Evaluating the Accuracy of Ground-Based Hemlock Dwarf Mistletoe Rating: A Case Study Using the Wind River Canopy Crane

ABSTRACT: The accuracy of ground based estimates using the six-class dwarf mistletoe rating system was evaluated in an old-growth Douglas-fir/western hemlock forest by comparing ground ratings by five different observers to an examination of tree crowns from a construction crane at the Wind River Canopy Crane Research Facility, Washington. A total of 139 dominant, codominant, and intermediate western hemlock were evaluated. No consistent pattern emerged to indicate where overall error was made. All but one observer was relatively accurate at identifying noninfected trees (73 to 95% noninfected trees accurately rated by four observers). However, the observers were less accurate at estimating the DMR class of the infected trees (11% to 37% of the infected trees accurately rated), including a number of trees incorrectly rated by two or more DMR classes. One observer rated 98% of the trees as having infections, while the crane survey estimated only 53% of the trees as having infections. Each observer divided the individual tree crowns into thirds and estimated infections based on summing lower, middle, and upper canopy levels. There was no pattern to the errors associated with estimates by canopy level. One observer significantly overestimated all canopy levels, one observer estimated all accurately, one observer significantly underestimated all canopy levels, one observer underestimated the mid and upper canopies, and one observer underestimated the lower and upper canopies. The principal reasons for inaccurate dwarf mistletoe ratings were assumed to be difficulty in accurately estimating crown thirds, misidentification of infections because of various stem deformities or accumulation of organic debris resembling infections, and the difficulty in observing infections high above the ground and through dense vegetation. Only one of the five observers accurately represented the spatial pattern of the infection center. The implications of this research vary depending on whether the results are to be used for timber management or for research and modeling applications. West. J. Appl. For. 15(1):8-14.

Western hemlock dwarf mistletoe (Arceuthobium tsugense) is a parasitic vascular plant that causes an important disease of western hemlock (Tsuga heterophylla) (Hawksworth and Wiens 1996). Infections are localized on individual branch segments and initially cause swelling of the branch tissue. Eventually this swelling can develop into deformed branches and cause brooming or multiple branching at the swollen region. These “witches’ brooms” are characteristic features that can be used to indicate the presence of the parasite (Shea and Stewart 1972, Hawksworth and Wiens 1996).

Western hemlock dwarf mistletoe spreads by explosively discharging seeds from a single-seeded berry (Hawksworth and Wiens 1996). Seeds can be “shot” up to 10 m or more from the female mistletoe plant (Smith 1977). The relative spacing of susceptible hosts plays an important role in determining whether an individual seed will infect another tree. In addition, the position of the mistletoe plant in the host crown affects its potential to reach adjacent trees (Smith 1977, Hawksworth and Wiens 1996).

Hawksworth (1977) described a six-class dwarf mistletoe rating system to capture both the overall severity of the disease within a tree crown and its vertical distribution. The six-class dwarf mistletoe rating (DMR) system assigns a value between zero and six for each tree. From the ground, the observer visually makes a division of the living canopy into equal upper, middle, and lower thirds. Each third is then rated

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as follows: 0—no mistletoe infections; 1—less than half the branches infected; and 2—more than half the branches infected. The ratings for each third are then summed to obtain a total rating for the tree. Stand DMR is defined as the mean of the individual susceptible host tree ratings and is used to describe whole stand infection (Hawksworth 1977).

The six-class dwarf mistletoe rating system is widely used in western North America to quantify the severity of dwarf mistletoe infection in coniferous forests. The system is simple to use in the field and thus practical for field foresters. The six-class system can be used to measure and then predict growth loss and mortality of infected trees and mistletoe spread and intensification. Therefore, it has been used in forest growth and yield simulation models that include the effects of dwarf mistletoe infection on stand dynamics (Edminster et al. 1991, Hawksworth et al. 1995). The six-class system is also used to quantify the severity and distribution of dwarf mistletoe populations within management units. This information becomes the basis for implementation of management options (Baranyay and Smith 1972, Hawksworth 1977, Hawksworth and Wiens 1996).

The system was originally developed in pine forests of the interior western North America, where stand structure allows observation of whole tree crowns. Whole crowns are difficult to observe, however, in the tall stature, high basal area forests of the Pacific Coast (Smith 1969). Field evaluations of the accuracy in use of the six-class system have been limited due to the difficulty in accessing tree crowns to check ground ratings. Smith (1969) used an older version of the dwarf mistletoe rating system for western hemlock and evaluated ratings by felling trees. The lower third of western hemlock crowns often has dead, broken, and missing branches, and the upper third of the crown often is hidden from view; therefore the use of a system that depended on lower and upper crown ratings is impractical for large western hemlock. Smith recommended a system that used the middle third of the crown only.

In 1995, a construction tower crane was erected in a tall stature, old-growth Douglas-fir (Pseudotsuga menziesii) western hemlock forest in the T.T. Munger Research Natural Area in southwestern Washington (Figure 1). The crane is 74.5 m tall with a jib arm of 85 m, providing access to 2.3 ha of forest via a suspended personnel basket. The crane research site includes a severe infection center of western hemlock dwarf mistletoe. The canopy crane provided the opportunity to field-check dwarf mistletoe rating estimates without destructive sampling.

The objective of this study was to compare standard field techniques for estimating DMR in a tall stature Douglas-fir/western hemlock forest with accurate ratings obtained by closely examining tree crowns using the Wind River Canopy Crane. Five observers, including two forest biotechnicians, two timber inventory cruisers, and a forest pathologist, were used to reflect the various skill levels of those who make DMR estimates in practice.

Methods

Study Site

The Wind River Canopy Crane Research Facility (WRCCRF) is located in the Wind River Experimental Forest, Gifford Pinchot National Forest, Washington (Latitude
45°49′13.76″, Longitude 121°57′06.88″) at 355 m elevation. In 1994, a 4 ha stem map was completed for a square centered on the crane. All trees (living and dead) with a dbh (1.3 m above ground) greater than 5 cm were mapped. The map included 2,168 trees, 917 of which were living western hemlock. Mean tree density was 442 stems/ha, and basal area was 83 m²/ha.

Approximately 1 ha of the 4 ha study site is occupied by a hemlock dwarf mistletoe infection center. Many of the tall (45 m+) western hemlock trees are severely infected with perhaps thousands of individual infections, and the tree crowns have large witches' brooms.

**Crane Survey**

As part of the baseline monitoring of the site, the trees accessible from the crane, primarily dominant, codominant, and intermediate crown class, were assigned permanent identification numbers. There were 320 accessible trees, 140 of which were western hemlock. One access hemlock was subsequently windthrown, leaving 139 trees. The mean height and diameter at breast height of these trees were 37.6 m and 56 cm. Total heights ranged from 10.5 to 55.7 m, and diameters ranged from 14 to 132 cm. Because the majority of trees were taller than 30 m, no attempt was made to compare DMR by different height classes.

These 139 trees were rated (DMR) for hemlock dwarf mistletoe using the crane. The gondola provided access to the entire crown and made possible a complete and accurate evaluation of mistletoe infection in each of the 139 trees. The crane is equipped with a system that reads the vertical distance between the gondola and the load jib. By lowering the gondola from the top to the bottom of the living crown, a crown length was determined. This length was divided by three to find the lower, middle, and upper crown heights. The gondola was slowly raised, halting at each third to allow the percentage of infected branches to be determined. After viewing both sides, a mistletoe rating was assigned to the tree.

**Ground Survey**

The 139 western hemlock accessible by crane were rated from the ground by five observers. Binoculars were used to aid in distinguishing mistletoe infections by the two biological technicians and the forest pathologist (observers A, B, and E), but not by the foresters (observers C, D). When surveying from the ground, mistletoe plants may not be visible, but swollen branches and witches' brooms can be used to identify infections from a distance. Often the tops of tall trees were hidden from view, either by other trees or by the lower canopy of the tree itself. This made rating trees more difficult, as described by Smith (1969).

In 1995, all 917 western hemlock in the 4 ha stem map were rated from the ground by observer A, who received one morning of training from USFS forest pathologists and the state pathologist from Idaho. The training included a description of how to rate trees using the six-class system and indicators of infection observed from the ground. In 1998, four additional observers rated the crane-accessible western hemlock. Observer B was a forest biologist with experience rating dwarf mistletoe in ponderosa pine. Observers C and D were timber inventory cruisers with several years experience rating western hemlock dwarf mistletoe. Observer E was a forest pathologist specializing in Pacific Northwest forest diseases, including western hemlock dwarf mistletoe.

**Data Analysis**

If there was a difference between the crane and the ground-based ratings, it was assumed that the rating measured from the crane was accurate. Average stand ratings were used to compare the crane survey with the five ground observers' estimates. The average ratings were determined for the entire trees, as well as for the three canopy levels. This reveals if the observers were overrating or underrating trees, on average. It also reveals if the observers were consistent across the three canopy levels; for example, if observers overrated the lower canopy, did they also overrate the middle and upper canopies?

Individual tree ratings were used to investigate the observers' consistency across DMR classes. First, the numbers of trees assigned by each observer to the six infection classes were examined. Second, the percentages of correctly rated trees—both noninfected and infected—were examined.

**Reliability of Independent Observers**

Cohen (1960) proposed a statistic for determining the reliability of two judges, who are independently categorizing a sample. Light (1971) extended this to the case of several raters compared to a standard rating. Light's test was applied to the lower, middle, and upper canopy levels to compare ground ratings of the five observers with the ratings from the crane. Unfortunately, Light's test only tests for agreement versus disagreement. Therefore, if the crane rating was, for example, a 2, Light's test treats a ground rating of 0 the same as a ground rating of 1. The null hypothesis for Light's test is that there is only chance agreement with an alternative hypothesis of better than chance agreement.

**Probability of Over or Under Rating**

The sign test checks if the observers were equally likely to overrate as to underrate. This test was applied to the five observers and the three canopy levels as well as to the whole tree ratings. Because 20 tests were performed, the significance level was checked against 0.05/20 = 0.0025 to keep the probability of type I error at the stated alpha.

**Whole Tree Ratings From Crane vs. Observers**

A two-way ANOVA with a randomized block design was conducted on the differences between the crane and the ground ratings for the whole tree ratings. The trees were the blocks, while the observers were the treatments. The observers were considered a random sample of all possible observers.

**Canopy Level Ratings From Crane vs. Observers**

A three-way ANOVA with a randomized block design was conducted on the differences between the crane and the ground ratings for the three canopy levels. The trees were the blocks, while the observers and the canopy levels were the treatments. The observers were considered a random sample of all possible observers. The canopy
levels were considered a fixed effect. Because this was a mixed effects model, it was necessary to use a Satterwaite approximate F test to test for the main effect of canopy level (Neter et al. 1985).

**Stem Map**

Finally, the infections were illustrated on stem maps, providing a qualitative visual representation of how ground-based and crane surveys compared. This assessed the observers' accuracy in determining the size and shape of the infection center.

**Results**

**Average Stand Ratings**

The stand DMR was 1.94 (on a scale from 0 to 6) based on the crane survey. The five ground ratings varied from 1.08 to 3.00, with a mean of 1.73 and a standard deviation of 0.77. One person (observer C) overrated stand DMR, one person (observer B) was close to the crane rating, and three people (observers A, D, and E) underrated the stand DMR (Figure 2).

The crane survey indicated that the upper canopy was the least infected, with an average class of 0.47 (on a scale of 0 to 2). The lower and middle canopies were approximately equally infected, with average classes of 0.73 and 0.74 respectively. The ground surveys revealed a similar pattern with the upper canopy least infected and the lower and middle canopies relatively equally infected. Observers tended to be consistent, either overrating all three or underrating all three canopy levels. The mean classes from the ground for the lower, middle, and upper canopies were 0.68 ± 0.29, 0.67 ± 0.29, and 0.38 ± 0.21 (Figure 2). There was not a clear difference among the canopy levels in respect to the likelihood of overrating or underrating.

**Individual Tree Ratings**

The crane survey found 47% of the western hemlock trees to be noninfected, with the remaining western hemlock trees evenly distributed among the six infection classes. Four of the ground observers found similar patterns, with the number of noninfected trees ranging 47 to 61% (Table 1). One person—observer C—estimated only 2% of the trees to be noninfected.

The five observers had accurate DMR for 20 to 65% of the trees. However, this included 66 noninfected trees. Most of the trees that were accurately rated from the ground—with the exception of observer C—were noninfected trees. The remaining four observers accurately identified from 73 to 95% of the noninfected trees and overrated 0 to 12% of the noninfected trees by two or more infection classes. Observer C accurately identified only 3% of the noninfected trees and overrated 76% of the noninfected trees by two or more classes.

In contrast, only 11 to 37% of the infected trees were assigned the correct DMR, and from 21 to 58% of the infected trees were incorrectly rated by two or more infection classes. Observer C—who was the least accurate at rating noninfected trees—was one of the most accurate at rating infected trees. Observer C assigned 36% of infected trees the correct DMR and had only 21% of the trees incorrectly rated by two or more classes.

Notice that, even though observer C's stand DMR for each canopy level were consistently high, the individual trees did not receive consistently higher ratings. The number of trees receiving class 4, 5, and 6 remained approximately equal: 40 trees from the crane survey, 42 from observer C. The main difference was that noninfected trees were given ratings of class 1, 2, and 3 by observer C. The other four observers were more consistent across infection class. Observer B—whose stand DMR was most accurate—seemed to be equally likely to overrate or underrate at each DMR class. Also, the three observers whose stand DMR were consistently low for each canopy level tended to underestimate both lightly infected and heavily infected trees.

**Reliability of Independent Observers**

In all three canopy levels, we rejected the null hypothesis and concluded that the ground raters have a better than random chance agreement with the crane ($P = 0.00$).

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**Table 1. Distribution of individual trees to the DMR infection classes for the crane and for the five observers. Note: the particular trees that are assigned to each of the classes vary between the crane and the five observers. For example, although 66 trees were assigned a DMR of 0 from the crane, and observer E assigned 65 trees a DMR of 0, these are not necessarily the same trees. Observer A and B—forest biotechs, Observer C and D—timber inventory cruisers, Observer E—forest pathologist.**
lower and mid canopies may show slightly higher agreement than the upper canopy (G statistic distributed as a standard normal: Upper—13.28, Mid—15.44, Lower—16.00).

**Probability of Over or Underrating**

The sign test indicated no consistent pattern between observer error and canopy levels. Observer C was the only observer with significant overestimation, significantly overestimating all three canopy levels. Observer B had no significant over- or underestimation in the three levels, and observer D underestimated all three levels. Observer A underestimated the mid and upper canopy, while observer E underestimated the lower and upper canopy.

**Whole Tree Rating From Crane vs. Observers**

The two way ANOVA on whole tree ratings indicated there was a significant observer effect ($P = 0.00$). In general, the observers were very different from one another.

**Canopy Level Rating from Crane vs. Observers**

The main observer effects were significant ($P = 0.00$), as was the observer-canopy level interaction ($P = 0.00$). The main effect for canopy level, however, was not significant ($P = 0.90$). To examine this relation in greater detail, an interaction plot was used (Figure 3). From this, one can see that observer C—who, from the sign test, overestimated all three canopy levels—overestimated the lower canopy to a greater extent than the mid and upper canopy. On the other hand, observer D—who, from the sign test, underestimated all three canopy levels—underestimated the lower and mid canopies to a greater extent than the upper canopy. Both of these observers were most accurate in the upper canopy. This was not always the case. Observers A and B were most accurate in the lower canopy, and observer E was most accurate in the mid canopy.

The interactions between the trees and the observers and between the trees and the canopy levels were also significant. This implies that the relative error of the five observers varied from tree to tree. For example, for some trees, observer A was the most accurate, while for other trees observer B was the most accurate. Also, the relative error of the three canopies varied from tree to tree. For example, for some trees there were greater errors in the upper canopy, and for other trees there were greater errors in the mid or lower canopy.

**Spatial Pattern of Infection Center**

Mapping the mistletoe spatial pattern from the results of the crane survey indicates that the infection center is discrete (Figure 4). Little overlap occurs between infected and noninfected trees. Observer B, who had the most accurate stand DMR, found a similar pattern. Observer C found 98% of the trees infected, with no boundary to the infection center. The infection center from the remaining three observers had a diffuse boundary, with intermingling between infected and noninfected trees, and a scattering of lightly infected trees throughout the noninfected portions of the stand (Figure 4).

![Figure 3. Interaction plot from the three-way ANOVA on canopy levels. Observer A and B—forest biotechs, Observer C and D—timber inventory cruisers, Observer E—forest pathologist.](image)

![Figure 4. Comparison of the spatial pattern of dwarf mistletoe infection, using the six-class dwarf mistletoe rating system, of 139 accessible western hemlock trees from the crane versus from the five ground observers. The plot is 4 ha (200 m x 200 m). Scale for DMR is at upper right. Observer A and B—forest biotechs, Observer C and D—timber inventory cruisers, Observer E—forest pathologist.](image)
Discussion

This case study indicates that there can be wide variability among observers in estimating DMR in a tall stature Douglas-fir/western hemlock forest. No consistent pattern emerged among observer errors. An individual observer tended to be consistent in over-, under- or accurately estimating the DMR of individual trees (Figure 2, 3), while all observers differed in the canopy-level error patterns (Figure 3). The relative errors of the five observers varied from tree to tree. Most observers were relatively accurate at identifying noninfected trees, but were less accurate at estimating the DMR of the infected trees, rating a smaller but significant number of trees incorrectly by two or more DMR classes (Table 1). One observer considered almost every tree infected, therefore overestimating all the noninfected trees, but was most accurate at rating the infected trees.

We re-examined several of the trees that had been over- and underestimated from the ground. Many of those overestimated exhibited irregular branching patterns in the lower canopy, with no evidence of spindle-shaped swellings, aerial shoots, or brooming. These trees also had large clumps of lichen and moss that may have been mistaken for witches’ brooms. Also, inaccurate division between canopy levels may have caused some cases of overestimation. For example, in tree 2105, there were two infections in the middle canopy, one of which was at the bottom edge of the middle level. Four of the observers rated this tree as being infected in both the middle and the lower canopy.

Many of the trees that were underestimated from the ground had middle and upper canopies that were poorly visible, either because of dense foliage in the tree itself or because there were other trees growing near to the tree. Close neighbors had two effects on the measurements. First, they made it difficult to see the upper canopy, and second, it was difficult to determine which branch belonged to each tree. Also in some of the trees with underestimates, there were numerous infections that had developed spindle shaped swellings and aerial shoots but had not formed witches’ brooms.

Smith (1969), Hawksworth (1977), and Geils and Mathiasen (1990) reviewed problems associated with the six-class system. Very small trees and trees with compact, short crowns present problems for rating, as do tall trees in dense forests. Geils and Mathiasen found that most small Douglas-fir trees could be rated accurately but that some large trees would be incorrectly rated. However, because the number of trees underestimated was approximately the same as the number of trees overestimated in their study, they reported that the average rating for an area based on a large sample would tend to closely approximate the actual average DMR. Our results, however, indicate that in tall stature western hemlock forests, this occurred with only one of the observers. Of the remaining observers, one consistently rated noninfected as infected, while three others were generally conservative and tended to underestimate the DMR.

The stem map of the crane DMRs reveals a discrete infection center, with well defined borders and relatively little intermingling between infected and noninfected trees. The stem maps produced by the observer ratings show several types of spatial pattern. The most critical may be observers A, D, and E, who described an infection center that was less intense, with less well defined borders, and more intermingling of infected and noninfected trees, with a scattering of lightly infected trees throughout noninfected areas of the stand. The falsely identified and lightly infected trees may have little effect on the current status of the stand, and there may be little difference in vigor between a DMR 0 and DMR 1 tree. This would affect attempts to model the disease progression, however, acting as false seed sources for additional infection centers.

Small Infections

Small infections that cannot be seen from the ground in tall stature forests present a special problem when estimating DMR. Some of the errors reported in this study occurred because small spindle-shaped swellings were not seen by the observers but were detected from the gondola. This affects DMR when these infections are in an otherwise noninfected portion of the crown. Two small infections in the mid and upper crown can shift a DMR from 0 to 2. How important are these swellings, and are they relevant to the ecology and economy of the forest?

These small swellings are probably most important in otherwise noninfected trees because this will form the basis for spread and intensification of the disease. Often, these lightly infected trees are at the margins of infection centers and represent the leading edge of the disease spread. Ecologically they are important in effecting the dynamics of the mistletoe population. We have found, in subsequent DMR surveys of the T.T. Munger RNA, that close attention to trees on the margins of infection centers is the best place to really focus on attempting to find these types of infections.

An individual small infection in a tree crown does not influence the carbon balance of the tree and therefore will not affect tree growth and development in the short term. The 5 to 10 yr estimate of tree growth impacts from mistletoe infection will not be influenced by these small infections, and therefore they may not be relevant to this type of short term economic analysis.

Management Implications

The application of this case study to hemlock dwarf mistletoe management is different depending on the need for the survey. Stand level surveys for timber management require a reasonable estimate of the overall stand DMR and information on the spatial distribution across the management unit. This information may be used in deciding what type of silvicultural system would work best and if the entire site should be treated. Whether or not the average DMR is 1.6 or 1.8 may not be important, and therefore missing some small spindle-shaped swellings may not matter. However, field survey data often has multiple uses such as determining the current level of disease infestation in a forest and then subsequently forming the basis for future assessments of intensification and spread. An example of this is reported by Filip et al. (1993), who attempted to use DMRs from timber inventory assessments on three national forests of Oregon.
and Washington. They were unable to estimate intensification and spread of dwarf mistletoe because of errors made by the original observers.

Researchers, silviculturists, and modelers all require accurate assessments of dwarf mistletoe in a stand if they are to properly select trees for sampling, investigate impact of dwarf mistletoe on timber productivity, or model intensification and spread of mistletoe. Thomson et al. (1985) noted that field estimates of DMR did not reflect accurate assessments made after felling trees, and this affected their attempt to sample equal numbers of trees in each of three infection classes for research. Small infections on trees that may affect DMR will have implications for development of infection centers if these infections are on the outer center edges or represent new infection centers, and therefore, care should be taken to properly estimate DMR. The implication for models that predict intensification and spread include: (1) overestimating and/or underestimating the future extent of the infection center, (2) incorrectly predicting direction of spread, (3) incorrectly estimating rates of mortality, (4) overestimating and/or underestimating wood volume impacts, and (5) incorrectly predicting wildlife benefits.

Conclusions

The six-class DMR system remains important for predicting management implications and understanding the biology of dwarf mistletoe, even in tall stature Douglas-fir/western hemlock forests. Although Smith (1969) recommended a system that used only the mid crown, the value of whole crown estimates outweighs the extra work. For example, to understand the potential for intensification and spread of hemlock dwarf mistletoe one must know the vertical distribution within the stand. The six-class DMR system can provide information on whether the infections are in the lower crowns or all though the stand, which can guide silviculturists in choosing regeneration and sanitation systems.

Field personnel need to have continuous feedback on the accuracy of their observations. This helps them modify their estimates to incorporate whatever error tendencies they may have. Our results indicate that every individual may have different error tendencies, either overestimating, underestimating, or accurately estimating DMR. Therefore, the problem is best dealt with by working with individuals to help them understand where the sources of error may occur.

Literature Cited


