Pre-epidemic Mortality Rates for Common *Phytophthora ramorum* Host Tree Species in California[1]

T.M. Barrett[2]

Abstract

Understanding the impacts of *Phytophthora ramorum* on forests will require knowledge of pre-disease distribution, abundance, and rates of change for affected species. This study estimated pre-epidemic mortality rates for nine common host tree species: bigleaf maple (*Acer macrophyllum*), California bay laurel (*Umbellularia californica*), California black oak (*Quercus kelloggi*i), canyon live oak (*Quercus chrysolepi*s), coast live oak (*Quercus agrifolia*), Douglas-fir (*Pseudotsuga menziesii*), madrone (*Arbutus menziesii*), coastal redwood (*Sequoia sempervirens*), and tanoak (*Lithocarpus densiflorus*) using inventory data from 1981 to 1984 and 1991 to 1994 statewide inventories of private (and some public) forest land. Mortality rates that were developed represent the average annual mortality for trees that were at least 12.5 cm in diameter at 1.4 m above the ground (dbh) at the time of the first (1981-1984) inventory. Natural mortality for all trees was estimated at 0.5 percent of trees per year, with rates for individual host species ranging from 0.1 to 0.6 percent. Overall, growth exceeded natural mortality and harvest for most host species between 1981 to 1984 and 1991 to 1994. Tanoak, the most numerous tree species in the quarantined counties, increased in volume and number of trees by more than 15 percent over the decade.

Key words: forest change, forest health, forest monitoring, oak decline, sudden oak death

Introduction

As of January of 2005, 14 coastal counties in California (Alameda, Contra Costa, Humboldt, Lake, Marin, Mendocino, Monterey, Napa, San Mateo, Santa Clara, Santa Cruz, San Francisco, Solano and Sonoma) were quarantined for *Phytophthora ramorum*. There are more than two million hectares of forestland in this quarantined

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[2] Research Forester, Forest Inventory and Analysis, Pacific Northwest Research Station, Forestry Sciences Lab, P.O. Box 3890, Portland, Oregon 97208 (email: tbarrett@fs.fed.us)

area, with more than two-thirds of the forest in private ownership.[3] Among other factors, the extent of the affected area, the prevalence of host species for *P. ramorum* within the forestland, and the associated mortality of some common host species result in the possibility of substantial effects on forest ecosystems.

Monitoring the impacts of the disease on forests requires knowledge of pre-disease distribution and abundance of affected species. Most tree species have populations that are not in equilibrium from decade to decade, with natural and human-caused impacts, such as wildfire, climate change, forest management, and development, resulting in long-term change even for very large geographical regions. Therefore, in addition to knowledge of pre-disease distribution and abundance, pre-disease rates of change (mortality, recruitment, and growth) are also important for understanding disease effects.

Unfortunately, mortality is one of the most difficult of commonly measured forest attributes to estimate precisely for large regions. Reasons include its relative infrequency, spatially and temporally correlated occurrence, and the necessity of having inventory systems in place before the time period of interest. In this paper, mortality rates for host tree species in California are developed using available statewide inventory data for the time period 1981-1984 to 1991-1994. The estimated rates are accompanied by additional information on net change in quarantined counties to provide context for their interpretation.

Methods

Mortality was calculated using data from a 1981-1984 statewide inventory of forestland in California that was remeasured in 1991-1994. The inventory was conducted by the USDA Forest Service Forest Inventory and Analysis program and excluded forestland on national forests and lands reserved from timber harvesting (Waddell 1996). There were 4,824 sampling units (plot locations) distributed throughout the state; 1010 of these were located in timberland and were used for estimating tree mortality on timberland. I also used a supplementary woodland inventory with 1218 sampling units; of these, 180 plots were located on accessible woodland and were used for estimating mortality of woodland trees. At the initial visit, live trees that were 17.5 cm in diameter at 1.4 m above ground (dbh) were sampled with a basal area prism on five points located around a central subplot; smaller trees were sampled with five fixed-area plots. The field crew tagged trees greater or equal to 12.5 cm dbh and recorded the azimuth and distance to trees to aid

[3] California inventory 2001-2003 (unpublished data on file), Forest Inventory and Analysis, Pacific Northwest Research Station, Portland, Oregon.

in identification at the next inventory. At the 1991-1994 inventory, trees that had died in the intervening years were recorded as either (1) harvested; (2) culturally killed (including girdling or spraying with herbicide); or (3) naturally dead (USDA Forest Service 1994). Trees that died and were subsequently harvested probably would have been recorded as harvested.

Annual mortality was based on the number of growing seasons between measurement dates for the plots. Annual mortality was calculated as a simple arithmetical average over the remeasurement interval, rather than an annually compounded value. The relatively short remeasurement interval resulted in only small differences between these methods. I used combined ratio estimators from Cochran (1977) to calculate mortality and standard error. Point-in-time estimates were made using double sampling for stratification (Cochran 1977). The mortality rates are an estimate of the total number of trees that died in the population divided by the total number of initial live trees in the population. The probability of inclusion for mortality trees was based on the 1981-1984 inventory, adjusted for plots on land that transferred to national forest ownership or reserved status.

The estimated forest land in the population was 4.8 million hectares. Because of the difficulty of reestablishing plots when land is disturbed, mortality from permanent conversion of forest land to other uses, such as residential development or roads, is not included in rates below. The estimated rate of conversion of forest to nonforest between 1981-1984 and 1991-1994 was less than 1 percent per decade; even if all trees on these plots were killed, it would be a minor component of mortality statewide. Plots where the owner denied access to the property add some additional uncertainty to estimates.

Host species for which mortality rates were estimated included bigleaf maple (*Acer macrophyllum*), California bay laurel (*Umbellularia californica*), California black oak (*Quercus kelloggii*), canyon live oak (*Quercus chrysolepis*), coast live oak (*Quercus agrifolia*), Douglas-fir (*Pseudotsuga menziesii*), madrone (*Arbutus menziesii*), coastal redwood (*Sequoia sempervirens*) and tanoak (*Lithocarpus densiflorus*). Other host species were either not considered trees (e.g., Shreve's oak) or were uncommon enough in California to preclude meaningful estimates of mortality (e.g., California buckeye).

Results

When all tree species in California were combined, the estimated rate of natural mortality was 0.5 percent per year (*table 1*). When culturally killed and harvested trees are included, overall mortality doubled to 1.0 percent per year. Standard errors were high, particularly for woodland species such as coast live oak. Coastal redwood had a very low rate of natural mortality of 0.1 percent per year. Mortality from harvesting and cultural treatments was higher for commercial species (Douglas-fir and redwood) and tanoak, a frequent associate.

Table 1—*Average annual mortality in California from 1981-84 to 1991-94 by species for trees >= 12.5 cm dbh*[1]

	Average annual mortality[2]		**Average annual natural mortality**	
Species	**Rate**	**SE**[3]	**Rate**	**SE**
	-------------------------*Percent of initial live trees* ---------			
California black oak	0.76	0.18	0.58	0.15
Coast live oak	0.59	0.33	0.49	0.29
Tanoak	1.39	0.29	0.36	0.08
Bigleaf maple	0.56	0.28	0.47	0.27
California-laurel	0.69	0.34	0.45	0.29
Canyon live oak	0.40	0.19	0.27	0.18
Douglas-fir	1.20	0.17	0.30	0.06
Pacific madrone	0.84	0.22	0.56	0.17
Redwood	1.53	0.37	0.10	0.03
All California tree species	1.05	0.11	0.49	0.07

[1] Excludes national forests, reserved forests, and nonforest.
[2] Includes trees that were harvested, culturally killed, or died of natural causes.
[3] SE is standard error.

These rates can serve as a baseline for future monitoring of the effects of the disease. However, whether the population of a particular tree species is at equilibrium depends on how natural and human-caused mortality is balanced with regeneration and growth. Because the age and size distribution of trees can also change, population trends may differ depending on whether these are assessed by number of trees, biomass, foliage, or other attributes.

In this case, I chose to look at (1) numbers of trees and (2) volume as indicators for change in the populations of host tree species. Using volume as an indicator is useful because it allows comparison to published estimates of change on California timberlands between the late 1960s and 1981-1984; in addition, it is typically very closely correlated with above-ground tree biomass. In the fourteen California counties under quarantine in January of 2005, the *P. ramorum* host species bigleaf maple, California black oak, California bay laurel, canyon live oak, Douglas-fir, and tanoak all showed volume increases between 1981-1984 and 1991-1994 (*table 2*).

Table 2—*Initial volume in 1981-84 and change in volume from 1981-84 to 1991-94 by P. ramorum host species for 14 California counties under quarantine in January, 2005*[1,2]

Species	1981-84 Volume	Annual net change in volume: Change	Annual net change in volume: SE[3]	Change over decade
	Thousand cubic meters			*Percent*
Bigleaf maple	2,327	+ 64	15	+ 28
California black oak	15,565	+ 200	48	+ 13
California laurel	12,614	+ 326	89	+ 26
Canyon live oak	10,182	+ 182	62	+ 18
Coast live oak	29,632	+ 322	185	+ 11
Douglas-fir	82,503	+ 1,520	338	+ 18
Pacific madrone	30,015	+ 370	84	+ 12
Redwood	124,674	+ 481	654	+ 4
Tanoak	38,554	+ 952	191	+ 25
All 9 species	346,065	+4,418	957	+ 13

[1] Does not include national forests or lands reserved from timber harvesting
[2] Volume calculated for trees at least 12.5 cm dbh, stump to 10 cm top, discounted for cull.
[3] SE is standard error

However, looking at the same populations in terms of number of trees shows somewhat different results (*table 3*). Canyon live oak, tanoak and Douglas-fir still show large percentage increases in the quarantined region. The difference in the increase for Douglas-fir volume (an 18 percent increase) compared to the increase in number of trees (a 28 percent increase) is characteristic of a shift in the population from larger to smaller trees. California black oak and coast live oak had higher estimates of change in volume (*table 2*) than change in numbers of trees (*table 3*). This is the result of a shift in the size distribution from smaller to larger trees, perhaps caused by low recruitment of trees crossing the 12.5 cm dbh threshold.

Table 3—*Initial trees in 1981-84 and change in trees from 1981-84 to 1991-94 of P. ramorum host species for 14 California counties under quarantine in Jan. 2005*[1, 2]

Species	1981-84 Trees	Change in tree numbers: Net change	SE[3]	Change over decade
	1000 trees	*------------- 1000 trees / decade ------*		*Percent*
Bigleaf maple	6,175	+ 1,666	704	+ 27
California black oak	34,311	- 105	794	- 0
California laurel	48,051	+ 5,714	3,420	+ 12
Canyon live oak	25,017	+ 4,253	2,652	+ 17
Coast live oak	84,014	+ 757	4,293	+ 1
Douglas-fir	76,472	+ 21,109	4,103	+ 28
Pacific madrone	70,796	- 938	1,816	- 1
Redwood	114,322	+ 5,527	4,386	+ 5
Tanoak	159,927	+ 28,553	5,740	+ 18
All 9 species	637,272	+ 69,023	12,116	+ 11

[1] Does not include national forests or lands reserved from timber harvesting
[2] All trees with dbh ≥ 12.5 cm
[3] SE is standard error

Discussion and Conclusion

One question of interest is whether these rates of change were unique to the time period of 1981-1984 to 1991-1994. For the north coast region of California, hardwood growing stock volume on timberland was reported to increase by an average annual rate of 2.7 percent from 1964-1967 to 1981-1984 (Lloyd and others 1986). For the central coast region, hardwood growing stock volume was estimated to increase by an average annual rate of 1.1 percent between 1968-1971 and 1981-1984 (Colclasure and others 1986). For the state, Bolsinger (1988) reported net annual volume growth on timberland of 3.5 percent for tanoak, 3.1 percent for Pacific madrone, 3.5 percent for California bay laurel, and 2.4 percent for California black oak.[4] The 1981-1984 to 1991-1994 average annual volume increases reported here for forest land in the quarantined counties (*table 2*) are 1.7 percent for tanoak, 1.1 percent for Pacific madrone, 2.2 percent for California laurel, and 1.6 percent for California black oak.

If the 1960s to 1980s values were combined with the 1980s to 1990s values, then cumulative volume increases for these four species would range from 40 to 60 percent over 20 years. The estimates cannot actually be combined because the geographic regions in the published reports do not coincide with the quarantined counties discussed in this paper. However, the increase of volume reported here for hardwood timberland species (bigleaf maple, California black oak, California bay laurel, Pacific madrone, and tanoak) appears to be consistent with a longer term trend in coastal California counties between 1964-1971 and 1991-1994.

Ultimately, populations of host species will be determined by levels of disease resistance (Garbelotto and others 2001) along with the pre-disease distribution and abundance of host tree species. The results shown here suggest that in the 10 years prior to the first observation of the disease, several host tree species were undergoing significant shifts in total numbers and volume, along with changes in individual tree size distribution within the population. Effects of the disease are most likely to be compared to conditions prior to its discovery, or as ongoing measurements as the disease progresses. However, it also may be useful to keep in mind that the populations of species affected by *P. ramorum* were not in an equilibrium state in the decades prior to the discovery of the disease.

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[4] Values in Lloyd, Moen, and Bolsinger (1986), Colclasure, Moen, and Bolsinger (1986) and Bolsinger (1988) are for unreserved timberland outside of national forests. Bolsinger (1988) values cited here do not include harvest, which was 6 percent of net annual growth.

References

Bolsinger, C.L. 1988. **The hardwoods of California's timberlands, woodlands, and savannas.** Resourc. Bull. PNW-RB-148. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Station. 148 p.

Cochran, W.G. 1977. **Sampling techniques (3rd ed).** New York: John Wiley and Sons. 428 p.

Colclasure, P.; Moen, J.; and Bolsinger, C.L. 1986. **Timber resource statistics for the north coast resource area of California.** Res. Bull. PNW-RP-133. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, 32 p.

Garbelotto, M.; Svihra, P.; and Rizzo, D.M. 2001. **Sudden oak death syndrome fells 3 oak species.** California agriculture 55:1:9-19.

Lloyd, J.D., Jr.; Moen, J.; and Bolsinger, C.L. 1986. **Timber resource statistics for the north coast resource area of California.** Res. Bull. PNW-RP-131. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, 32 p.

USDA Forest Service. 1994. **Field instructions for the inventory of California 1992-94.** Pacific Northwest Research Station, Forest Inventory and Analysis. www.fs.fed.us/pnw/fia/local-resources/pdf/field_manuals/ca/1991_94_field_manual_california.pdf [2/15/05]

Waddell, K.L. 1996. **California inventory procedures and techniques reference documentation.** Pacific Northwest Research Station, Forest Inventory and Analysis. www.fs.fed.us/pnw/fia/local-resources/pdf/field_manuals/ca/california_inventory_techniques_manual.pdf [2/15/05]