Thirty Years of Root Disease and Bark Beetle-Caused Mortality in a Mixed-Conifer Forest along the Chiwawa River in Central Washington

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Summary

In 1981 and 2010, nine 12- to 77-ha stands totaling about 400 ha were surveyed for tree mortality and cause. Except for parts of 2 of 9 stands, there was no evidence of harvesting from 1981 to 2010. Most stands had fewer healthy-appearing trees/ha and basal area/ha in 2010 than in 1981. Most stands had more seedlings and saplings in 2010 than in 1981; however, most were pest-susceptible grand fir and Douglas-fir. Frequency of mortality varied greatly by stand and year surveyed. Most mortality was associated with root diseases caused by *Phellinus sulphurascens*, *Armillaria ostoyae*, or *Heterobasidion occidentale* and the bark beetles *Dendroctonus brevicomis*, *D. pseudotsugae*, *D. ponderosae*, or *Scolytus ventralis*. Differences between the 1981 and 2010 surveys were significant for incidence of mortality caused by *H. occidentale* or mortality from bark beetles. Unless there is severe wildfire or sufficient harvesting to create effective gaps for seral-species regeneration and survival, forests within the evaluated area will continue to support many bark-beetle and root-pathogen populations that create more dead trees and mortality gaps as grand fir and Douglas-fir continue to occupy significant portions of all canopy levels within the forest.

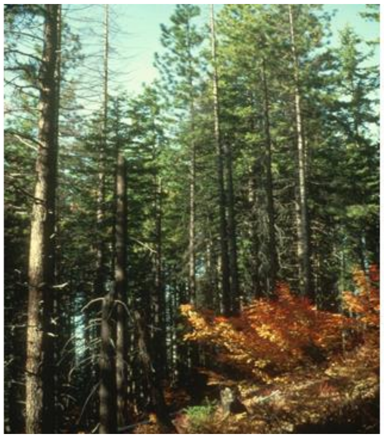
Introduction

Tree mortality in western conifer forests is a complex process involving many related factors (Shigo 1985, Waring 1987, Franklin *et al*. 1987, Hessburg *et al*. 1994, Edmonds *et al.* 2000, Filip *et al.* 2007a, b). Conifer mortality tends to be more common in higher-elevation forests or eastside forests of the Pacific Northwest where stress from weather, fire, insects, and diseases result in high rates of mortality (Campbell and Liegel 1996). Some conifer species are more prone to death than others. For instance, grand fir (*Abies grandis*) and Douglas-fir (*Pseudotsuga menziesii*) have a long history of being particularly susceptible to attack and subsequent mortality from many forest insects and pathogens (Wickman 1992, Hessburg *et al.* 1994, Campbell and Liegel 1996, Filip *et al.* 2007a, b).

Major agents resulting in grand fir and Douglas-fir mortality include the diseases: laminated root rot caused by *Phellinus sulphurascens* (formerly *Phellinus weirii*, Cook *et al*. 2013), Armillaria root disease caused primarily by *Armillaria ostoyae*, and annosus root disease on grand fir caused by *Heterobasidion occidentale* (formerly s-type *H. annosum*, Goheen and Willhite 2006). Major insect species causing death include the fir engraver (*Scolytus ventralis*) on grand fir, Douglas-fir beetle on Douglas-fir (*Dendroctonus pseudotsugae*), and western spruce budworm (*Choristoneura occidentalis*) and Douglas-fir tussock moth (*Orgyia pseudotsugata*) on true firs and Douglas-fir. All of these pests have a long history of occurrence in the upper-elevation forests of central Washington (Hessburg *et al.* 1994). Excessive tree mortality and subsequent down wood also increase the risk of wildfire (Filip *et al*. 2007a, b).

The Chiwawa River valley is a major watershed in central Washington. The upper reaches are managed by the USDA Forest Service, Okanogan-Wenatchee National Forest, Wenatchee River Ranger District as a late-successional reserve with the Glacier Peak Wilderness forming the northern boundary of the watershed. The area is heavily utilized by recreationists and because of its location, has received limited tree-harvesting activity in at least the last 50 years**.** The watershed therefore represented a unique opportunity to observe and compare, in a relatively pristine forest, the incidence of tree mortality from primarily forest diseases and insects over several decades. The area is dominated by Douglas-fir and grand fir. A 1981 survey was done to determine the incidence and location of forest insect damage and diseases in order to formulate silvicultural prescriptions to reduce pest-caused mortality (Filip 1982).

The objective of our evaluation was to compare the incidence of disease and insect-caused mortality in 1981 and 2010 for nine stands in the Chiwawa River valley.



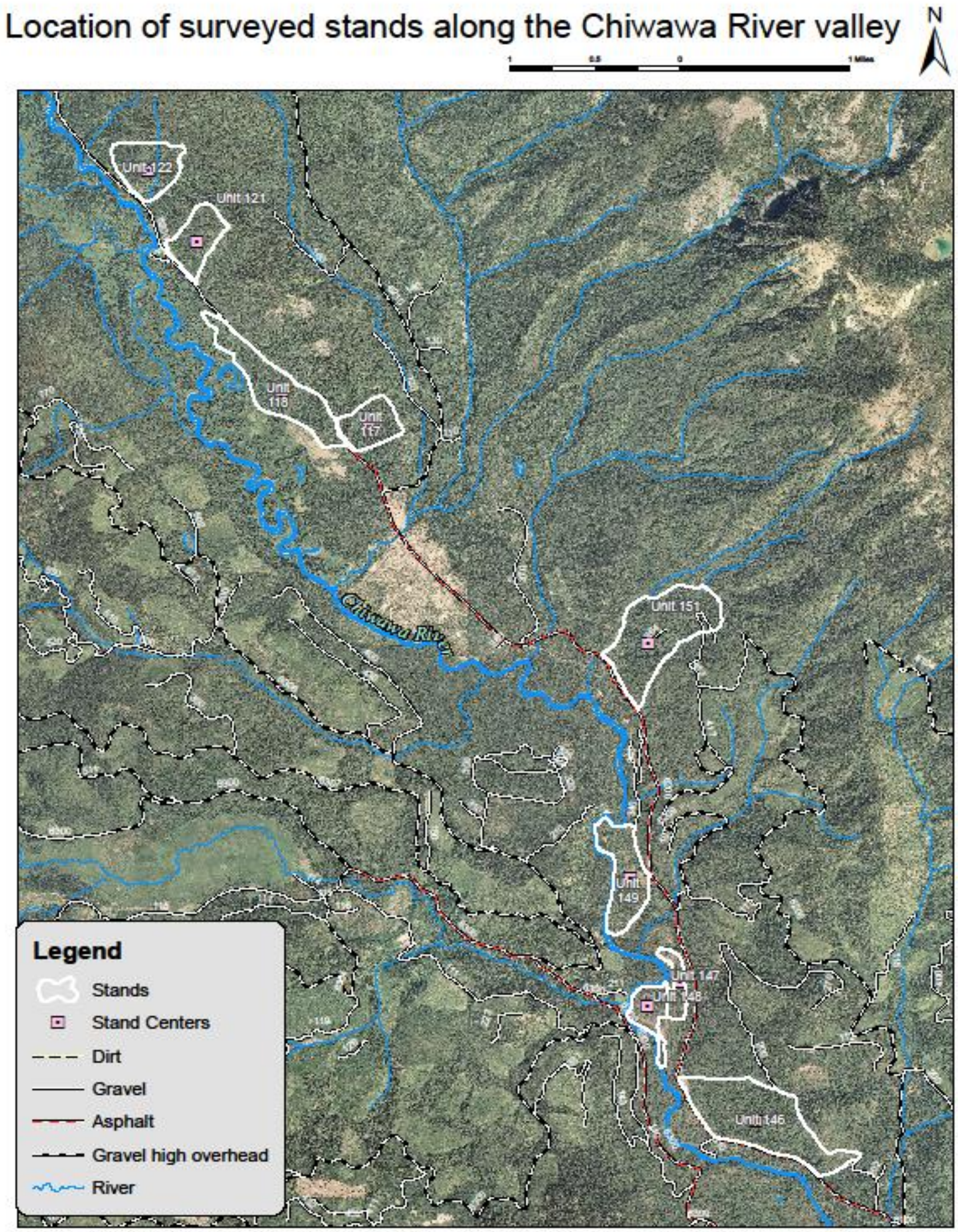


Fig. 1 – Map of the area surveyed in 1981 and 2010 along the Chiwawa River showing the nine numbered stands outlined in white and the GPS stand centers (pink squares).

Methods

Site and Stand Description

The survey area is located about 40 km north of Leavenworth, WA and 10 km north of Lake Wenatchee in the Chiwawa River valley (latitude 47°9'N, longitude 120°7'W, Fig. 1). Elevation ranges from 700 to 900 m. Mean annual precipitation is 100 to 150 cm. Five plant associations occur in the survey area (Table 1): grand fir/vine maple (*Acer circinatum*), grand fir/vine maple/queencup beadlily (*Clintonia uniflora*), grand fir/pinegrass (*Calamagrostis rubescens*), grand fir/pinegrass-lupine (*Lupinus* spp.), and grand fir/Cascade Oregon grape (*Berberis nervosa*) (Lillybridge *et al*. 1995).

The forest is uneven-aged and dominated by grand fir and Douglas-fir with some ponderosa pine (*Pinus ponderosa*), lodgepole pine (*P. contorta*), and western white pine (*P. monticola*) on the drier sites. Western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), Pacific silver fir (*Abies amabilis*), Engelmann spruce (*Picea engelmannii*), red alder (*Alnus rubra*), black cottonwood (*Populus balsamifera* spp. *trichocarpa*), quaking aspen (*P. tremuloides*), and willow (*Salix* spp.) occur in the wetter riparian zones. Except for parts of two 12- and 29-ha stands, there was no evidence of tree harvesting from 1981 to 2010 in the areas surveyed.

Table 1. Site and stand characteristics of nine stands sampled in 1981 and 2010 along the Chiwawa River on the Wenatchee River Ranger District in central Washington.

Stand no.	Area (ha)	Elev. (m)	Aspect	Slope (%)	Plant association[1]	Tot. no. of plots	No. of all-data plots[2]
117	36	811	W	20	ABGR/ACCI	49	13
118	61	726	Flat	0	ABGR/ACCI/CLUN	76	16
121	40	878	SW	30	ABGR/ACCI	50	11
122	77	866	SW	25	ABGR/ACCI	55	15
146	59	853	S	10	ABGR/ACCI	75	13
147	15	768	Flat	0	ABGR-CARU	49	9
148	12	792	Flat	0	ABGR-CARU-LUPIN	44	9
149	29	706	Flat	0	ABGR/ACCI/CLUN	24	24
151	64	863	SW	20	ABGR/BENE	36	36

[1]Plant associations are ABGR=*Abies grandis*, ACCI=*Acer circinatum*, CLUN=*Clintonia uniflora*, CARU=*Calamagrostis rubescens*, LUPIN=*Lupinus* spp., BENE=*Berberis nervosa* (Lillybridge *et al*. 1995).

[2]Data were collected for all trees on every fifth plot (all-data plots) except for stands 149 and 151 where all trees were measured on all plots. On all other plots, data were recorded for only dead trees, or for live trees with signs or symptoms of pest attack (Filip 1982).

Sampling methods

In August and October 1981, each of nine stands (Fig. 1) was sampled using fixed-radius (0.004 ha) circular plots and variable-radius (20 or 40 [$ft.^2$/ac] BAF or 4.6 or 9.2 [m^2/ha]) BAF) plots located at 40.2 m intervals along parallel transects 201 m apart (Filip 1982, Fig. 2). The first transect was randomly started at a stand boundary. Resource aerial photographs from the Wenatchee River Ranger District (former Lake Wenatchee Ranger District) were used to delineate stand boundaries and determine areas. Only trees $\geq$12.7cm dbh (diameter at 1.3 m) were included in variable-radius plots (Fig. 3). Only trees <12.7cm dbh but $\geq$15.2 cm in height were included in fixed-radius plots.

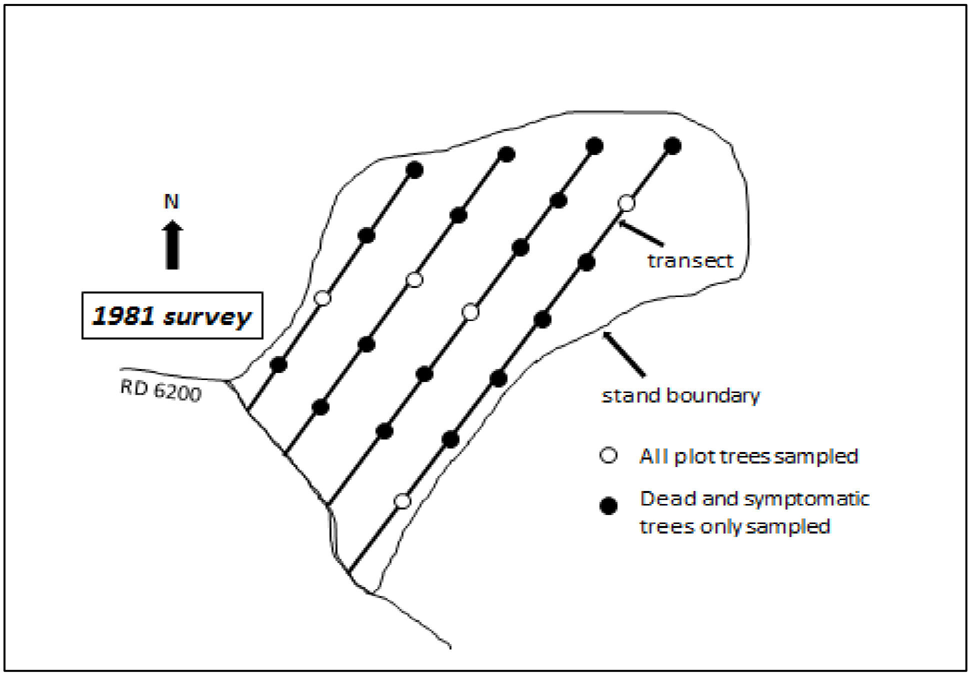


Fig. 2 – Diagram of a sampled stand showing typical transect design and plot locations in 1981.

Seven of nine stands were surveyed using a two-tiered sampling approach. Data were collected for all trees on every fifth plot (all-data plots) except for stands 149 and 151 where all trees were measured on all plots (Table 1, Fig. 2). On all other plots, data were recorded for only dead trees, or for live trees with pest signs or symptoms. Because tree mortality or infections in live trees often form only a small portion of any stand, sampling for these trees was more intense (i.e. dead trees and live, symptomatic trees were recorded on all plots).

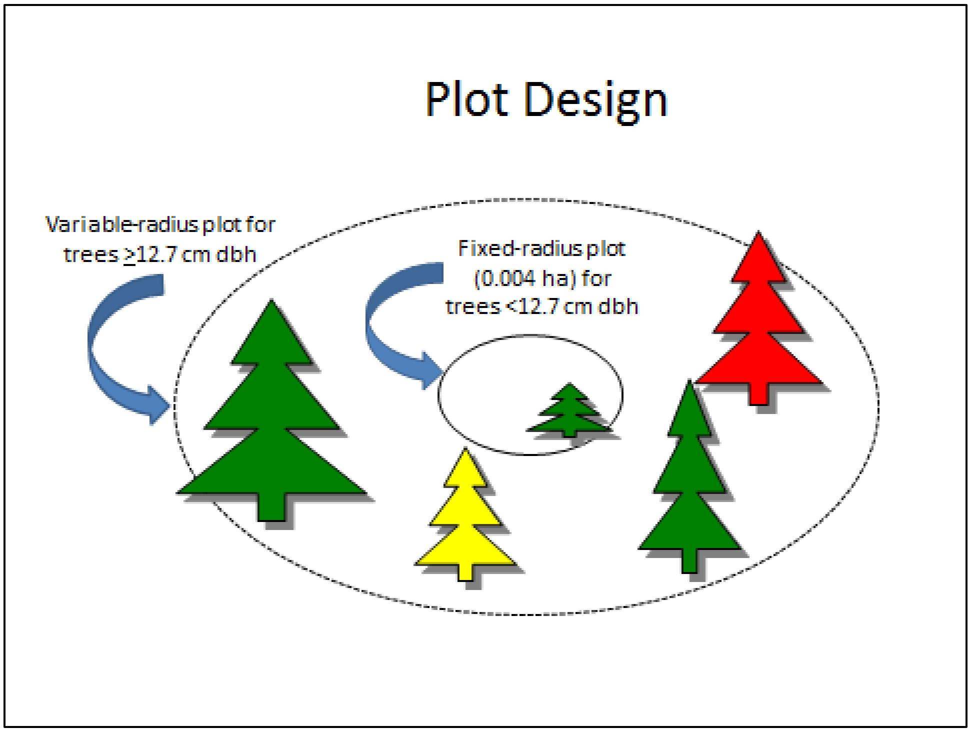


Fig. 3 - Design of the plot system used in 1981 and 2010 to survey stands with fixed-radius plots and variable-radius plots with the same centers.

The following data were recorded for each plot tree: 1) tree species, 2) dbh (nearest 0.1cm), 3) tree condition (healthy-appearing, live-infected, dead), and 4) cause of symptoms or mortality. In addition, the following data were collected for each stand: 1) mid-point elevation (nearest m), 2) aspect, 3) percent slope, and 4) plant association (Lillybridge *et al*. 1995). Pests on live trees or tree mortality were not recorded for seedlings (trees < 2.5 cm dbh but ≥15.2 cm in height). All seedlings <15.2 cm in height were not recorded.

Root diseases in the area surveyed typically result in forest gaps ranging in size from individual trees to several hectares, with openings dominated by vine maple and other shrubs. Root diseases were identified after partial excavation and dissection of roots and root collars. Only dead or symptomatic trees (thin crowns, dead tops, or basal resinosis) were sampled for root disease. No attempt was made to detect root diseases in living trees without above-ground symptoms. Laminated root rot was identified by the presence of white ectotrophic mycelium on excavated roots or laminated decay with setal hyphae in decayed roots (Goheen and Willhite 2006). Annosus root disease was identified by roots with characteristic white, stringy decay or by the presence of characteristic conks on infected roots. Armillaria root disease was diagnosed by the presence of typical white mycelial fans beneath the bark at the root collar, or by characteristic yellow, stringy, decayed wood. Other root diseases were identified by conks or decayed wood. In most cases, trees identified as being killed by root diseases also had bark beetle galleries under the stem bark, but such trees were recorded as being killed by root disease.

Mortality caused by bark beetles was identified by removing sections of bark at dbh and observing characteristic gallery patterns on dead or dying trees (Goheen and Willhite 2006). Principal bark beetles included the fir engraver on grand fir, the Douglas-fir beetle, the western pine beetle (*D. brevicomis*) on ponderosa pine, and the mountain pine beetle (*D. ponderosae*) on ponderosa, lodgepole, and western white pines. No attempt was made to detect bark beetle presence in living trees without symptoms (thin crowns, partially killed stems, stem resinosis). Dead or dying trees with bark-beetle galleries also may have been infected by root pathogens, but unless there were root-pathogen symptoms or signs on partially excavated roots, cause of death was recorded as bark beetles.

Other causes of tree mortality included stem breakage from decay, dwarf mistletoes, rust cankers, and animal and weather-related damage. Stem decay caused by *Echinodontium tinctorium*, the Indian paint fungus, was identified by the typical conks on the boles of infected trees (Goheen and Willhite 2006). The presence of witches' brooms and/or branch swellings in the tree crown indicated dwarf mistletoe (*Arceuthobium* spp.). White pine blister rust, caused by *Cronartium ribicola*, and western gall rust, caused by *Endocronartium harknessii*, were diagnosed by their characteristic cankers and swellings on white pine and lodgepole pine, respectively. These diseases also were recorded on living trees. Most causes of tree mortality listed as "other" could not be identified when there were no signs or symptoms of causal agents. Dead trees (standing or down) with intact bark on less than half of their circumference at the root collar were considered to have been dead >20 years and were not sampled, since such trees are often too deteriorated to identify causal agents. This also avoided the possibility of including the same dead trees in both the 1981 and the 2010 surveys.

Because tree mortality caused by the fir defoliators, western spruce budworm or Douglas-fir tussock moth, usually has no signs of the causal agents, mortality could not be attributed to these defoliators. Trees heavily defoliated by these insects often are attacked by fir engravers, Douglas-fir beetles, or root pathogens that do leave signs. Many trees with mortality attributed to root diseases or bark beetles may have been previously defoliated by insects, but this is unlikely. There have been no outbreaks of Douglas-fir tussock moth in the survey area in the last 30 years. Western spruce budworm has defoliated firs in parts of the survey area in 2007-09 and in 2011 but not for the last 30 years since 2007.

Laminated root rot caused by *Phellinus sulphurascens*

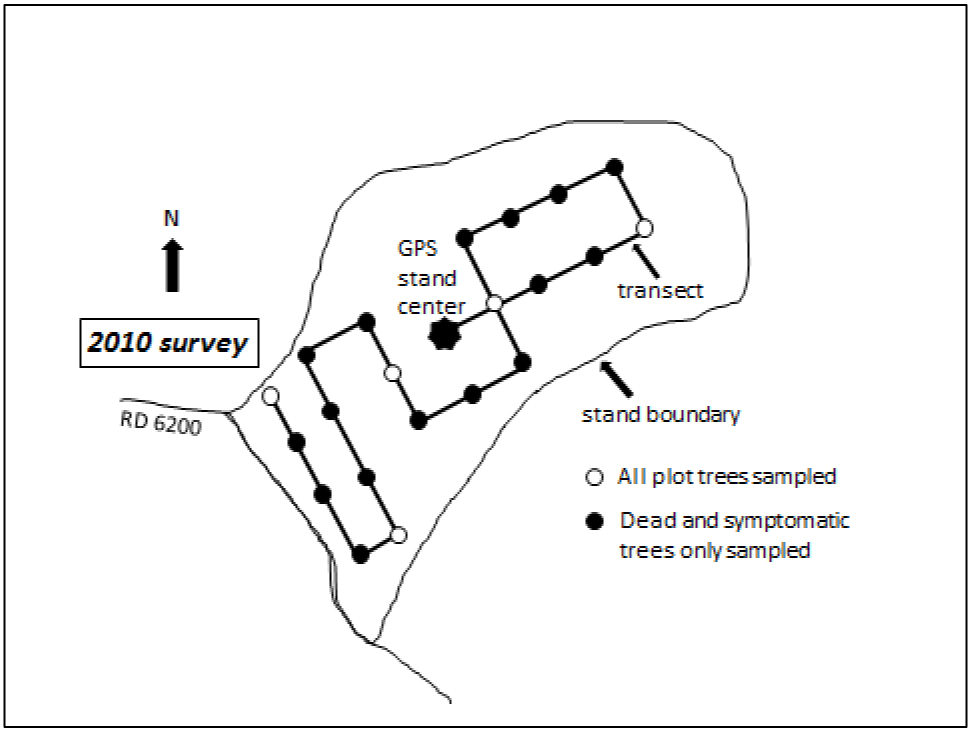


Fig. 4 – Diagram of a sampled stand showing typical transect design and plot locations in 2010.

In June, July, and September 2010, each of the nine stands was re-sampled as above, except that a portable Global Positioning System (GPS) unit was used to locate the exact stand center to begin the sampling transect (Fig. 4). Transects were previously arranged to start at the stand center point, fit within the stand, and sample the exact number and type of plots examined in 1981. Because permanent plots were not established in 1981, most plots established in 2010 probably were not at the exact same location as the plots established in 1981.

From the collected data, trees/ha and basal area (m^2)/ha (BA/ha) were calculated for each stand and year, and tabulated for each tree species-tree condition/cause class. Data were analyzed using ANOVA (Hoel *et al*. 1971). We used a paired Student t-test to identify significant differences between surveys in 1981 and 2010 in the incidence (trees/ha and BA/ha) of pest-caused tree mortality and pest presence in live trees. The experimental unit was the stand (nine total stands). We used the SAS 9.3 GLM procedure to test the comparisons.

Results

In 1981 and 2010, nine 12- to 77-ha stands totaling about 400 ha were sampled for tree mortality and pathogens in living trees (Table 1). Except for parts of stands 148 and 149, there was no evidence of tree harvesting from 1981 to 2010. Harvesting in these stands resulted in small clearcuts of 5-10 ha that were planted with ponderosa pine, lodgepole pine, Douglas-fir, and blister-rust-resistant white pine.

Large Trees (≥12.7 cm dbh)

For most of the nine stands on either a trees/ha or a basal-area/ha basis, there were fewer apparently healthy trees ≥12.7 cm dbh in 2010 than in 1981 (Figs. 5 and 6). There was significantly (P=0.03) less healthy-appearing Douglas-fir in 2010 than in 1981 for trees/ha

(Table 2, Fig. 7). Percent tree mortality, however, varied between the 1981 and 2010 surveys (Fig. 8 and 9). Mortality by cause was also rather variable between 1981 and 2010 (Fig. 10).

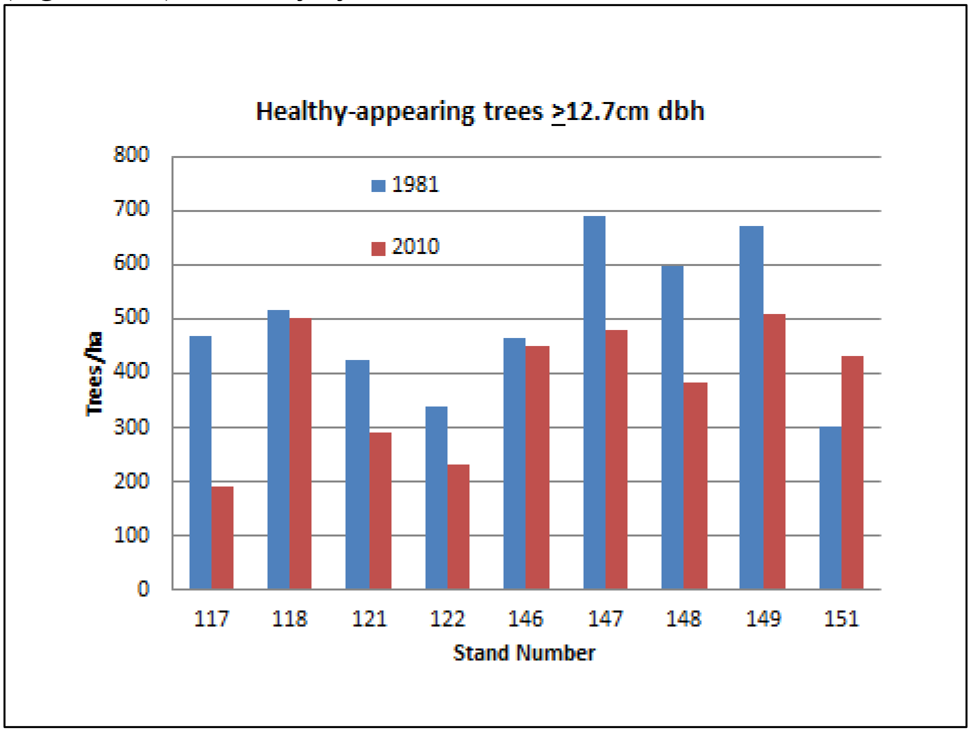


Fig. 5 – Healthy-appearing **trees/ha** (all species) by stand number and year surveyed.

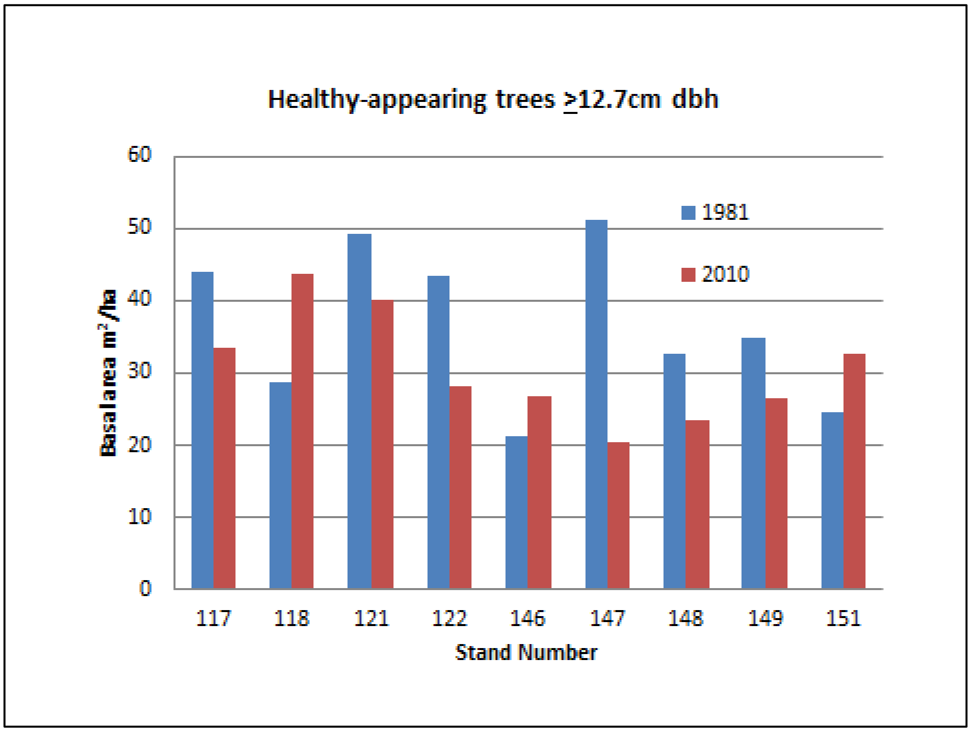


Fig. 6 – Healthy-appearing trees by **basal area/ha** (all species) by stand number and year surveyed.

Table 2. Frequency of healthy-appearing and dead trees by tree species and causal agent with significant (P<0.10) differences between surveys in 1981 and 2010 for nine stands on the Wenatchee River Ranger District in central Washington. A paired Student t-test was used to test for significant differences where a **positive difference** indicates that the trees/ha or basal area/ha in 2010 is greater than the trees/ha or basal area/ha in 1981 for the given mortality agent. A **negative difference** indicates the opposite.

Tree condition by species, causal agent, and amount		Estimated difference between 1981 and 2010	Std. error	P-value
Healthy-appearing trees (≥12.7 cm dbh)				
Douglas-fir	**trees/ha**	-62.03	23.14	0.028
Dead trees (≥12.7 cm dbh) by causal agent				
Douglas-fir beetle	**trees/ha**	3.54	1.48	0.044
	basal area (m^2)/ha	0.62	0.30	0.071
Fir engraver in grand fir	**basal area (m^2)/ha**	0.23	0.07	0.016
Pine bark beetles				
Ponderosa pine	**basal area (m^2)/ha**	-0.18	0.08	0.058
	trees/ha	-3.78	1.87	0.078
Lodgepole pine	**trees/ha**	-6.18	2.25	0.025
Annosus root disease				
Douglas-fir	**basal area (m^2)/ha**	0.07	0.02	0.020
Grand fir	**trees/ha**	5.93	1.91	0.014
	basal area (m^2)/ha	0.39	0.15	0.027
***Echinodontium*-caused decay breakage in grand fir**	**basal area (m^2)/ha**	-0.06	0.03	0.087
Other or unknown causes of mortality				
Engelmann spruce	**basal area (m^2)/ha**	0.11	0.05	0.058
Lodgepole pine	**basal area (m^2)/ha**	-0.19	0.10	0.083
Douglas-fir	**trees/ha**	-10.64	4.94	0.064
Healthy-appearing saplings (<12.7 cm dbh)				
Lodgepole pine	**trees/ha**	62.55	29.37	0.066
	basal area (m^2)/ha	0.28	0.13	0.063
Dead saplings by causal agent				
Annosus root disease				
Grand fir	**trees/ha**	4.59	1.36	0.010
	basal area (m^2)/ha	0.013	0.006	0.064
Other or unknown causes of sapling mortality				
Douglas-fir	**trees/ha**	-26.43	8.64	0.016
	basal area (m^2)/ha	-0.08	0.03	0.017
Lodgepole pine	**basal area (m^2)/ha**	-0.03	0.01	0.074

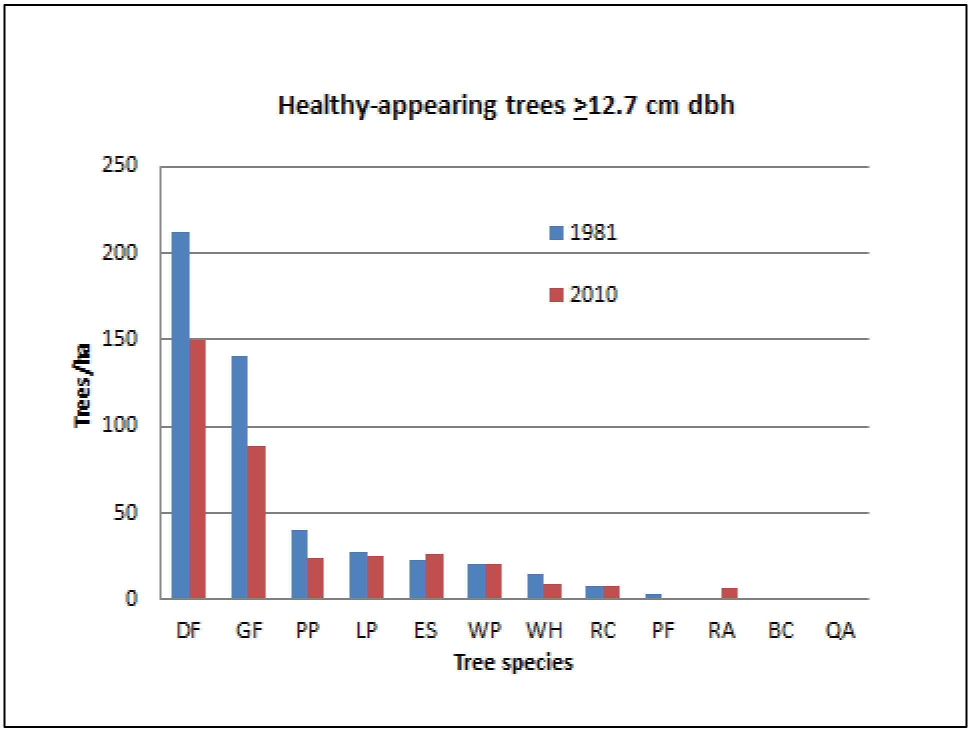


Fig.7 – Healthy-appearing trees/ha (all stands) **by tree species** and year surveyed. DF=Douglas-fir, GF=grand fir, PP=ponderosa pine, LP=lodgepole pine, ES=Engelmann spruce, WP=western white pine, WH=western hemlock, RC=western redcedar, PF=Pacific silver fir, RA=red alder, BC=black cottonwood, and QA=quaking aspen

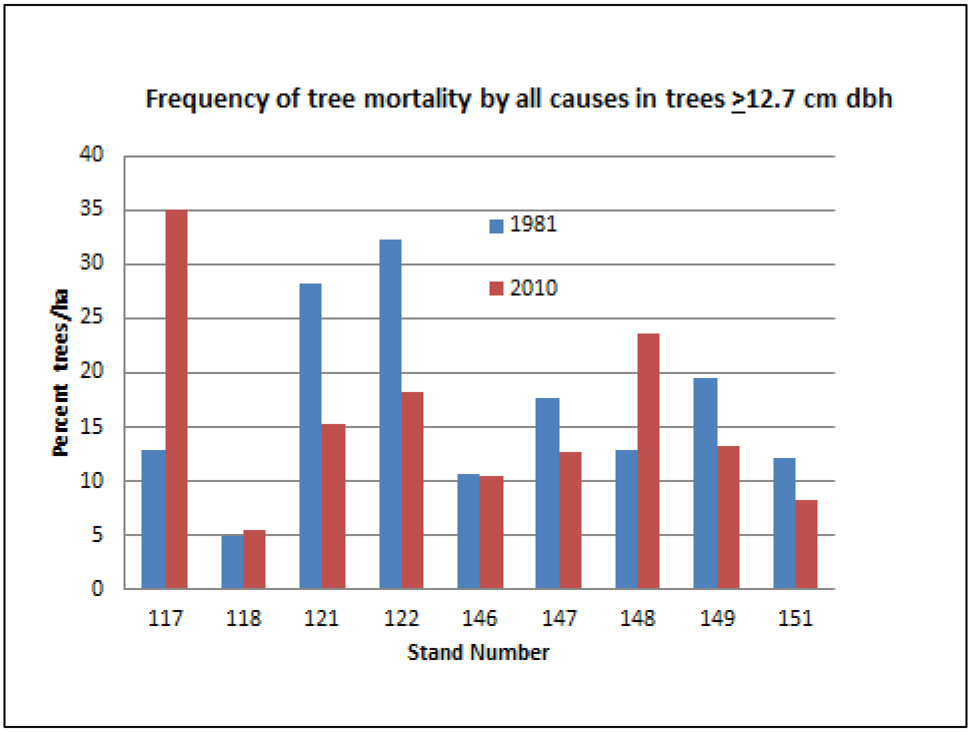


Fig. 8 – Frequency of tree mortality (all species) in **percentage of trees/ha** by stand number and year surveyed.

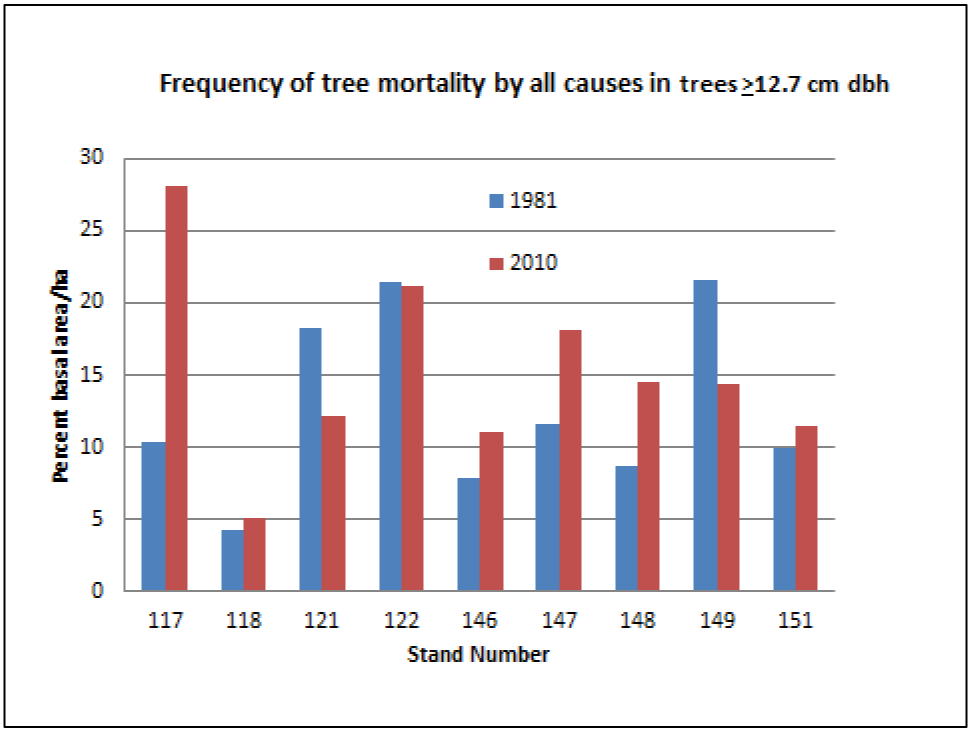


Fig. 9 – Frequency of tree mortality (all species) in **percentage of basal area (m^2)/ha** by stand number and year surveyed.

Bark-beetle-caused tree mortality was quite variable between 1981 and 2010 because mortality frequency varied depending on the species of bark beetles (Fig. 10). There was more bark beetle-caused fir mortality in 2010 than in 1981 with significant differences in BA/ha for fir engraver in grand fir (P=0.02) and Douglas-fir beetle in Douglas-fir for trees/ha (P=0.04) and BA/ha (P=0.07) (Table 2). However, there was significantly less bark beetle-caused pine mortality in 2010 than 1981 (Fig. 10) with significant differences in bark beetles (mostly mountain pine beetle and western pine beetle) in ponderosa pine trees/ha (0.08), BA/ha (P=0.06) and mountain pine beetle in lodgepole pine trees/ha (P=0.03, Table 2). Mortality was especially high in 1981 in stands 148 and 149 caused by the mountain pine beetle in lodgepole and western white pine (Fig. 11). These two stands received some harvesting after 1981.

Relatively high levels of mortality were found in Douglas-fir and grand fir from root diseases, especially from laminated root rot in stands 121 and 122 in 1981 and stand 117 in 2010 (Fig. 12). For *Heterobasidion*-caused tree mortality, there was significantly more BA/ha loss in Douglas-fir (P=0.02) and grand fir (P=0.03), and significantly (P=0.01) more loss in trees/ha for grand fir in 2010 than in 1981 (Table 2). Reasons for this are unknown, since infection and subsequent mortality from *H. occidentale* are closely related to high levels of stand harvesting and stump creation, but relatively little harvesting occurred in the study area after 1981. On the other hand, the amount of grand fir regeneration increased since 1981 (Fig. 14 and 18) due to disturbances caused by scattered overstory mortality. Grand fir is highly susceptible to *H. occidentale* (formerly *H. annosum*, Goheen and Willhite 2006) and may have contacted the pathogen from infected roots of overstory firs. Douglas-fir is not considered to be highly susceptible to *H. occidentale* in Oregon and Washington, but damage does appear to increase with increasing latitude. Other root pathogens found in relatively minor amounts included *Phaeolus schweinitzii* in Douglas-fir and *Inonotus tomentosus* in Engelmann spruce.

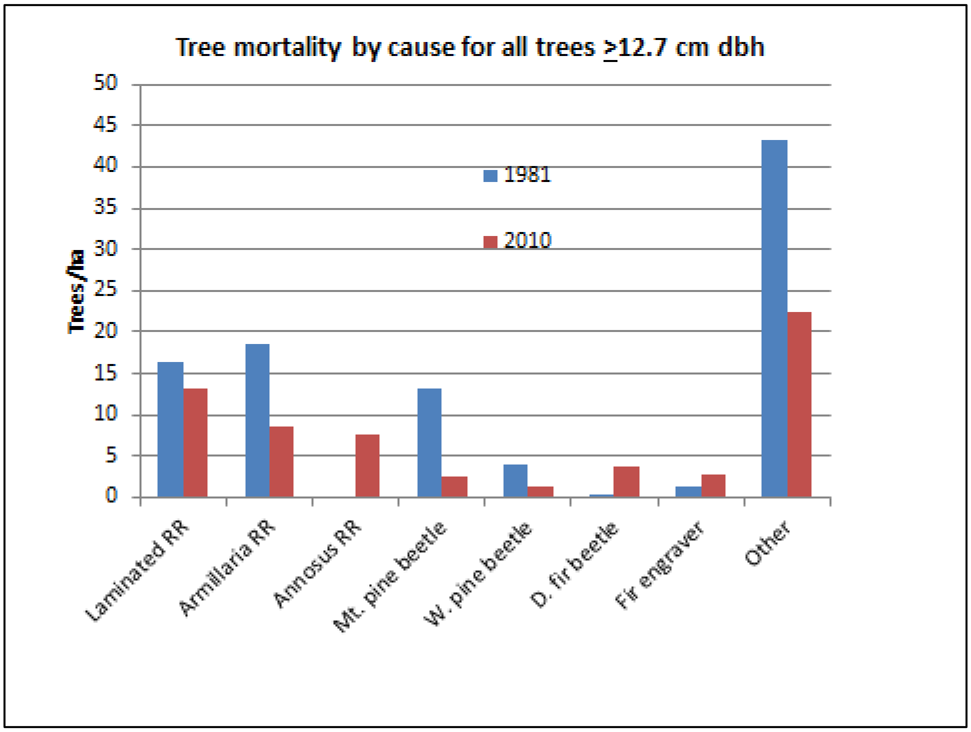


Fig. 10 – Tree mortality (all stands) in trees/ha **by causal agent** and year surveyed.

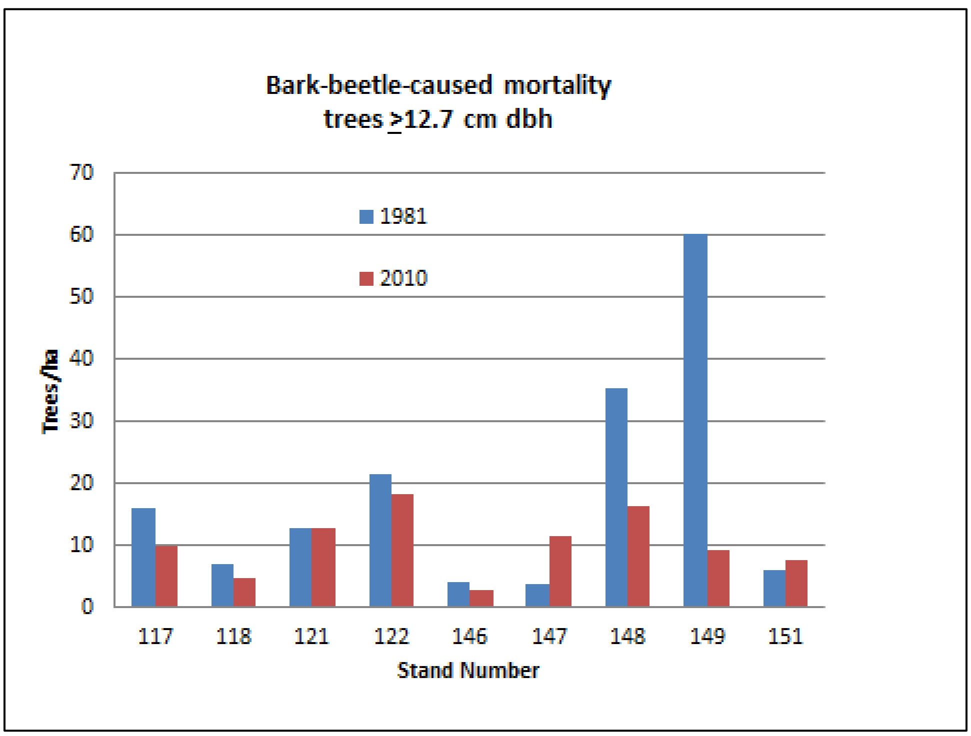


Fig. 11 – **Bark beetle**-caused tree mortality in trees/ha by stand number and year surveyed.

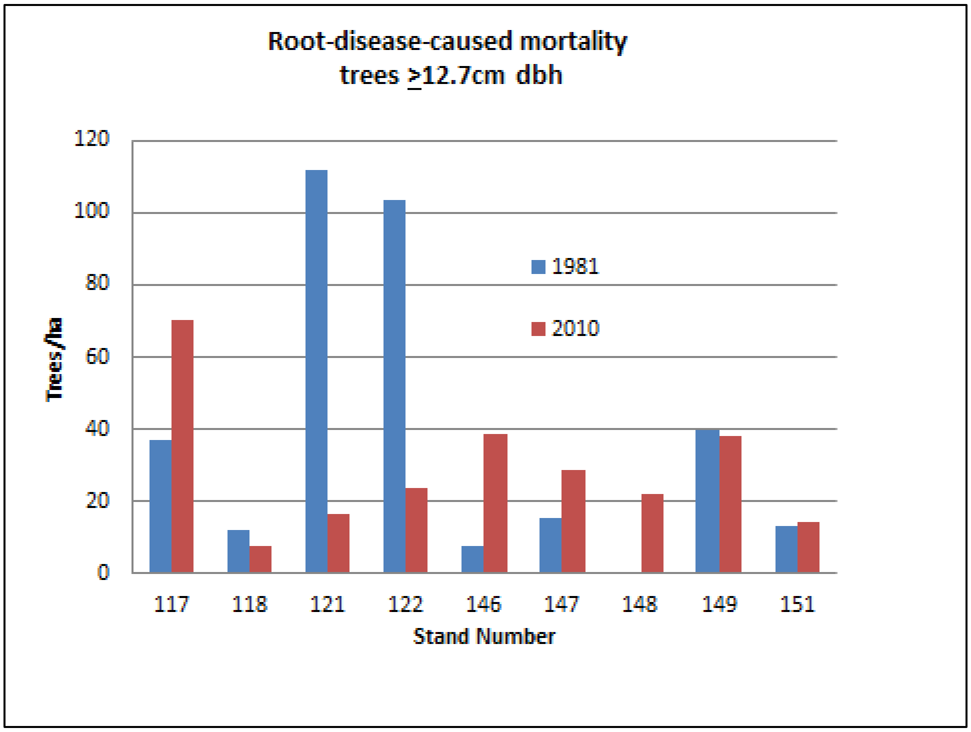


Fig. 12– Root disease-caused tree mortality in trees/ha by stand number and year surveyed.

Other causes of tree mortality besides root diseases and bark beetles included stem decay and breakage caused by the Indian paint fungus, Douglas-fir dwarf mistletoe, white pine blister rust, western gall rust on lodgepole pine, and animal and weather-related damage. Most other causes of mortality were not identified. There was significantly (P=0.09) more BA/ha mortality loss due to stem breakage in grand fir caused by the Indian paint fungus in 1981 than in 2010 (Table 2). There was significantly more mortality losses from other causes in Engelmann spruce BA/ha in 2010 than in 1981 (P=0.06). There was significantly less mortality loss from other causes in 2010 than in 1981 for lodgepole pine BA/ha (P=0.08) and Douglas-fir trees/ha (P=0.06).

Incidence (trees/ha) of Douglas-fir dwarf mistletoe in live trees was generally greater in 1981 than in 2010 except in stands 146 and 151, but differences were not significant (P=0.96). No Douglas-fir dwarf mistletoe was detected in stands 118 and 148. Some western dwarf mistletoe (*A. campylopodum*) was found on ponderosa pine.

Incidence of white pine blister rust in live pines also was generally greater in 1981 than in 2010, and especially high in stand 149. There was no white pine blister rust detected in stands 121 and 146 in either year. Some western gall rust was found on live, young, lodgepole pine in stand 148 in 1981 and 2010.

The Indian paint fungus was found in 5 of 9 stands, decaying mostly living grand fir but also some Engelmann spruce, Pacific silver fir, and western hemlock. Some trees with conks had stem breakage below the live crown resulting in tree death (see above). Besides *E. tinctorium*, only conks of *Phellinus pini* were found on a few living trees.

Saplings (2.5 to 12.6 cm dbh)

More healthy-appearing saplings were found in 2010 than in 1981 (Fig. 13). There was significantly more healthy-appearing lodgepole pine saplings/ha (P=0.07) and BA/ha (P=0.06) in 2010 than in 1981 (Table 2, Fig. 14). There were more grand fir saplings than other species, especially in 2010 (Fig. 14). Sapling mortality was greater in 1981 than in 2010 (Fig. 15). The highest frequency of mortality was in ponderosa pine in 1981 mostly from other causes (Fig. 16), but there were relatively few healthy-appearing or killed ponderosa pine saplings (Fig. 17). Douglas-fir, grand fir, ponderosa pine, lodgepole pine, white pine, and Englemann spruce had more mortality, mostly from other causes, in 1981 than in 2010 (Fig. 16). Differences were significant, however, for Douglas-fir saplings/ha (P=0.02) and BA/ha (P=0.02) and lodgepole pine BA/ha (P=0.07).

Most sapling mortality was from other or unidentified causes, but there was scattered mortality from laminated, Armillaria, and annosus root diseases, usually associated with disease centers in the overstory trees. As with larger trees, there was significantly more grand fir mortality due to annosus root disease for trees/ha (P=0.01) and BA/ha (P=0.06) in 2010 than in 1981 (Table 2). Sapling mortality due to white pine blister rust occurred in one stand in 1981 and four stands in 2010. Most saplings were too small to be killed by any of the major bark beetle species.

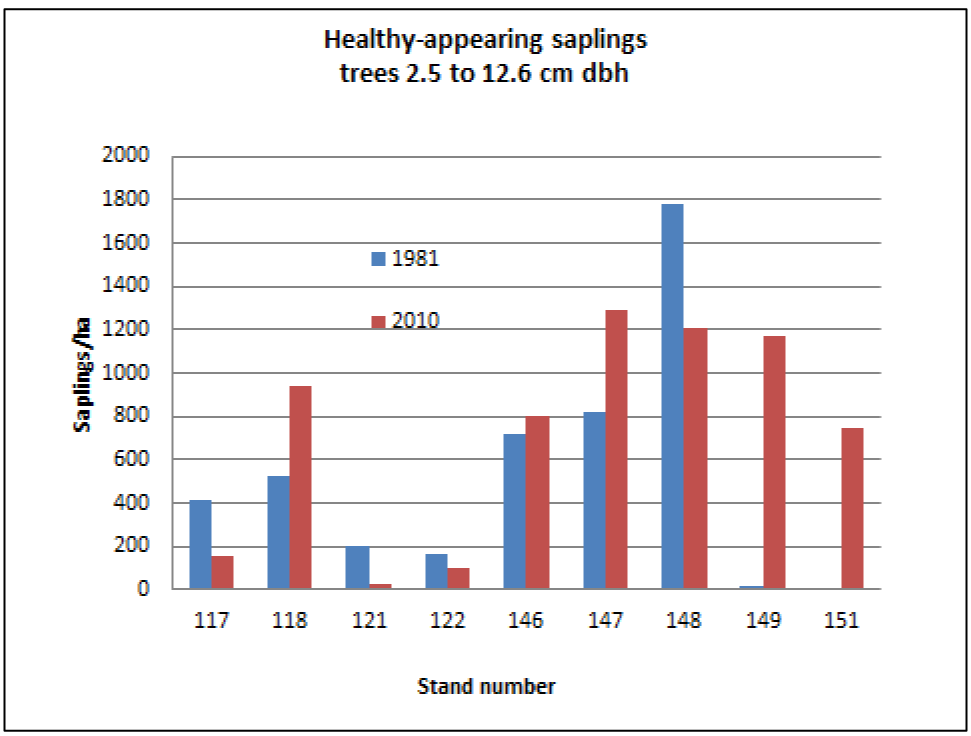


Fig. 13 – Healthy-appearing **saplings**/ha (all species) **by stand number** and year surveyed.

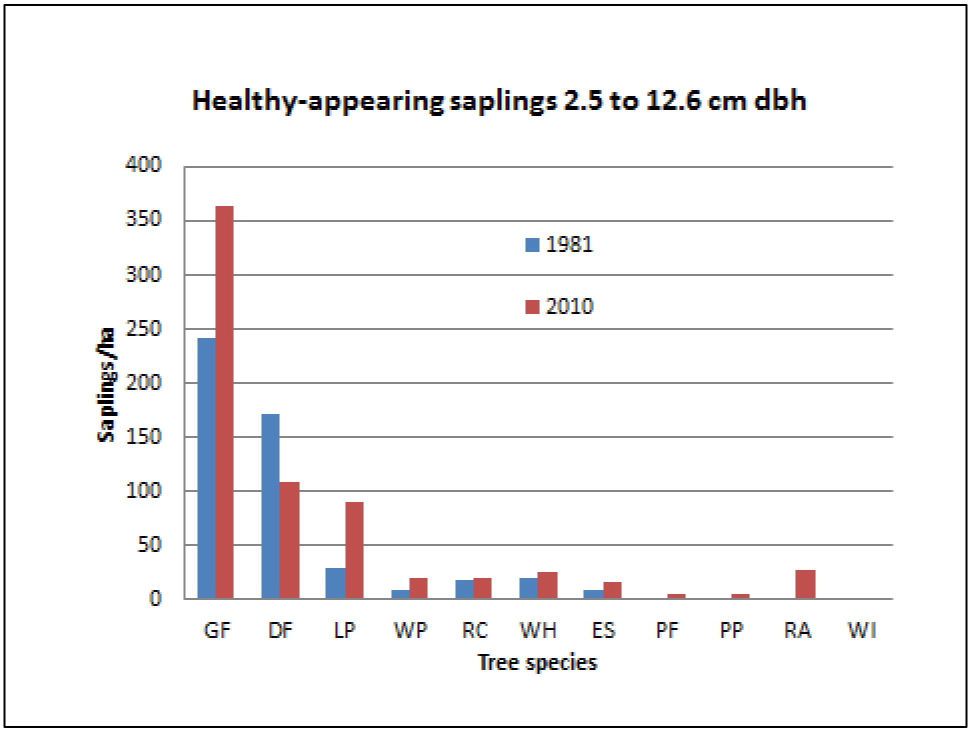


Fig. 14 – Healthy-appearing saplings/ha (all stands) **by tree species** and year surveyed. DF=Douglas-fir, GF=grand fir, PP=ponderosa pine, LP=lodgepole pine, ES=Engelmann spruce, WP=western white pine, WH=western hemlock, RC=western redcedar, PF=Pacific silver fir, RA=red alder, WI=willow

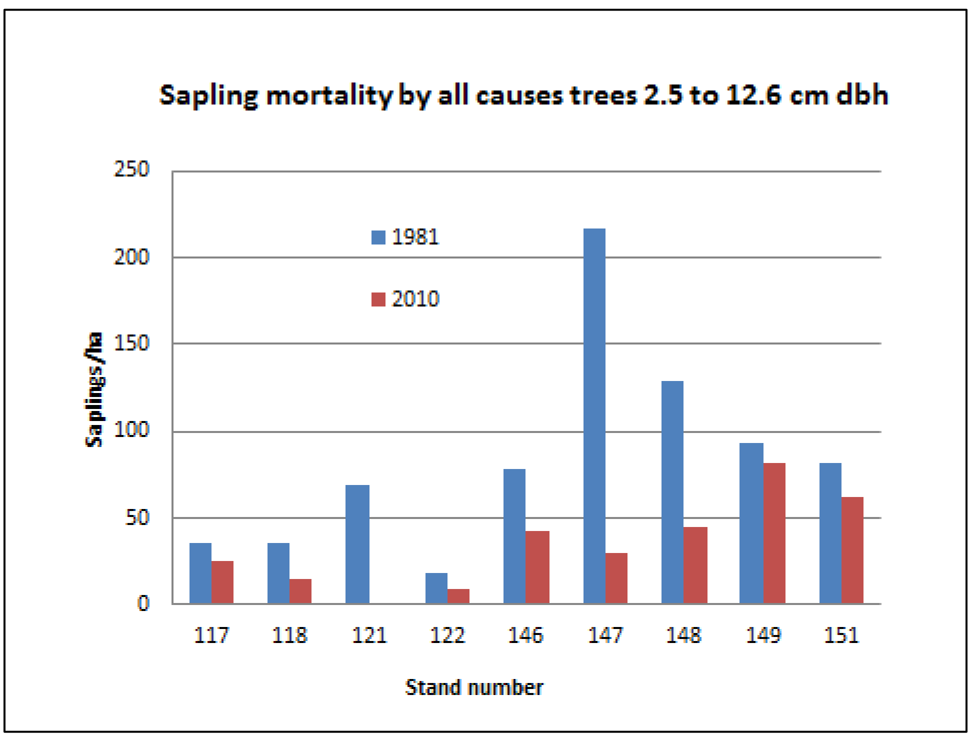


Fig. 15 – Sapling mortality in **trees/ha** (all species) **by stand number** and year surveyed.

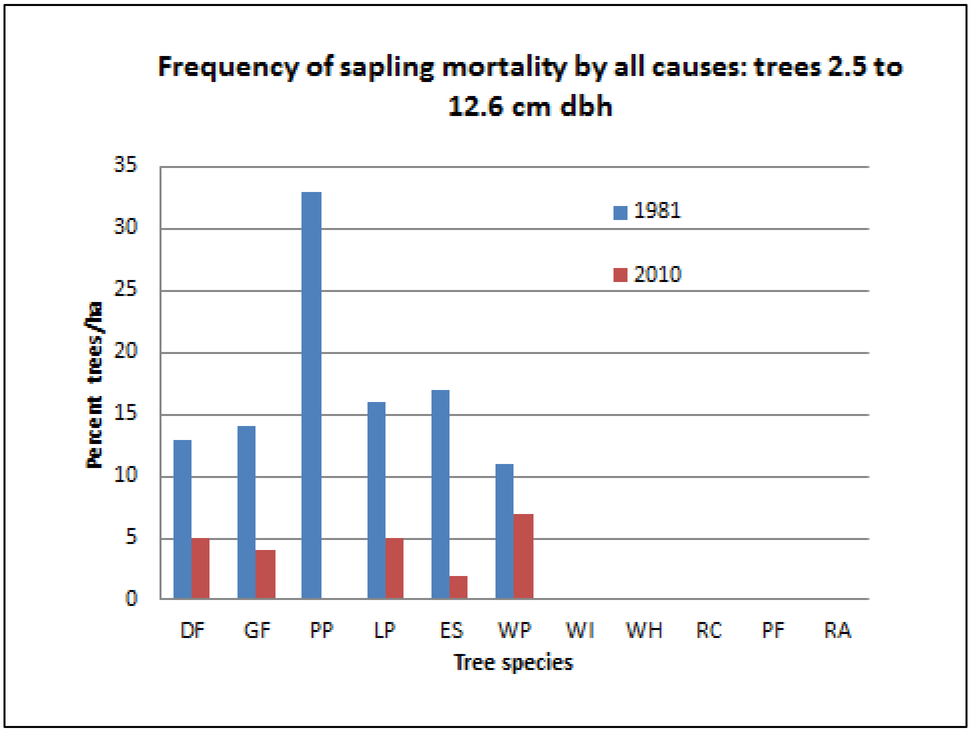


Fig. 16 – Frequency of sapling mortality in **percentage of trees/ha by tree species** and year surveyed. DF=Douglas-fir, GF=grand fir, PP=ponderosa pine, LP=lodgepole pine, ES=Engelmann spruce, WP=western white pine, WI=willow, WH=western hemlock, RC=western redcedar, PF=Pacific silver fir, RA=red alder

Douglas-fir dwarf mistletoe was found on living saplings in one stand in 1981. Lodgepole pine dwarf mistletoe (*A. americanum*) was found on living saplings in one stand in 2010. White pine blister rust was found on living white pine saplings in one stand in 1981 and four stands in 2010. *Echinodontium tinctorium* was found fruiting on a live sapling in one stand in 1981. Although conks of *E. tinctorium* are not common on trees <40-years old, suppressed grand fir trees <12.7 cm dbh can be >40-years old.

Although seedling mortality (trees <2.5 cm dbh but $\geq$ 15.2 cm in height) was not recorded, most stands generally had more healthy-appearing seedlings in 2010 than in 1981. Grand fir had the most seedlings/ha, especially in 2010 (Fig. 18).

Indian paint fungus (*Echinodontium tinctorium*)

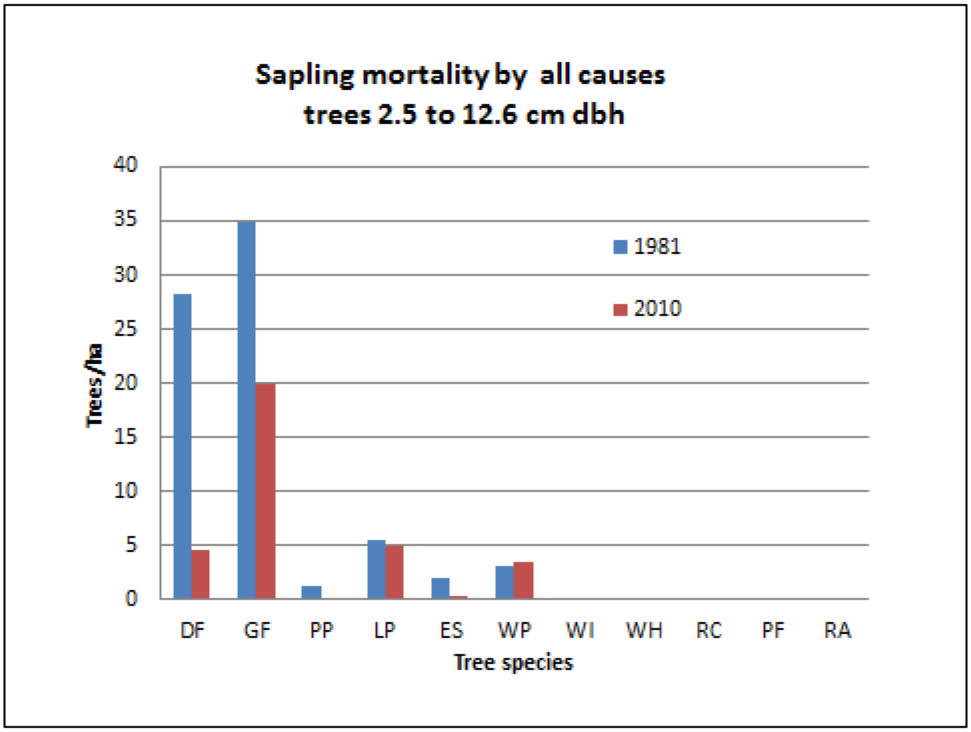
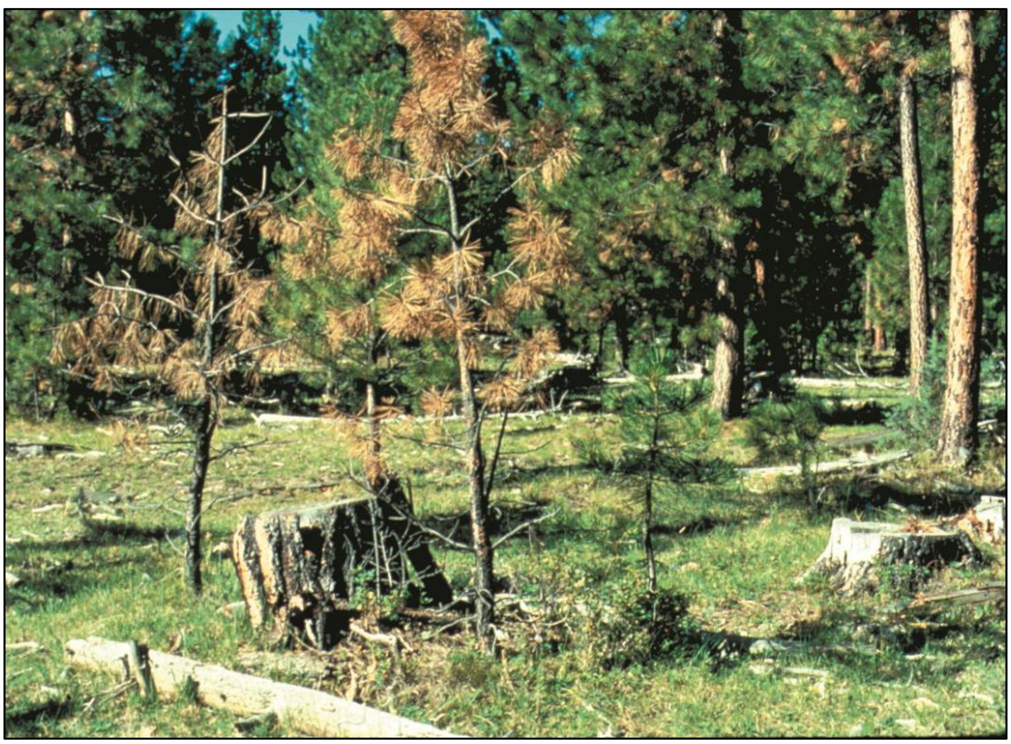


Fig. 17 – Sapling mortality in **trees/ha by tree species** and year surveyed. DF=Douglas-fir, GF=grand fir, PP=ponderosa pine, LP=lodgepole pine, ES=Engelmann spruce, WP=western white pine, WI=willow, WH=western hemlock, RC=western redcedar, PF=Pacific silver fir, RA=red alder



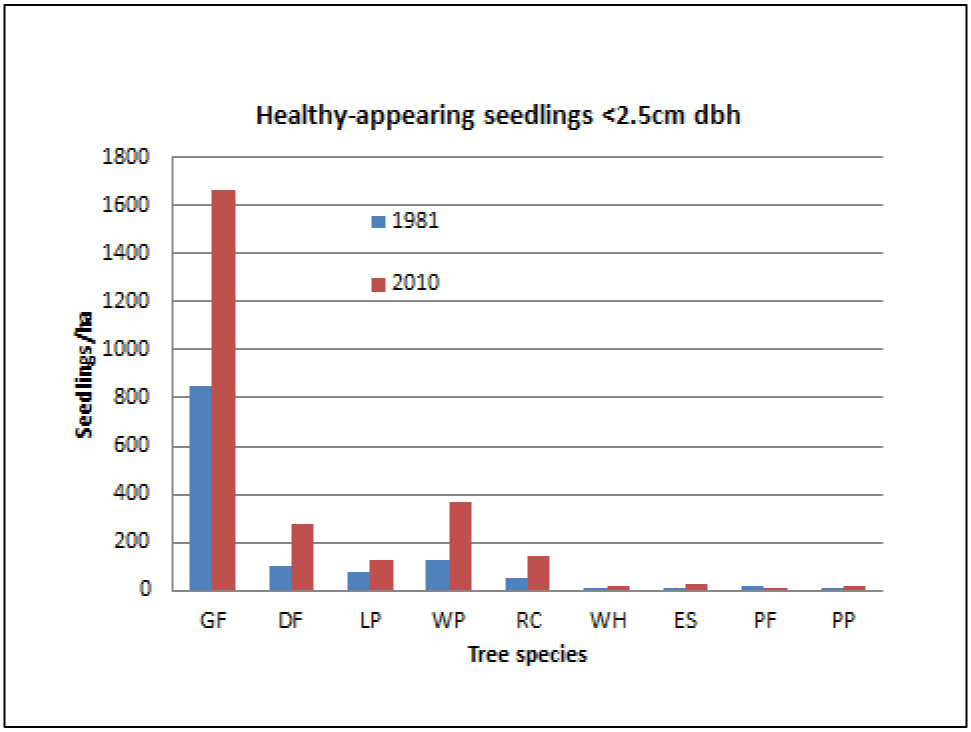


Fig. 18 – Healthy-appearing **seedlings**/ha (all stands) by tree species and year surveyed. DF=Douglas-fir, GF=grand fir, PP=ponderosa pine, LP=lodgepole pine, ES=Engelmann spruce, WP=western white pine, WH=western hemlock, RC=western redcedar, PF=Pacific silver fir

Discussion

The Chiwawa River valley in central Washington presented a unique opportunity to observe and compare, in a relatively pristine forest, the incidence of tree mortality from primarily forest diseases and insects over several decades. The forest is dominated by Douglas-fir and grand fir, highly pest-prone species. Over the past 30 years, there were fewer healthy trees in 2010 than in 1981. Except for parts of two stands, there was no evidence of tree harvesting from 1981 to 2010 in the areas surveyed. As a result, both trees/ha and basal area/ha increased to levels that effectively supported the spread and intensification of bark beetles and root pathogens in these stands.

Root pathogens spread primarily by root contact among susceptible hosts, and true firs especially have a long history of root-pathogen spread and subsequent tree mortality in overly dense forests (Hessburg *et al*. 1994; Filip *et al.* 2007a, b, 2010). Bark beetles are attracted to stressed trees as a result of high stand densities, root infections, excessive windthrow, prolonged drought, severe defoliation, and several combined factors. Extensive tree mortality, while perhaps contributing to the ecological value of the area (Franklin *et al.* 1987), will need to be mitigated when it negatively affects the developed parts of the watershed such as several campgrounds, trailheads, private inholdings, and the road system, especially in the lower Chiwawa River valley. Dead, diseased, and fire-damaged trees are more prone to failure, and the hazard should be mitigated to insure public safety along roads and within developed sites at the very least (Toupin *et al.* 2008, Filip *et al*. 2014).

The stands that we evaluated are designated as late-successional reserve and as such, serve to perpetuate older-stand structures and all of the organisms associated with such forests. Preserving late-successional stages in eastside forests of the Pacific Northwest is difficult at best and perhaps impossible in the long term. As we found in our survey, climax species such as grand fir and Douglas-fir are prone to attack and mortality from a myriad of pests that function to help return the forest to a seral stage. Most insect and disease outbreaks in our evaluated area, however, have not been severe enough to adequately create gaps to support large areas of seral species such as ponderosa or western white pine. In fact, for the past 30 years, grand fir and Douglas-fir regeneration, as well as vine maple, have dominated most pest-created openings in the survey area (Figs. 14 and 18).

Unless severe wildfire or sufficient harvesting occur to create adequate gaps for seral-species regeneration and survival, forests within the Chiwawa River valley will continue to support high populations of bark beetles and root pathogens that create more dead trees, mortality gaps, and subsequent down wood and soil organic matter. Such activity may meet the current objectives of the late-successional reserve but at an eventual cost. Should severe wildfire occur, as in adjacent watersheds, the esthetic and recreational values of the area may change for decades to a fire-altered landscape with long-term hazards from burned and killed trees in the developed areas.

Conclusions

1. **Most stands had less trees/ha and basal area/ha in 2010 than in 1981.**
2. **Most stands had more seedlings and saplings in 2010 than in 1981; however, most were pest-susceptible grand fir and Douglas-fir.**
3. **Frequency of mortality varied greatly by stand and year surveyed. Most mortality was caused by root diseases and bark beetles.**
4. **Except for parts of 2 of 9 stands, there was no evidence of tree harvesting from 1981 to 2010.**
5. **Unless severe wildfire or sufficient harvesting occurs to create adequate gaps for seral-species regeneration and survival, forests in the Chiwawa River valley will continue to support high bark-beetle and root-pathogen populations, and grand fir and Douglas-fir will continue to occupy significant portions of all canopy levels within the forest.**
6. **If severe wildfire occurs, the esthetic and recreational values of the area may change for decades to a fire-altered landscape with long-term hazards from burned and killed trees in the developed areas.**

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