Forest Health Alternate Plans for the Small Forest Landowner in Eastern Washington: Criteria for evaluating candidate stands for likelihood of mortality due to insects, disease, and fire

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Introduction:

This document is intended to provide technical guidance related to diagnosing and addressing existing or imminent mortality in eastern Washington riparian zones due to insects, disease, and fire. This information can be used by landowners and natural resource professionals in designing, evaluating, and implementing alternate plans.

Washington's Forest Practices Rules restrict active management in riparian zones east of the crest of the Cascade Mountains. The rules state that a minimum of fifty trees per acre at least six inches in diameter at breast height (DBH, 4.5 feet above ground) are required to maintain adequate riparian functions (Washington State Forest Practices Board Manual Sec. 21). Mortality of trees resulting in less than fifty trees per acre surviving in the riparian zone may compromise riparian function. If management in a riparian area is deemed necessary to address imminent mortality, the small forest landowner has the option to submit an **alternate plan** that includes a forest health management strategy to accelerate restoration of full riparian function.

A candidate stand for forest health alternate plans is defined in **Board Manual Sec. 21, part 1.3:**
Riparian forests susceptible to significant tree mortality are likely to benefit from active management in the riparian zone to promote forest health and restore riparian function when:

- Within **five years** due to the effects of insects, disease, pathogens or recent fire the riparian forest would be expected to have **only fifty or fewer trees larger than 6-inches DBH per acre with healthy crowns remaining**; and,
- Active management would be expected to provide improved riparian function faster than would occur in the unmanaged stand while maintaining comparable interim protection of riparian function.

Objective:

This document describes criteria that can be used to identify candidate stands for **alternate plans** to address imminent mortality. Criteria are specific to each mortality agent and host species. In many cases, **individual** trees within the candidate stand must be identified as dead or likely to die within five years as a result of insect, disease, or fire activity. However, for **specific bark beetles and root diseases**, groups of currently unaffected susceptible host trees may be identified as at risk of mortality within five years.

Determining the candidate stand:

1. The Board Manual Sec. 21 definition of "Candidate Riparian Stands" states: "Diseased or insect-infested stands show evidence that the disease or insect is present either within the riparian area or in adjacent stands and would be expected to cause significant mortality in the riparian area within five years." Pathogens or insects must be **accurately identified** within the candidate stand. However, for some specific bark beetles and root diseases, mortality in an adjacent stand may warrant an alternate plan if trees within the candidate stand meet susceptibility criteria defined in this document.
2. Estimated current and expected mortality (within five years) will result in 50 or fewer trees per acre larger than 6-inches DBH with healthy crowns remaining.
3. Proposed active management will improve riparian function faster than would occur in the unmanaged stand while maintaining comparable interim protection of riparian function. See Board Manual Sec. 21 for guidelines on mitigation of sediment delivery, equipment limitation zone (ELZ), and retention of snags and large woody debris.
4. Proposed active management is limited to the **scope** of problem. Management should be limited to the geographic area within or in appropriate proximity to the current pest activity.

Definitions:

- Hazard rating – Evaluation of the susceptibility of a stand to infestation by a specific insect or pathogen based on site and stand conditions. Examples of site and stand attributes included in hazard rating models are proportion of host species, stand density index, average diameter, site index, or precipitation zones. **Hazard ratings cannot be used to predict mortality of individual trees.**
- Healthy crown – Trees having at least 1/3 of their total height in live crown.
- Mixed stand mortality – Most insects and pathogens are host specific mortality agents. In a mixed stand, expected mortality due to each agent-host combination is added to calculate total expected stand mortality.
- Mortality – For the purpose of this evaluation, mortality is defined as total, permanent loss of live crown. Total crown color of tan, buff, brown, or red foliage indicates mortality of non-deciduous conifers. Apparent total defoliation by defoliating insects (i.e. western spruce budworm and Douglas-fir tussock moth) is not necessarily an indicator of mortality. Defoliated trees may recover the following spring. Therefore, zero bud break in spring is an indicator of mortality. If mortality must be determined before spring, a method of sampling for dead cambium at four quadrants around the root collar can be used (Filip et al. 2007).
- Pest complexes – Tree mortality is often the result of injury by multiple factors or agents (Edmonds et al. 2000; Filip et al. 2007).
    - **Predisposing factors** reduce resources that trees can allocate for defense; examples include planting species not suitable to the site, drought, or competition.

    - **Inciting factors** can compromise or exhaust tree defense mechanisms; examples include non-lethal fire injury, root disease, or defoliation.
    - **Contributing factors** are opportunistic agents, such as bark beetles, that subsequently kill compromised trees.
- Proximity – A criterion used to estimate expected mortality from specific **bark beetles and root diseases only**. Proximity is the distance between candidate trees and ongoing mortality in adjacent trees that may be a source of infestation or infection. In the case of bark beetles, trees that are already dead (red foliage or no foliage) are not likely to be occupied by beetles and may not represent a source of infestation. In some cases, Douglas-fir trees attacked by Douglas-fir beetle may change color the same year of attack. Another exception would be mountain pine beetle infested trees attacked in June or early July that have turned red but beetles have not yet flown. Therefore, bark should be removed from red-dead trees to confirm presence or absence of live bark beetles.
- Risk rating – For some bark beetles, risk ratings integrate beetle pressure (size and proximity of an active infestation) and susceptibility of candidate host trees to predict the amount and likelihood of damage to a stand. **Risk ratings cannot be used to predict mortality of individual trees.**
- Successful bark beetle attack – One or more female bark beetles has reached the inner bark and excavated egg galleries in the inner bark. Often indicated by red boring dust or pink to red colored pitch. This criterion varies by species.

Major mortality agents in eastern Washington:

The following annotated list of major mortality agents in eastern Washington is divided into sections that address different damage agents. For each agent, the most susceptible hosts and a brief guide to agent identification are given. Specific criteria used for predicting host mortality, usually for individual trees, are listed for each agent. Other agents that commonly co-occur are listed as either "inciting" or "contributing" factors. Guidelines for evaluating the likelihood of mortality in nearby healthy trees are given under the headings "proximity" or "stand risk rating." Some agents have more than one section because the guidelines vary by host. For example, the mountain pine beetle has a separate section for each of its main hosts: lodgepole pine, ponderosa pine, and western white pine.

Dwarf Mistletoes

There are **many species** of dwarf mistletoe, *Arceuthobium* spp.

Hosts: Most dwarf mistletoe species only affect one species of conifer, although there are exceptions. Most eastern Washington conifers are affected by one or more species of dwarf mistletoe.

Identification:

Signs: Parasitic plants with scale-like leaves of various colors growing on the trunk or branches of the host trees.

Symptoms: Abnormal growth in the tree crown forming "witches brooms" or swelling of stems and branches. Crown deformities are slow to develop and slow to kill.

Mortality criteria: Trees that are likely to die within five years are conifers that have Hawksworth dwarf mistletoe rating of 5 or 6. Although some trees with a rating of 5 or 6 may survive for many years, their growth loss is very high and they will remain a source of infection for nearby healthy trees of the same species. See Appendix 1 for a description of the Hawksworth dwarf mistletoe rating system (Hawksworth 1977).

Contributing factors:

Bark beetles: Trees that are severely infected with dwarf mistletoe (Hawksworth rating > 4) are more susceptible to bark beetle attack and will likely die within five years if they are successfully attacked by bark beetles (fir engraver, mountain pine beetle, Douglas-fir beetle, spruce beetle and western pine beetle only). To determine the likelihood of mortality, refer to the mortality criteria for the bark beetle species involved.

Proximity: Only individual trees with a Hawksworth dwarf mistletoe rating of 5 or 6 meet the criteria.

Root Diseases

Laminated root rot, *Phellinus weirii*

Hosts: The most susceptible host species are Douglas-fir, grand fir, and mountain hemlock.

Identification:

Signs: Decayed roots with red, whiskery setal hyphae. White to grey ectotrophic mycelia **on the bark surface** of roots.

Symptoms: Slow decline of crown health with sparse, chlorotic, foliage. Severely infected trees may have a distress cone crop. A localized area of symptomatic host trees with damage progressively more severe near root rot center. Fallen trees with broken roots, missing roots, decayed roots, or "root balls." Decayed wood tends to separate (laminate) along annual rings.

Mortality criteria: Symptomatic live trees that are likely to die within five years have foliage transparency > 45% (FIA Field Manual 2007b). See Appendix 2 for method to estimate foliage transparency. Sign(s) of laminated root rot must be positively identified.

Contributing factors:

Bark beetles: Trees that are infected with positively identified *Phellinus* are more susceptible to bark beetle attack and will likely die within five years if they are successfully attacked by bark beetles (fir engraver and Douglas-fir beetle only). To determine the likelihood of mortality, refer to the mortality criteria for the bark beetle species involved.

Proximity: Symptomatic host trees with chlorotic, sparse foliage, and > 20% crown transparency can be considered likely to die within five years if they are within 30 feet (FIA Field Manual 2007a) of a symptomatic live tree with positively identified *Phellinus* that meets the mortality criteria above, or within 30 feet of a standing or down dead tree or decaying stump with positively identified *Phellinus*. Host trees greater than 30 feet from an infected tree or stump do not meet the criteria.

Armillaria root disease, *Armillaria* species

Hosts: Virtually all trees and many woody plants are susceptible to *Armillaria*, especially if they are stressed or have low vigor. In eastern Washington, Douglas-fir and grand fir are most susceptible.

Identification:

Signs: Lower stem or roots with thick, white, fan-shaped mycelial mats **under the bark surface**. If mycelial mats found on dead trees can be easily wiped off with a finger, they may be harmless decay fungi. Black to brown thread-like rhizomorphs may be found under root bark. Brown or honey-colored mushrooms may appear at the base of infected trees in the late summer or fall.

Symptoms: Slow decline of crown health with sparse, chlorotic, foliage. Copious resin flow at the base of the stem. Infected trees may have a distress cone crop. A localized area of symptomatic host trees with damage progressively more severe near root rot center. Fallen trees with broken roots, missing roots, decayed roots, or "root balls."

Mortality criteria: Symptomatic live trees that are likely to die within five years have foliage transparency >45% (FIA Field Manual 2007b). See Appendix 2 for method to estimate foliage transparency. Sign(s) of *Armillaria* root disease must be positively identified.

Contributing factors:

Bark beetles: Trees that are infected with positively identified *Armillaria* are more susceptible to bark beetle attack and will likely die within five years if they are successfully attacked by bark beetles (fir engraver, mountain pine beetle, Douglas-fir beetle, western pine beetle, red turpentine beetle, and spruce beetle only). To determine the likelihood of mortality, refer to the mortality criteria for the bark beetle species involved.

Proximity: Symptomatic host trees with chlorotic, sparse foliage, and > 20% crown transparency can be considered likely to die within five years if they are within 30 feet (FIA Field Manual 2007a) of a symptomatic live tree with positively identified *Armillaria* that meets the mortality criteria above or a decaying stump with positively identified *Armillaria*. Host trees greater than 30 feet from a symptomatic live tree do not meet the criteria.

Annosus root disease, *Heterobasidion annosum*

Hosts: Most conifers; grand fir is very susceptible in eastern Washington.

Identification:

Signs: Signs of annosus are difficult to identify in living hosts. Nearby stumps may have fruiting bodies (conks). The Annosus conk is brown on the upper surface and creamy white on the lower surface. The margin of the white area on conks is without pores. Decaying lower stem or roots may have black flecks in wood. Separation of wood along annual rings (delamination) may occur with pitting only on one side.

Symptoms: Slow decline of crown health with sparse, chlorotic, foliage. Infected trees may have a distress cone crop.

Mortality criteria: Symptomatic live trees that are likely to die within five years have foliage transparency >45% (FIA Field Manual 2007b). See Appendix 2 for method to record foliage transparency. Sign(s) of Annosus root disease must be positively identified.

Contributing factors:

Bark beetles: Trees that are infected with positively identified Annosus are more susceptible to bark beetle attack and will likely die within five years if they are successfully attacked by bark beetles (fir engraver, mountain pine beetle, and western pine beetle only). To determine the likelihood of mortality, refer to the mortality criteria for the bark beetle species involved.

Proximity: Host trees that do not meet the criteria may not be harvested.

Other Diseases

White pine blister rust, *Cronartium ribicola*

Hosts: Only **five-needle pines**: western white pine and whitebark pine.

Identification:

Signs: Yellow to orange fruiting bodies on cankers in spring and early summer.

Symptoms: Scattered red, dead branches (flagging). Darkened spindle-shaped branch swellings. Diamond shaped cankers on stem. Pitch streaming from cankers.

Mortality criteria: Trees that are likely to die within five years have **stem** cankers in the lower two thirds of the tree's height that cover 70% of the circumference of the main stem. Multiple cankers can be combined if they are within 3 vertical feet of each other (FIA Field Manual 2007a).

Contributing factors:

Bark beetles: Trees that are infected with positively identified white pine blister rust stem cankers in the lower two thirds of tree's height are more susceptible to bark beetle attack and will likely die within five years if they are successfully attacked by mountain pine beetles. To determine the likelihood of mortality, refer to the mortality criteria for mountain pine beetle in western white pine.

Proximity: Host trees that do not meet the criteria may not be harvested.

Bark Beetles

Fir engraver (FE), *Scolytus ventralis*

Hosts: Grand fir and subalpine fir

Identification:

Signs: Horizontal egg gallery 4 to 12 inches long that deeply etches the sapwood with an enlarged mating chamber in center. Larval galleries often decrease in length away from the mating chamber.

Symptoms: Red-brown boring dust and exit holes on main stem. Fading yellow to orange foliage in the crown. Occasionally, patches of bark are killed and the tree survives. Evidence of FE galleries may be etched in the wood surface in killed patches. Woodpeckers may be feeding on bark beetles occupying green-foliage trees.

Mortality criteria: Evidence of FE stem attacks is an unreliable predictor of tree mortality. Clear pitch streams are the most common evidence of FE attack; however they may indicate either an effective defense by the tree or a successful FE attack. It is also possible for individual fir engravers to successfully attack fir, but kill only patches of cambium. Host firs can compartmentalize the wound and continue growth. These patch kills can cause red branch flagging in isolated areas of the crown or top kill. Firs may survive several isolated attacks over many years. For these reasons, **trees that are likely to die within five years will have both a)** pitch streams, pitch droplets, or dry attacks spaced ≥ 1 attack per 6 inches of circumference distance over the entire circumference of the lower stem within an area of 3 vertical feet **and b)** evidence of reddening foliage throughout the entire crown (Furniss and Carolin 1977; Ferrell 1986).

Inciting factors:

Root disease: Fir trees that have positively identified root disease are more susceptible to FE attacks and will likely die within five years if they are successfully attacked by FE. During non-drought periods, fir engraver infestation is often in trees infected with root disease, so one should always check for root disease in or near trees infested with fir engraver.

Defoliators: Fir trees that have been defoliated by Douglas-fir tussock moth or western spruce budworm are more susceptible to FE attack and are more likely to die within five years if they are successfully attacked by FE.

Dwarf mistletoe: Fir trees with successful FE attacks and a Hawksworth rating >4 are likely to die within five years.

Balsam woolly adelgid: Fir trees with successful FE attacks and greater than 30% topkill are likely to die within five years.

Stand risk rating: If true fir trees within ¼ mile of the candidate stand are currently being attacked by FE, use the Scott (1996) risk rating to evaluate the susceptibility of the candidate stand. See Appendix 3 to calculate the stand risk rating. Trees that are already dead (red foliage or no foliage) likely are no longer occupied by beetles and may not represent current attack/infestation of FE. Bark should be removed from red-dead trees to confirm presence or absence of live bark beetles. If the Scott's composite score is ≥ 15, then some mortality within the candidate stand is likely. Trees that are likely to die within five years are of similar species, size, and vigor to those currently being attacked within ¼ mile of the infested stand.

Mountain pine beetle (MPB), *Dendroctonus ponderosae*

Host: Lodgepole pine

Identification:

Signs: Straight vertical egg gallery 10 to 30 inches long with a crook at the lower end. Larval galleries branch from random locations on both sides of the egg gallery.

Symptoms: Large (~1 in. diameter) white to red colored pitch tubes or orange-red boring dust in bark crevices on main stem. Fading yellow-green to yellow foliage in crown. Woodpeckers may flake off bark and expose wood. Occasionally, 'strip attacks' may occur on one side of the stem.

Mortality criteria: Trees that are likely to die within five years have pitch tubes from successful attacks (cream to pink in color, not clear or white) or dry attacks ≥ 4 per square foot of the entire stem circumference within an area of 3 vertical feet (Raffa and Berryman 1983). Evidence of pitch tubes combined with a fading yellow crown indicates a high likelihood of mortality.

Inciting factors:

Root disease: Lodgepole pine trees that have positively identified root disease are more susceptible to MPB attacks and will likely die within five years if they are successfully attacked by MPB.

Dwarf mistletoe: Lodgepole pine trees with successful MPB attacks and a Hawksworth rating >4 are likely to die within five years.

Stand risk rating: Trees that are likely to die within five years are of similar species, size, and vigor to those currently being attacked within ¼ mile of the infested stand. Trees that are already dead (red foliage or no foliage) likely are no longer occupied by beetles and may not represent current presence of MPB. An exception would be MPB infested trees attacked in June or early July that have turned red but beetles have not yet flown. Therefore, bark should be removed from red-dead trees to confirm presence or absence of live bark beetles. If lodgepole pine trees within ¼ mile of the candidate stand are currently being attacked by MPB, use one of the following risk or hazard rating systems:

- **The Shore and Safranyik (1992) risk rating system:**

  This system can be used to evaluate the candidate stands for **MPB risk in lodgepole pine only**. See Appendix 4 for methods to calculate the risk index. The risk index ranges from 0 to 100 and can be used as an estimate of the percentage of stand basal area at risk of mortality.

- **The Scott (1996) risk rating system:**

  If live lodgepole pine trees within ¼ mile of the candidate stand are currently being attacked by MPB, use the Scott (1996) risk rating to evaluate the susceptibility of the candidate stand. See Appendix 3 to calculate the stand risk rating. Trees that are already dead (red foliage or no foliage) likely are no longer occupied by beetles and may not represent current attack/infestation of MPB. An exception would be MPB infested trees attacked in June or early July that have turned red but beetles have not yet flown. Therefore, bark should be removed from red-dead trees to confirm presence or absence of live bark beetles. If the Scott's composite score is ≥ 15, then some mortality within the candidate stand is likely. Trees that are likely to die within five years are of similar species, size, and vigor to those currently being attacked within ¼ mile of the infested stand.

Mountain pine beetle (MPB), *Dendroctonus ponderosae*

Host: Ponderosa pine

Identification:

Signs: Straight vertical egg gallery 10 to 30 inches long with a crook at the lower end. Larval galleries branch from random locations on both sides of the egg gallery.

Symptoms: Large (~1 in. diameter) white to red colored pitch tubes or orange-red boring dust in bark crevices on main stem. The red turpentine beetle, *Dendroctonus valens*, may cause similar pitch tubes, but these are usually restricted to the lowest six feet of the stem. Fading yellow-green to yellow foliage in the crown. Woodpeckers may flake off bark and expose wood. Occasionally, 'strip attacks' may occur on one side of the stem.

Mortality criteria: Trees that are likely to die within five years have pitch tubes from successful attacks (cream to pink in color, <u>not</u> clear or white) or dry attacks spaced ≥ 1 attack per 6 inches of circumference distance over the entire circumference of the lower stem within an area of 3 vertical feet. Pitch tubes must also be evident above six feet from ground level to distinguish MPB from damage caused by red turpentine beetle. Evidence of pitch tubes combined with a fading yellow crown indicates a high likelihood of mortality.

Inciting factors:

Root disease: Ponderosa pine trees that have positively identified root disease are more susceptible to MPB attacks and will likely die within five years if they are successfully attacked by MPB.

Dwarf mistletoe: Ponderosa pine trees with successful MPB attacks and a Hawksworth rating >4 are likely to die within five years.

Red turpentine beetle: Ponderosa pines with successful attacks of both MPB and red turpentine beetle are likely to die within five years.

Stand risk rating: If ponderosa pine trees within ¼ mile of the candidate stand are currently being attacked by MPB, use the Scott (1996) risk rating to evaluate the susceptibility of the candidate stand. See Appendix 3 to calculate the stand risk rating. Trees that are already dead (red foliage or no foliage) likely are no longer occupied by beetles and may not represent current attack/infestation of MPB. An exception would be MPB infested trees attacked in June or early July that have turned red but beetles have not yet flown. Therefore, bark should be removed from red-dead trees to confirm presence or absence of live bark beetles. If the Scott's composite score is ≥ 16, then some mortality within the candidate stand is likely. Trees that are likely to die within five years are of similar species, size, and vigor to those currently being attacked within ¼ mile of the infested stand.

Mountain pine beetle (MPB), *Dendroctonus ponderosae*

Host: Western white pine

Identification:

Signs: Straight vertical egg gallery 10 to 30 inches long with a crook at the lower end. Larval galleries branch from random locations on both sides of the egg gallery.

Symptoms: Large (~1 in. diameter) white to red colored pitch tubes or orange-red boring dust in bark crevices on main stem. The red turpentine beetle, *Dendroctonus valens*, may cause similar pitch tubes, but these are usually restricted to the lowest six feet of the stem, and are usually larger, reddish masses of resin and frass. Fading yellow-green to yellow foliage in crown. Woodpeckers may flake off bark and expose wood. Occasionally, 'strip attacks' may occur on one side of the stem.

Mortality criteria: Numerous pitch tubes or dry attacks (boring dust) on stems of host trees with at least some green foliage. Trees that are likely to die within five years have pitch tubes from successful attacks (cream to pink in color, <u>not</u> clear or white) or dry attacks spaced ≥ 1 attack per 6 inches of circumference distance over the entire circumference of the lower stem within an area of 3 vertical feet. Pitch tubes must also be evident above six feet from ground level to distinguish MPB from damage caused by red turpentine beetle. Evidence of pitch tubes combined with a fading yellow crown indicates a high likelihood of mortality.

Inciting factors:

White pine blister rust: Trees that are infected with positively identified white pine blister rust stem cankers in the lower two thirds of tree's height are more susceptible to bark beetle attack and will likely die within five years if they are successfully attacked by mountain pine beetle.

Root disease: Western white pine trees that have positively identified root disease are more susceptible to MPB attacks and will likely die within five years if they are successfully attacked by MPB.

Dwarf mistletoe: Western white pines with successful MPB attacks and a Hawksworth rating >4 are likely to die within five years.

Proximity: Host trees that do not meet the criteria may not be harvested.

Douglas-fir beetle (DFB), *Dendroctonus pseudotsugae*

Host: Douglas-fir

Identification:

Signs: Straight vertical egg gallery 5 to 18 inches long. Larval galleries branch in groups from alternating sides of the egg gallery.

Symptoms: Red-orange boring dust in bark crevices and at base of tree. Pitch streams indicate that the tree is attempting to defend itself and should not be used as an indication of successful attack. Foliage fading from yellow-green to yellow. Occasionally, 'strip attacks' may occur on one side of the stem.

Mortality criteria: Trees that are likely to die within five years have successful attacks (red-orange boring dust) ≥ 6 per square foot of the entire stem circumference within an area of 3 vertical feet (Hedden and Pitman 1978). Evidence of successful attacks combined with a fading yellow crown indicates a high likelihood of mortality.

Inciting factors:

Root disease: Douglas-fir trees that have positively identified root disease are more susceptible to DFB attacks and will likely die within five years if they are successfully attacked by DFB.

Defoliators: Douglas-fir trees that have been defoliated by Douglas-fir tussock moth or western spruce budworm are more susceptible to DFB attack and are more likely to die within five years if they are successfully attacked by DFB.

Dwarf mistletoe: Douglas-fir trees with successful DFB attacks and a Hawksworth rating >4 are likely to die within five years.

Fire: The probability of Douglas-fir mortality due to fire injury (Reinhardt and Ryan 1989) may increase by as much as 20% if DFB has successfully attacked the tree (Hood and Bentz 2007). Refer to mortality criteria for fire injury.

Stand risk rating: If live Douglas-fir trees within ¼ mile of the candidate stand are currently being attacked by DFB, use the Scott (1996) risk rating to evaluate the susceptibility of the candidate stand. See Appendix 3 to calculate the stand risk rating. Trees that are already dead (red foliage or no foliage) likely are no longer occupied by beetles and may not represent current attack/infestation of DFB. In some cases, Douglas-fir trees attacked by DFB may change color the same year of attack, especially in dry years. Therefore, bark should be removed from red-dead trees to confirm presence or absence of live bark beetles. If the Scott's composite score is ≥ 18, then some mortality within the candidate stand is likely. Trees that are likely to die within five years are of similar species, size, and vigor to those currently being attacked within ¼ mile of the infested stand.

Western pine beetle (WPB), *Dendroctonus brevicomis*

Host: Ponderosa pine

Identification:

Signs: Serpentine intercrossing egg galleries in a pattern that resembles spaghetti. Egg and larval galleries **do not increase in size** like larval galleries of wood borers. After eggs hatch, larvae tunnel away from the cambium and complete their development in the outer bark. So, when bark is peeled, egg galleries will be apparent and only a very small part of each larval gallery will be visible.

Symptoms: Red boring dust in bark crevices and at base of tree. Pitch tubes, if present, are very small (<1/2 inch) and reddish if successful attacks. Initial attacks often occur midway up the stem. Larger pitch tubes may be evidence of mountain pine beetle. Fading pale green to yellow foliage in crown. Because larvae develop on the outer bark, it is common to see outer bark chipped off by woodpeckers.

Mortality criteria: Trees that are likely to die within five years have pitch tubes from successful attacks (cream to pink in color, <u>not</u> clear or white) or dry attacks ≥ 8 per square foot of the entire stem circumference within an area of 3 vertical feet (Miller and Keen 1960; C. J. Fettig, personal communication). Evidence of pitch tubes combined with a fading yellow crown indicates a high likelihood of mortality.

Inciting factors:

Root disease: Ponderosa pine trees that have positively identified root disease are more susceptible to WPB attacks and will likely die within five years if they are successfully attacked by WPB.

Dwarf mistletoe: Ponderosa pines with successful WPB attacks and a Hawksworth rating >4 are likely to die within five years.

Stand risk rating: If live ponderosa pine trees within ¼ mile of the candidate stand are currently being attacked by WPB, use the Scott (1996) risk rating to evaluate the susceptibility of the candidate stand. See Appendix 3 to calculate the stand risk rating. Trees that are already dead (red foliage or no foliage) likely are no longer occupied by beetles and may not represent current attack/infestation of WPB. Bark should be removed from red-dead trees to confirm presence or absence of live bark beetles. If the Scott's composite score is ≥ 15, then some mortality within the candidate stand is likely. Trees that are likely to die within five years are of similar species, size, and vigor to those currently being attacked within ¼ mile of the infested stand.

Spruce Beetle (SB), *Dendroctonus rufipennis*

Host: Engelmann spruce

Identification:

Signs: Straight vertical egg gallery 3 to 12 inches long with a small crook at the lower end. Larval galleries branch in groups from alternating sides of the egg gallery and merge to form common feeding areas.

Symptoms: Red-brown boring dust in bark crevices and at base of tree. Pitch tubes are not formed by the host. This insect has a 2-year life cycle and fading pale green to yellow foliage does not appear in the crown until about 1 year following attack. The trees often drop up to 30 percent of their older needles in the spring following the summer of attack. Crown color change is not uniform and may take two years to completely fade. Up to 1/3 of old green needles may be dropped from infested green trees during the spring following the summer of attack. Woodpeckers may flake off bark. Occasionally, 'strip attacks' may occur on one side of the stem.

Mortality criteria: Trees that are likely to die within five years have evidence of boring dust in bark crevices spaced ≥ 1 attack per 6 inches of circumference distance over the entire circumference of the lower stem within an area of 3 vertical feet. Evidence of boring dust combined with a fading yellow crown or green needle drop indicate a high likelihood of mortality.

Inciting factors:

Root disease: Engelmann spruce trees that have positively identified root disease are more susceptible to SB attacks and will likely die within five years if they are successfully attacked by SB.

Stand risk rating: If live Engelmann spruce trees within ¼ mile of the candidate stand are currently being attacked by SB, use the Scott (1996) risk rating to evaluate the susceptibility of the candidate stand. See Appendix 3 to calculate the stand risk rating. Trees that are already dead (red foliage or no foliage) likely are no longer occupied by beetles and may not represent current attack/infestation of SB. Bark should be removed from red-dead trees to confirm presence or absence of live bark beetles. If the Scott's composite score is ≥ 15, then some mortality within the candidate stand is likely. Trees that are likely to die within five years are of similar species, size, and vigor to those currently being attacked within ¼ mile of the infested stand.

Pine engraver beetles, *Ips* species

Hosts: all pines

Identification:

Signs: Adult *Ips* beetles have three to six toothlike spines on the upper rear surface of each wing cover. Egg galleries beneath the bark etch the surface of the sapwood. The egg galleries are usually Y-, H-, or star-shaped with an enlarged central chamber where mating occurs. Galleries are not packed with frass.

Symptoms: *Ips* beetles are associated with slash, small diameter standing trees, and the tops of larger trees. *Ips* beetles do not increase their population in slash below 3 inches in diameter. Yellow to red boring dust accumulates in bark crevices and on the ground. Foliage of successfully attacked trees fades quickly in the summer to yellow, orange, or red. Complete crown discoloration in the top third to half of large pines is likely caused by successful *Ips* beetle attack.

Mortality criteria: Small diameter pines (≤ 8 inches DBH) with boring dust on bark around the entire circumference of the stem are likely to die within five years. *Ips* beetle infestation may cause top kill in large pines

(> 8 inches DBH). *Ips* beetles are not likely to be the primary cause of mortality in large diameter pines.

Inciting factors:

Slash creation: Slash greater than 3 inches in diameter created during January through July can lead to increased *Ips* beetle populations. *Ips* beetles may then attack the tops of large pines or kill small diameter standing pines nearby.

Bark beetles: *Ips* beetles may attack large pines weakened by mountain pine beetle or western pine beetle. To determine the likelihood of mortality, refer to the criteria for the primary bark beetle involved.

Proximity: Host trees that do not meet the mortality criteria may not be harvested.

Stand hazard: If pine trees, downed wood, or slash adjacent to or within the candidate stand are infested with *Ips* beetles, then small diameter pines (≤ 8 inches DBH) in the candidate stand may be attacked by *Ips* beetles. However, it is difficult to predict whether *Ips* beetles will attack live trees. This is because injured trees, downed wood, or slash can provide enough attractive breeding material to keep *Ips* beetles out of live trees. *Ips* beetle outbreaks may be short-lived due to high overwintering mortality. If attacks on live trees occur, stands of small diameter (≤ 8 inches DBH) pines with basal area over 100 ft^2 per acre have a higher risk of mortality (Kegley et al. 1997).

Defoliators

Douglas-fir tussock moth (DFTM), *Orgyia pseudotsuga*

Hosts: Douglas-fir and grand fir

Identification:

Signs: Mature larvae have three distinctive tufts of black hairs, one on the posterior and two on the anterior and four white tufts in between. Younger larvae do not have this pattern. DFTM egg masses can be found through the fall and winter months. Egg masses are distinctive woolly balls that are attached to foliage, twigs, tree trunks, signs and structures in forests inhabited by DFTM. Often the female lays the egg mass on the felt-like cocoon she emerged from. There is a good photo of an egg mass in http://www.na.fs.fed.us/spfo/pubs/fidls/tussock/fidl-tuss.htm.

Symptoms: Foliage is eaten by DFTM larvae in the spring beginning in the tree top then moving down to outer branches below. Silk webbing sometimes caps tree tops. Spring defoliation is likely if two or more fresh egg masses are present per tree in the area.

Mortality criteria: Total defoliation by DFTM (100%, trees are completely stripped of leaves) will result in greater than 90% mortality to Douglas-fir and grand fir directly caused by DFTM. Defoliation of 99%

of the crown (a few green needles remaining) will result in less than 50% mortality (Wickman 1979). Therefore, **only trees in defoliation classes 6 (99%) and 7 (100%) for the current year are likely to die within five years from defoliation alone.** See Appendix 5 for defoliation classes. Defoliation estimates should be made after August, when larvae have finished feeding. Partial defoliation may result in top-kill, but rarely results in direct mortality. Top-kill cannot be detected until bud break the following spring. Secondary attack by bark beetles may result in mortality of partially defoliated trees.

Contributing factors:

Bark beetles: Host trees that have been defoliated by DFTM are more susceptible to bark beetle attack and are more likely to die within five years if they are successfully attacked by Douglas-fir beetle and fir engraver. To determine the likelihood of mortality, refer to the mortality criteria for the bark beetle species involved.

Proximity: Host trees that do not meet the mortality criteria may not be harvested.

Western spruce budworm (WSBW), *Choristoneura occidentalis*

Hosts: Douglas-fir, grand fir, and Engelmann spruce

Identification:

Signs: Mature larvae are about 1 inch long or less and have a black head capsule. They are orange-brown with uniform sized whitish spots on the body. The appearance of immature larvae can be viewed in http://www.fs.fed.us/r6/nr/fid/fidls/fidl53.pdf. Egg masses, adult moths, and pupae can be easily confused with other moth species.

Symptoms: Buds and emerging current-year foliage are eaten first in the spring, most commonly in the tree top. By July, new foliage that has been chewed turns red-brown, appears twisted, and is often webbed together. Heavily defoliated trees appear scorched.

Mortality criteria: The only method to reliably predict mortality directly caused by WSBW defoliation is to observe the current year's percentage of defoliation for five consecutive years (Alfaro et al. 1982). Estimates of previous year's defoliation are unreliable because needle drop may be caused by other factors (Brookes et al. 1985). See Appendix 6 for methods to record the current year's defoliation percentage. If the cumulative sum of percent defoliation over a five year period is greater than 350%, then trees are likely to die within five years (Alfaro et al. 1982). Partial defoliation may result in top-kill, but rarely results in direct mortality. Top-kill cannot be detected until bud break the following spring. Secondary attack by bark beetles (Douglas-fir beetle in Douglas-fir or fir engraver in true firs) may result in mortality of partially defoliated trees.

Contributing factors:

Balsam woolly adelgid (BWA): True firs with fresh balsam woolly adelgid stem infestation (i.e. lots of woolly masses) on the lower bole and greater than 30% topkill are likely to die within five years. Branch gouting caused by BWA is a localized, non-lethal host response to feeding; therefore cannot be used as a criterion to predict mortality.

Bark beetles: Host trees that have been severely defoliated by WSBW are more susceptible to bark beetle attack and are more likely to die if they are successfully attacked by Douglas-fir beetle and fir engraver. To determine the likelihood of mortality, refer to the mortality criteria for the bark beetle species involved.

Proximity: Host trees that do not meet the mortality criteria may not be harvested.

Western hemlock looper, *Lambdina fiscellaria lugubrosa*, and other loopers (Geometrid species)

Hosts: Western hemlock, Pacific silver fir, Douglas-fir

Identification:

Signs: Larvae move in the "inch worm" fashion by arching their body. Western hemlock looper larvae are present from June to September. Young western hemlock looper larvae have alternating grey and black bands and mature larvae are green to brown with a diamond shaped pattern on the back. Healthy eggs are present on moss and lichens.

Symptoms: Both current-year and older foliage is chewed. Branches are often incompletely defoliated, leaving random patches of green foliage. Partially chewed leaves can be found on the ground and may turn red on the branches. Western hemlock looper larvae may leave silk webs on branches.

Mortality criteria: Defoliation is likely to be high in areas dominated by multi-layered canopies of host species. Western hemlocks with greater than 75% of the crown defoliated in the current year are likely to die within five years (Alfaro et al. 1999; Goheen and Willhite 2006).

Proximity: Host trees that do not meet the criteria may not be harvested.

Other Insects

Balsam woolly adelgid (BWA), *Adelges picea*:

Hosts: Subalpine fir and grand fir

Identification:

Signs: Small (< 1/8 inch), white cottony masses on the bark of stem or branches. Inside are purple to black soft bodied, wingless insects. Amber colored eggs, if present, are laid loosely in the woolly masses.

Symptoms: Abnormal growth (gouting) of branches. Red discoloration of sapwood beneath the bark that resembles compression wood. Narrowly tapering crown that may have a higher than usual amount of black lichens.

Mortality criteria: True firs with fresh BWA stem infestations on the lower bole and greater than 30% topkill are likely to die within five years (Mitchell and Buffam 2001). The BWA stem infestation should be a minimum of 150 woolly masses in any square foot area of the main stem. Branch gouting caused by BWA is a localized, non-lethal host response to feeding; therefore cannot be used as a criterion to predict mortality. Do not mistake defoliation by DFTM or WSBW for topkill. Topkill must be observed between spring bud break and July. Fresh BWA woolly masses are fluffy and bright white, with a purplish insect hidden in the wool. When you smear them with a fingernail, they smear orange.

Contributing factors:

Bark beetles: Fir trees with successful FE attacks and greater than 30% topkill caused by BWA infestation are likely to die within five years.

Proximity: Host trees that do not meet the criteria may not be harvested.

Fire

Hosts: lodgepole pine, Engelmann spruce, subalpine fir, western redcedar, western hemlock, western larch, and Douglas-fir.

Mortality criteria: Use the criteria and methods in Appendix 7 (Reinhardt and Ryan 1989) to predict fire caused mortality in **lodgepole pine, Engelmann spruce, subalpine fir, western red cedar, western hemlock, western larch, and Douglas-fir.** Use species, DBH, and the percentage of crown scorched to look up probability of mortality in Appendix 7. Trees that are likely to die within five years as a direct result of fire must have a greater than 90% probability of mortality.

Proximity: Host trees that do not meet the criteria may not be harvested.

Host: Ponderosa pine

Mortality criteria: Use the criteria and methods in Appendix 8 (Saveland and Neuenschwander 1989) to predict fire caused mortality in **ponderosa pine.** Use DBH, and height (ft) of the highest point of the crown scorched to look up probability of survival in Appendix 8. Trees that are likely to die within five years as a direct result of fire must have a less than 20% probability of survival.

Proximity: Host trees that do not meet the criteria may not be harvested.

Appendix 1: Field method to assess likelihood of mortality due to **dwarf mistletoe**.

Hawksworth Dwarf Mistletoe Rating System (Hawksworth 1977):

1. Divide the live crown into thirds, and rate each third using the following scale:
   - 0 No visible infection
   - 1 < 50% of the total branches infected
   - 2 ≥ 50% of the total branches infected
2. Sum the three individual ratings to obtain a total mistletoe class (0 to 6) for the tree.

Example: A conifer tree has no infection in the top third of crown, light infection in the middle third, and has many brooms in the lower third. The total score is 0 + 1 + 2 = 3. The Hawksworth Dwarf Mistletoe rating for the tree is "3".

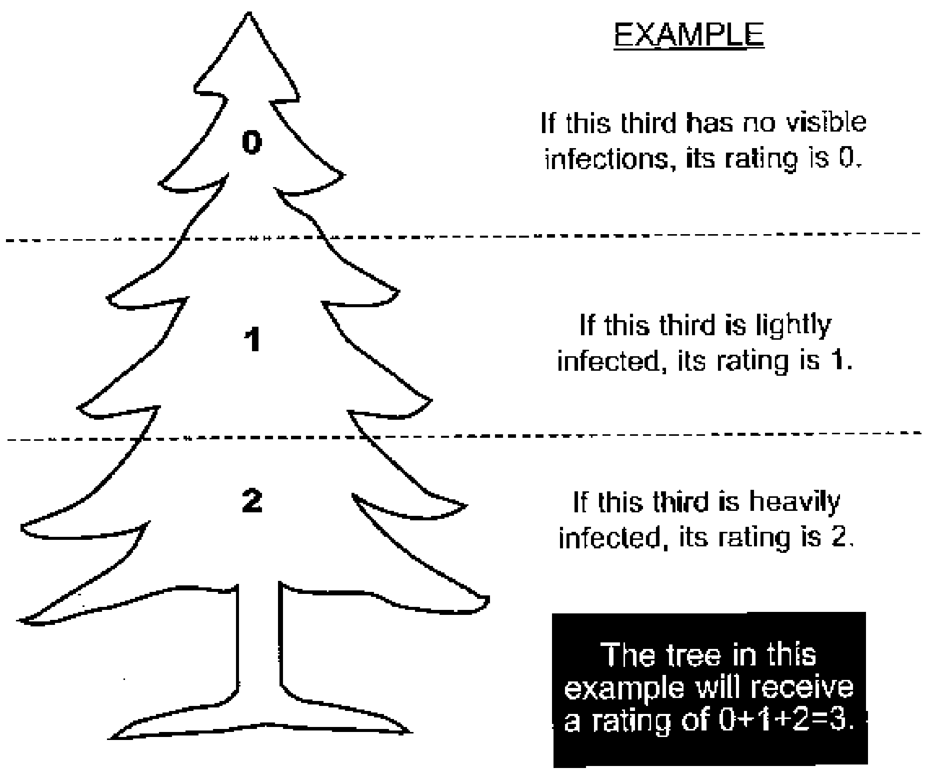


Figure from Goheen and Willhite (2006).

Appendix 2: Field method to assess likelihood of mortality due to **root disease**.

Foliage Transparency (FIA Field Manual 2007b):

Foliage transparency is defined as the amount of skylight visible through the live, normally foliated portion of the crown or branch. Each tree species has a normal range of foliage transparency. Changes in foliage transparency occur as a result of current damage, frequently referred to as defoliation, or from reduced foliage resulting from stresses during preceding years.

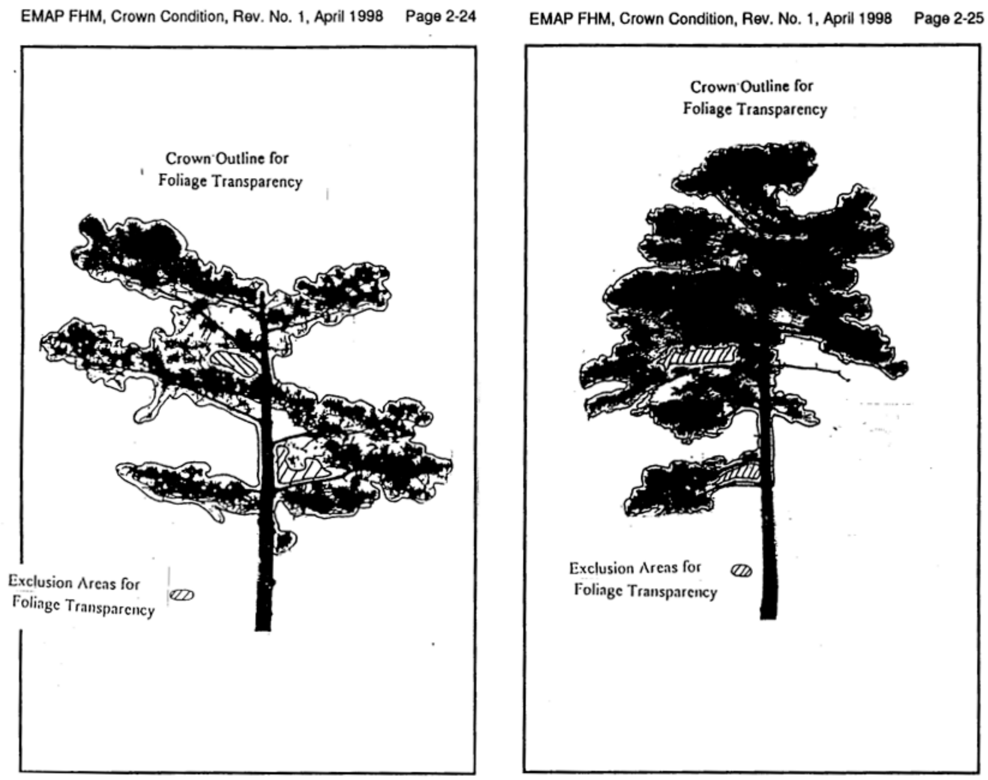
Estimate foliage transparency based on the live, normally foliated portion of the crown (Figure 1 indicates the crown outline) using the foliage transparency guide (Figure 2). Dead branches in the lower live crown, snag branches, crown dieback and missing branches or areas where foliage is expected to be missing are deleted from the estimate.

When defoliation is severe, branches alone will screen the light, but the individuals should exclude the branches from foliage and rate the areas as if the light was penetrating. For example, an almost completely defoliated dense spruce may have less than 20 percent skylight coming through the crown, but it will be rated as highly transparent because of the missing foliage. Old trees, and some hardwood species, have crown characteristics with densely foliated branches which are spaced far apart in the crown. These spaces between branches should not be included in the foliage transparency rating. When foliage transparency in one part of the crown differs from another part, the average foliage transparency is estimated and recorded.

Foliage transparency should be rated two times, from positions 90 degrees apart, about ½ to 1 tree length from the tree base. The two estimates should be averaged.

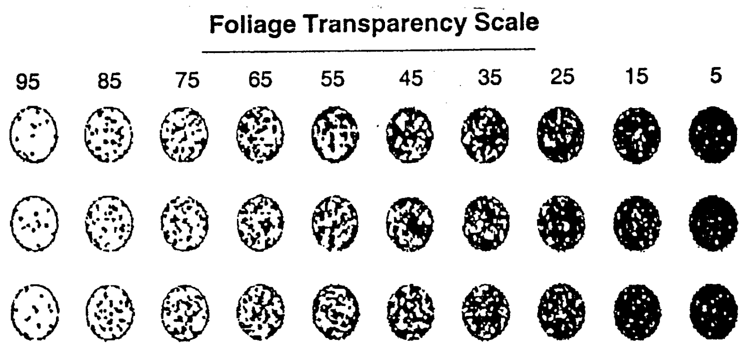
Appendix 2 (continued):

Figure 1. Crown Outline for determining foliage transparency



Appendix 2 (continued):

Figure 2. Foliage transparency guide



EMAP FHM, Crown Condition, Rev. No. 1, April 1998 Page 2-11

Appendix 3: Method to determine candidate stand risk rating for likelihood of **bark beetle** caused mortality (Scott 1996):

Procedure for Determining Imminent Susceptibility of Stands to Insects in the Blue and Wallowa Mountains of Southeastern Washington and Northeastern Oregon

Donald W. Scott
Zone Entomologist
Wallowa-Whitman National Forest
Blue Mountains Pest Management Zone
1401 Gekeler Lane
La Grande, Oregon 97850

Report No. BMZ-96-15

July 22, 1996

		SCORE
(1)	**Stand Susceptibility**	
	What is the current SDI[1] for plant association of this stand?	
	< 50% of UMZ	**(value = 1)**
	50-100% of UMZ	**(value = 2)**
	> 100% of UMZ	**(value = 3)**
(2)	**External Beetle Pressure (Last Year)**	
	What is the distance from this stand to the nearest known similar bark beetle infestation occurring outside this stand?	
	> 2.0 Miles	**(value = 1)**
	0.25-2.0 Miles	**(value = 2)**
	< 0.25 Miles	**(value = 3)**
(3)	**Internal Beetle Pressure (Last Year)**	
	How many beetle-killed trees (red-top trees killed last year) occur inside the stand?	
	< 3	**(value = 1)**
	3-10	**(value = 2)**
	> 10	**(value = 3)**

[1]Cochran, P. H.; J. M. Geist; D. L. Clemens; R. R. Clausnitzer; D. C. Powell. 1994. Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington. Research Note PNW-RN-513. Portland, OR: U. S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 21 p.

Continued on next page.

Appendix 3 (continued):

(4) Current Beetle Pressure

How many current-year (green-infested trees) beetle-infested trees occur in the stand?

< 10	(value = 1)
10-50	(value = 2)
> 50	(value = 3)

(5) Stand Size

How many acres in size is the stand?

> 100 acres	(value = 1)
40-100 acres	(value = 2)
< 40 acres	(value = 3)

(6) Bark Beetle Species Relative Aggressiveness

What single species of bark beetle currently within the stand (i.e. green-infested trees), or that killed trees in the stand last year (i.e. red-top trees), is causing most of the mortality in the stand?

No Beetles	(value = 0)
Fir Engraver	(value = 1)
Western Pine Beetle	(value = 2)
Pine Engraver	(value = 3)
Douglas-fir Beetle	(value = 4)
Spruce Beetle	(value = 5)
Mountain Pine Beetle	(value = 6)

(7) Blowdown Habitat

How many ponderosa pines, Douglas-firs or Engelmann spruces have blown down in the stand within the last 18 months?

None	(value = 0)
< 5 trees	(value = 1)
> 5 trees	(value = 2)

(8) Bark Beetle Predisposition--Root Disease and Mistletoe

Are root diseases or dwarf mistletoe present in species in the stand that are also affected by bark beetles?

None Present	(value = 0)
Dwarf Mistletoe Present	(value = 1)
Root Disease Present	(value = 2)

STAND COMPOSITE SCORE

Continued on next page.

Appendix 3 (continued):

Stand Classification Table:

Bark Beetle Species	**Composite Score Range**	**Degree of Imminence**	**Comments**
Fir Engraver	< 13 13-14 15-18	None Borderline Imminently Susceptible	Low likelihood of a fir engraver epidemic except in cases of defoliation, drought, root disease, and overstocking.
Western Pine Beetle	< 12 12-14 15-22	None Borderline Imminently Susceptible	Drought stress, root disease, and overstocking predisposes stands.
Pine Engraver	< 16 16-18 19-23	None Borderline Imminently Susceptible	Drought, blowdown, slash, and overstocking predisposes stands.
Douglas-fir Beetle	< 15 15-17 18-24	None Borderline Imminently Susceptible	Drought, defoliation, disease, dwarf mistletoe, overstocking, overmaturity, and logging slash predisposes stands.
Spruce Beetle	< 13 13-15 15-24	None Borderline Imminently Susceptible	Windthrow, logging slash and overmaturity predisposes stands.
Mountain Pine Beetle (ponderosa pine)	< 14 14-15 16-26	None Borderline Imminently Susceptible	Overstocking, root disease, and drought predisposes stands.
Mountain Pine Beetle (lodgepole pine)	< 13 13-14 15-26	None Borderline Imminently Susceptible	Overstocking, drought, and overmaturity predisposes stands.

Appendix 4: Method to determine candidate stand risk rating for likelihood of **mountain pine beetle** caused mortality to **lodgepole pine** (Shore and Safranyik 1992):

Calculate the stand susceptibility index (S) using the formula ($S = P \times A \times D \times L$) on the following page. There are instructions to calculate the four variables. Variable radius sample plots can be used to estimate average basal area per acre. One acre = 0.405 hectares (ha). DBH conversions: 15 cm DBH = 6 inch DBH; 7.5 cm DBH = 3 inch DBH. For location factor (L), be sure to convert elevation in feet to meters (1 foot = 0.3048 m).

It is not necessary to calculate risk index (R), instead, follow these steps:

1. Use Table 1 to determine relative infestation size (small, medium, or large).
2. Use relative infestation size from Table 1 to look up beetle pressure index (B) in Table 2. The proximity criteria for the nearest MPB infestation to the candidate stand is ¼ mile; therefore, use only the left two columns in Table 2 for distance to nearest infestation (¼ mile = 0.4 km).
3. Use the stand susceptibility index (S) and beetle pressure index (B) to look up risk index in Table 3.

Calculating the susceptibility, beetle pressure and risk indices

Calculating the susceptibility index

The susceptibility index for a given stand is based on four variables: relative abundance of susceptible pine basal area in the stand, age of dominant and codominant live pine, the density of the stand, and the location (latitude, longitude and elevation) of the stand. The expression for calculating the susceptibility index (S) is

$$S = P \times A \times D \times L$$

where

P is the percentage of susceptible pine basal area

A is the age factor

D is the density factor, and

L is the location factor.

The percentage of susceptible pine basal area (P) is calculated as

$$P = \frac{[\text{average basal area/ha of pine} \geq 15 \text{ cm dbh}] \times 100}{[\text{average basal area/ha of all species} \geq 7.5 \text{ cm dbh}]}$$

The age factor (A) is taken from the following table.

If the average age of dominant or codominant pine is:	Then the age factor is:
less than or equal to 60 years	0.1
61 to 80 years	0.6
more than 80 years	1.0

The density factor (D) is taken from the following table.

If the density of the stand in stems per ha (all species ≥ 7.5 cm dbh) is:	Then the density factor is:
less than or equal to 250	0.1
251 to 750	0.5
751 to 1,500	1.0
1,501 to 2,000	0.8
2,001 to 2,500	0.5
more than 2,500	0.1

There are three possible location factors (1.0, 0.7, and 0.3). The manner in which the location factor varies with the ranges of latitude, longitude, and elevation encountered in British Columbia is shown in Figure 1. To determine the location factor for a particular stand, first determine a parameter (Y) from the following equation:

$$Y = [24.4 \text{ Longitude}]-[121.9 \text{ Latitude}]-[\text{Elevation(m)}]+[4545.1]$$

The location factor is then determined from the value of Y using the following table.

If Y is:	Then the location factor is:
greater than or equal to 0	1.0
between 0 and -500	0.7
less than -500	0.3

Susceptibility indices will range from 0 to 100. The highest values indicate the most susceptible stands.

Determining the beetle pressure index

Beetle pressure is related to the size and proximity of a mountain pine beetle population affecting the stand being rated. To determine the beetle pressure index (B), determine the size category of the infestation from Table 1. After you have determined the size category of the infestation, use Table 2 to determine the beetle pressure index.

Calculating the risk index

The risk index (R) is calculated as follows:

$$R = 2.74[S^{1.77}e^{-.0177S}][B^{2.78}e^{-2.78B}]$$

where: e = Base of natural logarithms = 2.718
B = Beetle pressure index
S = Susceptibility index

Alternatively, the risk index can be found in Table 3. If the exact value of the beetle pressure index or susceptibility index is not represented in the table, an approximate risk index can be determined using the closest values represented or it can be interpolated between the two closest values found in the table. The risk index will range between 0 and 100; the highest values represent stands which would receive the most damage by the mountain pine beetle in the near future.

Appendix 4 (continued):

Table 1. Use this table to determine the relative size of a mountain pine beetle infestation within 3 km of the stand being rated

Number of infested trees outside stand within 3 km	Number of infested trees inside the stand		
	Less than 10	10 - 100	More than 100
<900	Small	Medium	Large
900 - 9,000	Medium	Medium	Large
> 9,000	Large	Large	Large

Table 2. Use this table to determine the beetle pressure index (*B*) from infestation size (determined from Table 1) and the distance from the stand being rated to the nearest edge of the mountain pine beetle infestation.

Relative infestation Size	Distance to nearest infestation (km)					
	in stand	0-1	1-2	2-3	3-4	4+
	Beetle pressure index (B)					
Small	0.6	0.5	0.4	0.3	0.1	0.06
Medium	0.8	0.7	0.6	0.4	0.2	0.08
Large	1.0	0.9	0.7	0.5	0.2	0.10

<u>Appendix 4 (continued):</u>

Table 3. Use this table to determine the risk index from the susceptibility and beetle pressure indices

Susceptibility index (*S*)	Beetle pressure index (*B*) .1	.2	.3	.4	.5	.6	.7	.8	.9	1.
10	<1	<1	2	3	5	6	7	8	8	8
20	<1	2	6	10	14	18	20	22	24	24
30	<1	4	10	17	24	30	35	39	40	41
40	1	6	14	24	33	42	49	54	56	57
50	1	7	18	30	42	52	61	67	70	71
60	2	9	20	34	48	61	70	77	81	82
70	2	10	22	38	53	67	78	85	89	91
80	2	10	24	40	56	71	82	90	95	96
90	2	10	24	41	58	73	85	93	98	99
100	2	11	25	42	59	74	86	94	99	100

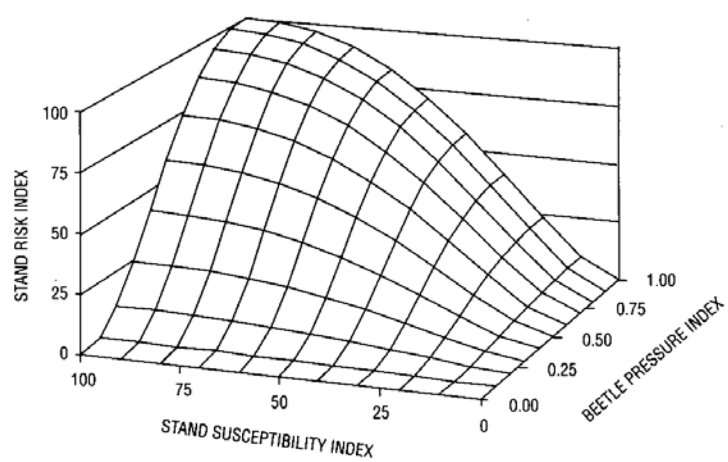


Figure 2. The risk index as a function of the susceptibility and beetle pressure indices

5

Appendix 5: Method to determine percentage crown defoliation caused by **Douglas-fir tussock moth** (Wickman 1979):

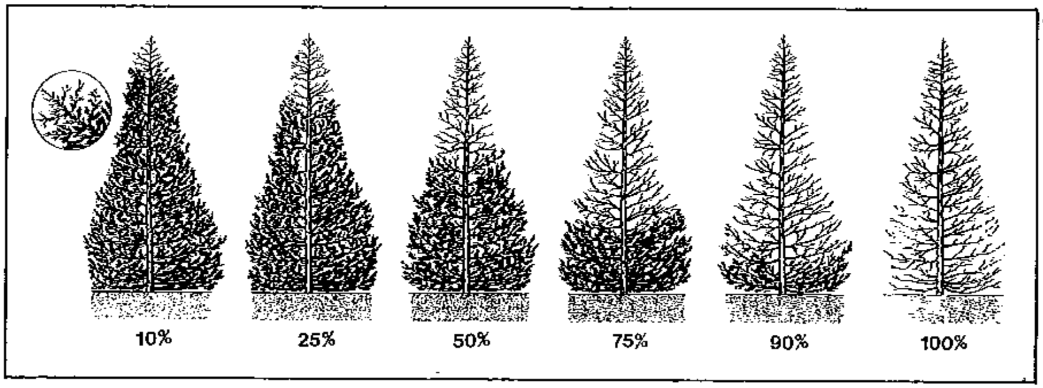


Figure 4.—Tree defoliation classes by percent of crown totally defoliated.

3. Estimate defoliation in one of seven classes as follows (fig. 4):

Class 1 (10 percent). Top 10 percent of the crown (mostly new foliage) is totally defoliated. Additional defoliation of new foliage may occur lower in the crown, but branches are not completely stripped.

Class 2 (25 percent). Branches are completely stripped of needles in the top quarter of the crown. This crown area is mostly new foliage, but some feeding on older foliage may also occur at this level. Most new foliage is removed lower in the crown.

Class 3 (50 percent). The top half of the crown is totally defoliated. There is significiant feeding on older needles at this level of defoliation. All new foliage is damaged in the lower half of the crown.

Class 4 (75 percent). The top three-quarters of the crown is totally defoliated. There is heavy feeding on older foliage and all new foliage is removed from the remainder of the crown. The crown may take on a very ragged or uneven appearance below the area of total defoliation.

Continued on next page.

Appendix 5 (continued).

Class 5 (90 percent). Green needles remain on only the lowest 10 percent of the crown. Sometimes only the lower whorl of branches is left with older green needles.

Class 6 (99 percent). The tree may have only a few green needles remaining on one of the lower branches.

Class 7 (100 percent). Trees are completely stripped of foliage. There may be some stubs of green needles remaining, but these will eventually be lost. At this level of defoliation, even the new buds may be eaten.

Appendix 6: Method to determine percentage crown defoliation caused by **western spruce budworm** (Alfaro et al. 1982; Crookston 1991):

1. Visually divide the crown into three equal sections.
2. Estimate the percentage of foliage missing from each section, to the nearest 10%.
3. Measure or estimate tree height.
4. Based on tree height, multiply percent defoliation observed for each crown third by the proportion of total biomass to get weighted defoliation (Table 1).
5. Add the three weighted defoliation values and multiply by 100 to get percent total defoliation value for the entire crown.

Table 1.

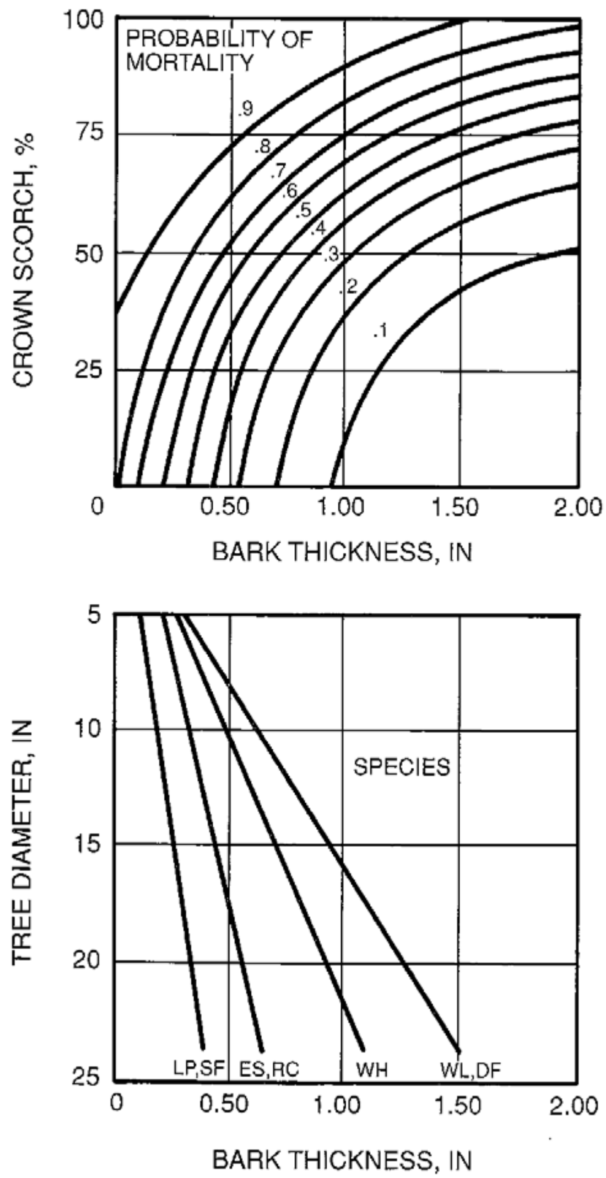
	Proportion of total crown biomass	
	Tree height < 23 ft.	Tree height ≥ 23 ft.
top third	0.05	0.15
middle third	0.30	0.45
bottom third	0.65	0.40

Example:
Percent defoliation observed for the top, middle, and bottom thirds of the crown in a 50 foot tall tree are 90%, 50%, and 10%. Multiply these observations by 0.15, 0.45, and 0.40, respectively. The results are three weighted defoliation values: 13.5%, 22.5%, and 4%. Add these values together to get percent total defoliation for the entire crown of 40%. Percent total defoliation = ([0.9 * 0.15] + [0.5 * 0.45] + [0.1 * 0.4]) * 100 = 40

	Observed defoliation	× Proportion biomass	= weighted defoliation
top third	90%	× 0.15	= 13.5%
middle third	50%	× 0.45	= 22.5%
bottom third	10%	× 0.40	= 4%
Sum weighted defoliation percentages:			40%
Percent total defoliation of the entire crown:			40%

<u>Appendix 7:</u> Method to determine probability of **fire**-caused mortality to **lodgepole pine, Engelmann spruce, subalpine fir, western red cedar, western hemlock, western larch, and Douglas-fir** (Reinhardt and Ryan 1989).

On the bottom chart, find the DBH of the individual tree (by species) you are considering. Follow an imaginary line straight up to the probability of 90% mortality curve (.9) on the upper chart. Follow an imaginary line to the left axis and read the amount of Crown Scorch (%). If the percent of crown that is scorched on the tree you are considering is less than that number, the tree does not meet the mortality criteria. If the percent of crown that is scorched on the tree you are considering is equal or greater than that number, then the tree does meet the criteria and is highly likely to die.



LP = lodgepole pine, SF = subalpine fir, ES = Engelmann spruce, RC = western red cedar, WH = western hemlock, WL = western larch, and DF = Douglas-fir.

Appendix 8: Method to determine probability of **fire**-caused mortality to **ponderosa pine** (Saveland and Neuenschwander 1989).

Based on the formula:

$$P = (1 + e^{(2.33-0.95x + .11y)})^{-1}$$

where: P = predicted mortality; x = DBH in inches; y = scorch height in feet.

On the chart below, find the curved line with the DBH value closest to the individual tree you are considering. Where the DBH line crosses the .20 survival probability line, follow an imaginary line straight down to the bottom axis. If the height of the highest point of crown scorch is less than that number, the tree does not meet the mortality criteria. If the crown scorch height on the tree you are considering is equal or greater than that number, then the tree does meet the criteria and is highly likely to die.

The crown scorch height threshold values for ≥ 80% ponderosa pine mortality are as follows:

DBH (in.)	Crown scorch height (ft) for ≥ 80% mortality
5	35
7	52
9	70
11	87

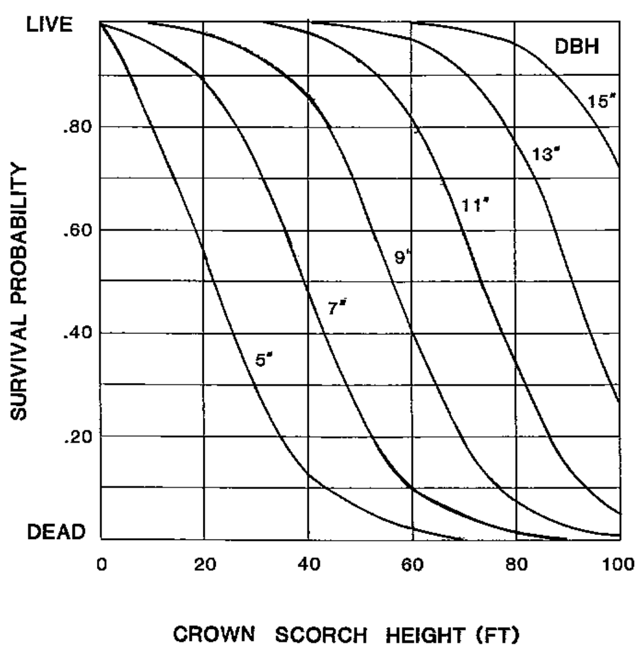


Figure 1.—Probability of survival versus scorch height and diameter at breast height (equation 1).

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