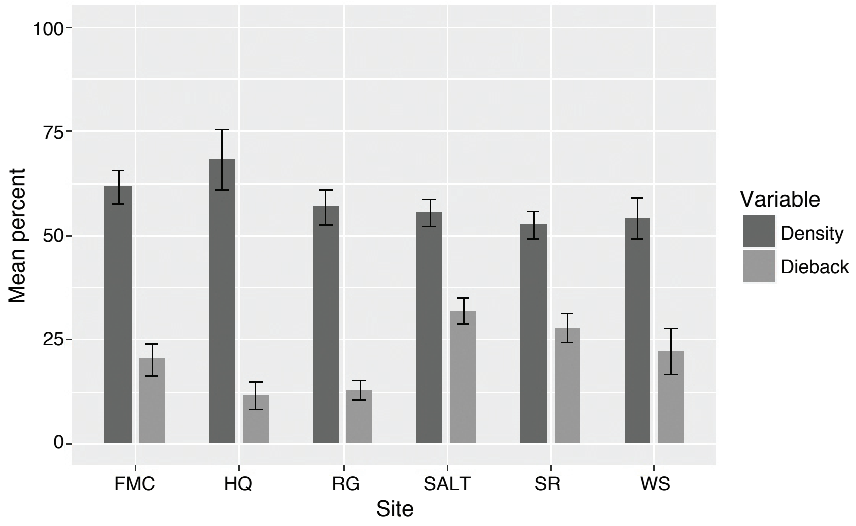

Figure 8.3—Bishop pine crown health metrics (mean percent crown density and mean percent crown dieback) across study sites with multiple plots containing Bishop pine.

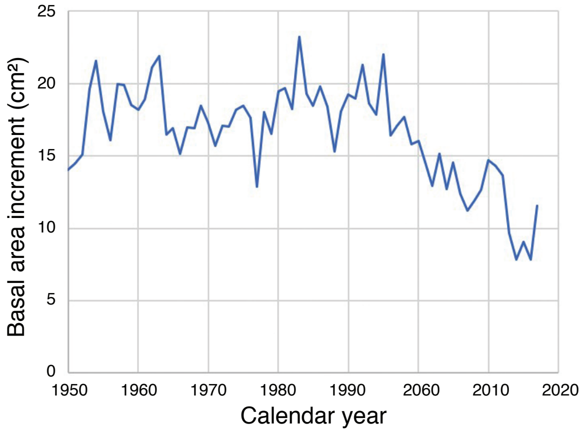

Figure 8.4—Basal area increment (BAI) averaged across all cored bishop pines at all study sites.

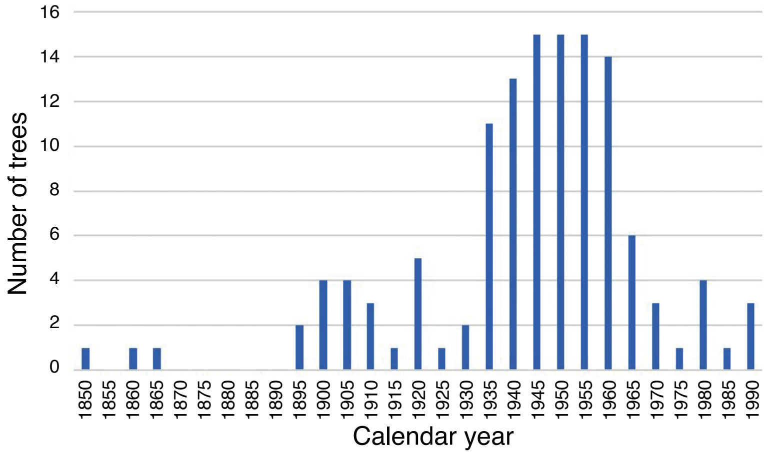

Figure 8.5—Dates of bishop pine establishment across study sites.

Pest Incidence

A large number of pests were observed on study pines; a list is given in table 8.1. Western gall rust incidence was locally heavy but averaged 1.2 on a 0–6 scale over all sites. Coastal dwarf mistletoe (*Arceuthobium littorum*) was severe only at the WS (pygmy forest) site (mean score 4.29 on a 0–6 scale), although it was present at several other sites (mean score <1). Some pests were observed at only one or a few locations (e.g., *P. cambivora*, the bark beetles); others were much more widespread (e.g., western gall rust, schweinitzii and tomentosus root rots, and stem decays). In general, widespread fungal activity was observed in this moist coastal ecosystem, both within woody substrates and in the prevalence of pathogenic fungi that disperse as spores in the air (e.g., *Diplodia scrobiculata, Fusarium circinatum*). At the southern sites, branch infections caused by *F. circinatum* have increased in number and prominence every year for the past few years, and symptomatic trees appear farther north along the roadside every year. Both *D. scrobiculata* and another *Fusarium* species (one closely related to *F. avenaceum*) have also been isolated from dead and dying seedling- and sapling-sized Monterey pines (*P. radiata*) in Sonoma, Mendocino, and Humboldt Counties.

Table 8.1—Pests observed on bishop pine, arranged by plant part affected

Pest (scientific name)	Disease caused (common name)	Plant part affected	Relative damage and extent
Armillaria spp.	Armillaria root disease	Large (structural) roots	Moderately severe/wide extent
Phaeolus schweinitzii	Schweinitzii root disease	Large (structural) roots	Moderately severe/wide extent
Onnia sp.	Tomentosus root disease	Large (structural) roots	Moderately severe/wide extent
Phytophthora cinnamomi	Phytophthora dieback	Fine roots	Severe/restricted extent
Elongisporangium (= *Pythium*) *undulatum*	None	Fine roots	Severe/restricted extent
Pythium spp.	None	Fine roots	Mild/wide extent
Phytophthora cambivora	Phytophthora dieback	Fine roots and root crown	Moderately severe/restricted extent
Fusarium circinatum	Pine pitch canker	Branches and stem	Severe/restricted but increasing extent
Phomopsis/Diaporthe spp.	Phomopsis canker	Branches and stem	Mild (tree), severe (seedling)/wide extent
Diplodia scrobiculata	Diplodia blight	Branches and stem	Mild (tree), severe (seedling)/wide extent
Arceuthobium littorum	Coastal dwarf mistletoe	Branches and stem	Severe/restricted extent (mostly pygmy forest)
Endocronartium harknessii	Western gall rust	Branches and stem	Severe/wide extent
Dendroctonus valens	Red turpentine beetle	Lower stem	Mild/restricted extent
Ips plastographus	Coastal pine engraver	Stem	Moderately severe/restricted extent
Pseudips mexicanus	Monterey pine Ips	Stem	Moderately severe/restricted extent
Hylastes spp.	Bark beetle	Stem	Moderately severe/restricted extent
Porodaedalia (= *Phellinus*) *pini*	White pocket/heart rot	Stem	Moderately severe/wide extent

Soils

Soils data are still under analysis, but field observations revealed large variations in soil physical characteristics from site to site, even in similar physiographic situations located within short distances from each other. Observations made so far have comprised gleyed soils, largely undeveloped sands, well-developed alfisols, and highly weathered, acidic spodosols. Water tables at several locations (e.g., MCK, FMC) are located high in the soil profile, and at FMC a blowdown event occurred at the edge of one plot in winter 2017–2018 involving large numbers of mature pines and revealing extensive *Armillaria* occurrence on the root systems.

DISCUSSION AND CONCLUSIONS

Our investigation confirms an ongoing, pervasive tree species decline in this part of the range of bishop pine. The decline fits a classic pattern involving many potential causal factors and varying rates and manifestations of decline at various sites. What distinguishes this decline from many others and gives it added urgency, however, is the already restricted range of the affected species. Although common patterns are hard to discern in the data from this project at this stage, the plots established and information gathered so far provide a solid foundation for further observation and the development of more focused research questions concerning specific mechanisms of decline. The literature of tree declines around the world shows the formidable range of possible causes of decline, but several of the most common can be ruled out in this isolated and relatively undisturbed part of the California coast, including air pollution (e.g., LeFohn and others 1997), overbrowsing (e.g., Diaci and others 2011), and excessively acidic soils (e.g., Park and others 2008). Increased mortality of this species in the southern part of its range (the Channel Islands) has been well documented (Baguskas and others 2014), with investigations of the cause centering on water stress, possibly caused by reductions in winter rainfall, summer fog delivery, or both; the importance of summer fog to tree maintenance and growth has been extensively covered by these research projects (e.g., Carbone and others 2013, Fischer and others 2016, Williams and others 2008). Johnstone and Dawson (2010) documented a moderate decrease in summer fog along the California coast during the last half of the 20th century, and Abatzoglou and others (2014) tracked a trend of warming winter temperatures throughout the Pacific Northwest. Both trends could potentially increase tree stress, directly decrease tree growth, and contribute to increased forest pest growth and activity.

In the northern part of bishop pine's range, the most common anecdotal explanation for the decline proposes the following chain of causes: (1) this pine has a short lifespan; (2) the pine depends on wildfire for successful regeneration, and wildfires have been absent along this part of the coast for many decades because of successful fire suppression efforts; (3) thus, the currently observed decline consists of an inevitable descent down a demographic curve coupled with no population replenishment (Giusti 2011).

However, our data, along with emerging understanding of plant aging, complicate this explanation in several ways:

1. No clear pattern of decline emerges from the data at this point in time. At some locations, bishop pine mortality is total or nearly so (e.g., the single plot at MCK, not included in fig. 8.3) or occurs in large patches or “centers,” while at other locations the decline manifests primarily as a more uniform and more progressive loss of crown vitality (e.g., FMC). We initially expected stands at the southern end of our study region to constitute healthy “reference” stands. However, while we saw less mortality of entire patches of trees in the south, we observed levels of crown decline comparable to those of still-living trees in the north. Patterns in the pygmy forest/oligotrophic soils locations differ from more mature coastal stands, with the former sites displaying far more pest-related issues, especially very obvious coastal dwarf mistletoe infestations; paradoxically, however, pygmy forest sites have more regeneration than sites with large-stature pines.
2. Our systematic survey revealed that, in several locations, pine decline involves not only bishop pine, but Monterey pine and shore pine (*P. contorta* ssp. *contorta*) as well.
3. There is an emerging understanding within the field of plant physiological ecology that most perennial plants, and among them especially trees, have no genetically programmed lifespans. Rather, aging in most of these perennial plants depends on some interplay between environmental stresses and plant physiological/metabolic processes and rates, although this interplay may produce relatively predictable demographic senescence curves for individual plant species (Lee and Muzika 2014).

Although lack of regeneration is clearly a major problem for bishop pine management throughout the range of this decline, unambiguous evidence that this is an age-related decline (i.e., cohort senescence *sensu* Mueller-Dombois 1987) is so far lacking. Within our dataset, some sites with very large, presumably old pines (e.g., HQ) displayed some of the densest crowns and least branch dieback, while conversely, other nearby sites (e.g., RG) also had large, old trees but much higher levels of crown transparency and branch dieback, and much greater mortality levels. Only two-thirds of the trees could be considered even-aged, having established within a 25-year time frame in the mid-20th century, whereas growth decline beginning in the 1990s was apparent across the dataset as a whole (fig. 8.4).

Our dataset so far supports the hypothesis that various stress factors are converging on bishop pine stands at unequal rates and with unequal effects throughout the range of the decline. Future work could concentrate on isolating some of these stress factors, which likely include the following:

1. Western gall rust and stem decay pathogens (and, at the pygmy forest sites, coastal dwarf mistletoes) that progressively break down tree crowns and that, in the absence of fire, rain down inoculum upon any regeneration that does exist beneath the forest canopy, leading to premature death. These pathogens likely thrive in the extended coastal wet climate, and periodic fire previously produced more heterogeneous stand structure and reduced pathogen inoculum within the stands.
2. A diverse set of exotic pathogens that are encroaching on bishop pine stands from various directions: *P. cinnamomi* and *F. circinatum* (pine pitch canker) in the south, *P. cambivora* in the north, and several of unclear provenance as well as unclear pathogenicity. We know little about the pathogenicity or spread of such pathogens as *Elongisporangium undulatum* and *D. scrobiculata* (Diplodia blight). Bark beetles may also be vectoring exotic vascular wilts such as *Leptographium wingfieldii* (blue stain fungus), which has been observed on bishop pine in Humboldt County (along with other, as-yet unidentified Ophiostomatoid wilt fungi).
3. Increased tree susceptibility to both native and nonnative pathogens and insects incited by underlying shifts in water availability and seasonal timing, solar radiation, nutrient cycling, and/or fog-delivered water to surface soils. Several residents have reported fewer summertime foggy days than in previous decades.

Future work has already commenced and includes the following: (1) further analysis and tabulation of study site soil physical characteristics; (2) detailed mapping and quantification of bishop pine decline throughout coastal Sonoma and Mendocino Counties using GIS techniques such as unsupervised and supervised image classification; (3) continued growth analysis using tree cores already collected and some to be collected in the future; and (4) addition of more plots to supply deficiencies in the existing dataset, particularly the addition of more healthy reference plots. Following this work, individual research projects can begin to investigate the roles of specific decline factors in more detail, especially underlying shifts in components of the coastal climate. Future management projects proposed by California State Parks (focused particularly on regenerating young pines), provided they include an adaptive management-oriented monitoring program, should also shed more light on how to promote healthier stands in the future.

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