Section 15
Guidelines for Estimating the Number of Marbled Murrelet Nesting Platforms and for Harvesting Adjacent to Lands Designated as Critical Habitat (State) for Marbled Murrelet

This section provides a general overview of marbled murrelet habitat and guidance:
- To determine whether a forest stand contains sufficient potential marbled murrelet nesting platforms to require a survey for murrelet occupancy,
- To determine if there is connectivity to occupied sites, and
- How to design a harvest unit in the 300-foot buffer adjacent to critical marbled murrelet habitat.

Forest practices activities on landowners owning less than 500 acres within 50 miles of saltwater are exempt from the SEPA policies in WAC 222-10-42 and critical habitat requirements in WAC 222-16-080 (h) unless there is an occupied site within or adjacent to the proposed harvest area or within and/or adjacent to a 300-foot average width buffer from an occupied site (see WAC 222-16-010 "Occupied marbled murrelet site" definition). If the definition of "Occupied marbled murrelet site" is met, the protection measures for landowners owning less than 500 acres will be the same as a landowner who owns more than 500 acres.

All landowners are required to minimize disturbance during the "daily peak activity period" (1 hour before to 2 hours after official sunrise and 1 hour before to 1 hour after official sunset) within the "critical nesting season" (April 1st-August 31st) for the following activities within 0.25 mile of an Occupied marbled murrelet site:
- Road construction and blasting (222-24030 (11),
- Felling/bucking (222-16-050 (6)),
- Cable Yarding (222-16-060 (8)),
- Helicopter yarding or other operations (222-30-065 (2),
- Ground-based yarding or heavy equipment operation (222-30-070 (11)), and
- Slash disposal or prescribed burning (222-30-100 (8)).

Consult with the Washington Department of Fish and Wildlife (WDFW) for information on the existence, location and status of occupied murrelet stands.

PART 1. GENERAL DESCRIPTION OF MARBLED MURRELET HABITAT IN WASHINGTON

Conducting an efficient field inspection or preliminary assessment of potential marbled murrelet (*Brachyramphus marmoratus*) habitat, it is extremely valuable for recognizing the forests characteristics and conditions likely to be used by murrelets. This habitat description, when combined with reading additional details in the “Identification of Marbled Murrelet Nesting Structures” guide published by Washington Department of Fish and Wildlife (WDFW), formal field training, and familiarity with known occupied sites, will assist in gaining proficiency in stand assessments. When conducting stand assessments in different regions of the state, the platform search image needs to be based on forest types of local occupied stands relative to geographical variation.

In Washington State, marbled murrelets typically nest within 50 miles of the marine shoreline in low-to mid-elevation, conifer, multi-layered canopy forests characterized by the presence of large diameter trees greater than 24 inches diameter at breast height (dbh) for western hemlock and 32 inches dbh for all other conifer species. Thirty-two inches dbh conifer species are typically mature enough to have large limbs that provide nesting structures (platforms) 7 inches wide or greater. Additionally, twenty-four inches dbh western hemlock with dwarf mistletoe infestation may have witches broom or other abnormal growth provide platforms.

Diameter breast height (dbh) is measured over the outside bark at "breast height" which is specifically defined as a point around the trunk at 4.5 feet above the forest floor on the uphill side of the tree. For the purposes of determining breast height, the forest floor includes the duff layer that may be present but does not include unincorporated woody debris that may rise above the ground line.

If the tree has an abnormal taper or growth at 4.5 feet, the measurement is taken above or below the abnormality and an estimate is made of what the dbh would have been with normal taper. On leaning trees, dbh is taken at a point 4.5 feet along the bole of the tree. If roots are above the ground, as is common in western hemlock, dbh is taken 4.5 feet above the root collar.

Potentially suitable murrelet nesting habitats are primarily old-growth and mature forests, but they may also include a variety of forest types including younger forests containing residual trees left from previous timber harvest and natural disturbances including windstorms and fire (See inset box for more information on **residual trees**, the term used for this board manual section). When evaluating a stand for the presence of platforms, it is important to consider the historical events and influences that may have created irregular structures that can be identified as platforms. Nesting habitat sometimes develops earlier in younger coastal forests with a high proportion of western hemlock. However, Douglas-fir dominated forests develop murrelet habitat characteristics at an older age. Forests with residual trees or other suitable stand attributes may be the products of windstorms, fire, local microclimates such as high humidity zones, previous timber harvest operations that did not remove all trees, or high site productivity for regrowth of historic clearcuts. These stands usually exhibit a broad range of interior conditions often including snags, decaying down material, and moss.

Residual, remnant or wolf trees. These are trees which have grown in the open, or are trees which were not harvested during previous harvest(s). Their diameters are generally significantly larger than the diameters of the adjacent stand. They often have full crowns on all sides, with branches well above or below the general canopy level of the rest of the stand. The crowns are uncrowded on two or more sides and receive full light from above and well down on two or more sides. Live crown ratios often exceed 75%.

The primary individual tree attribute for marbled murrelet nests within the broad range of forest types described above, is the presence of nesting platforms as described in WAC 222-16-010. Platforms may be the top of a large branch, forked limb, dwarf mistletoe infection, witches broom, deformities, overgrown broken tops, or other structure large enough to provide a useable surface for a nesting adult. Canopy cover directly over nests provides protection from predators and weather.

Washington coastal forests which have suitable stand structure for platforms and have murrelet occupancy include:

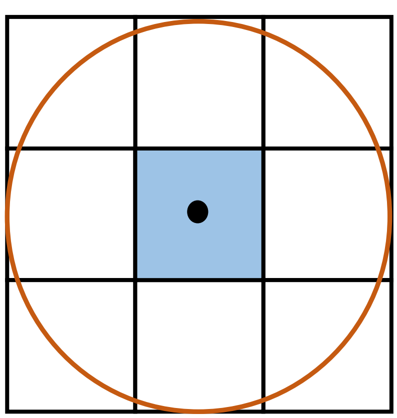
- Stands that have been affected by ice or windstorms,
- Second-growth forests originating from early 1900's harvest,
- Areas where less efficient logging or high-grading methods were used, and
- Unmanaged regrowth from late 1800's fire regimes.

Even-aged, second growth Douglas-fir forests in western Washington, originating in the last 60 years are a common example of unsuitable murrelet habitat. Some of those forests may indeed have large size classes of fast growing trees on high quality sites, but lack the large branches and irregular crown structures for platforms, cover, and moss potential.

For the purpose of habitat determination on ownerships greater than 500 acres, under Forest Practices rules, forest stands that have all of the following **forest stand characteristics** may have sufficient potential nesting platforms to require murrelet surveys. These stand characteristics are those typically found in multi-storied stands with moderate canopy closure:

1. Within 50 miles of marine waters.
2. Contiguous forested area containing trees capable of providing nesting opportunities (platforms).
3. At least 40% of the dominant and codominant trees are conifers.
4. At least 5 acres in size (a minimum convex polygon (MCP) encompassing trees with platforms that occur within 300 feet of one another).
5. Presence of large (>32inches dbh) confer trees (≥24 inches dbh for western hemlock).

What needs to be assessed:
There are two scenarios for habitat assessment. The first assessment determines the extent of suitable marbled murrelet habitat. The second determines the extent of occupied marbled murrelet habitat. If an area meets the five forest stand characteristics listed above, then a protocol murrelet survey is required. If the survey results in a detection that indicates occupancy, then occupied habitat needs to be delineated. For all types of detections, whether occupancy behavior is observed or not, the Public Lands Survey section becomes the detection section. Because murrelets have a median home range of 1.5 miles, the eight sections adjacent to the detection section comprise the Detection Area (Figure 15.1).



Marbled Murrelet Detection Area:

1. Means an area of land associated with a visual or audible detection of a marbled murrelet, made by a qualified surveyor which is documented and recorded in the Department of Fish and Wildlife data base.

2. The marbled murrelet detection area shall be comprised of the PLSS Section of land in which the marbled murrelet detection was made and the eight sections of land immediately adjacent to that section (see WAC 222-16-010).

Figure 15.1 Marbled murrelet detection area: Detection site ●; Detection Section ▭; Eight adjacent Sections □; 1.5 mile Detection area ○.

All stands meeting the five **forest stand characteristics** above should be assessed for the presence of platforms. The platform density requirements for suitable habitat change depending on the location of the proposed harvest or activity in relation to a Detection Area:

Outside a Detection Area and within the 50-mile zone where a landowner owns 500 acres or more:
Suitable habitat outside the Southwest Washington special landscape area must have an average of 7 platforms/acre or more. Within the special landscape area, suitable habitat must have an average of 5 platforms/acre or more.

Within the Detection Area:
Within detection areas (See Figure 15.1), suitable habitat must have an average of 2 or more platforms/acre.

PART 2. PROTOCOL PLATFORM ASSESSMENT METHODS

The Forest Practices Board has approved two alternative methods for determining whether or not there are enough platforms in eligible trees present in a stand to trigger murrelet surveys, see WAC 222-12-090. The Field Sampling Method employs sampling of candidate stands selected using local knowledge, aerial photographs, and inventory data. The Inventory Model Method utilizes the results of a platform model developed to query an inventory system and predict the likelihood of platforms. See Figure 15.2 below for a flow chart to aid in method selection.

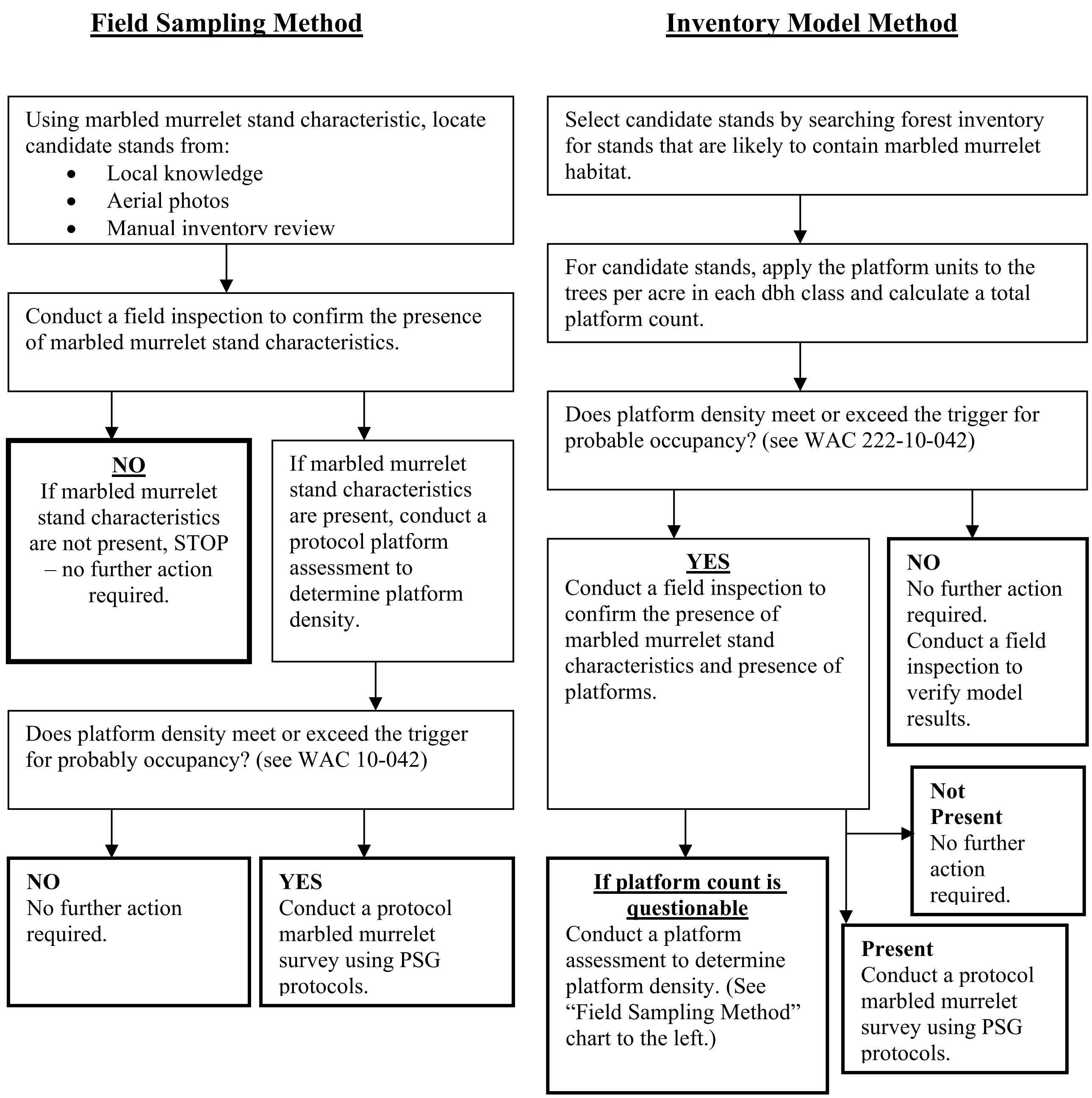


Figure 15.2 Protocol assessment methods selection flow chart.

2.1 Field Sampling Methods

Select stands that meet murrelet forest stand characteristics and field review to confirm the findings. In some cases, the field review will be sufficient to decide that the presence of marbled murrelet habitat, including the minimum density of platforms, is so obvious that further sampling is not needed. If the platform density meets or exceeds the trigger for probable occupancy, conduct a protocol marbled murrelet survey using the most current board-recognized Pacific Seabird Group (PSG) terrestrial survey methods (Forest Practices Board Manual Section 14) in effect at the beginning of the season in which surveys are conducted. If the platform density is below the trigger for probable occupancy, murrelet surveys are not required. Where field sampling is needed to determine the density of platforms in the stand, follow the methods described below.

1. Assess the forested area and the 300-feet adjacent to it with similar stand characteristics by field examination or use of aerial photos. Stands of similar habitat are considered contiguous unless

separated by at least 300-feet of forest lacking one or more of the distinguishing vegetative characteristics important to murrelets. Contiguous habitat includes all adjacent areas, regardless of the planned harvest boundaries that have similar stand structural characteristics or platform densities meeting rule requirements (WAC 222-10-042).

2. Use either the sample plot method or 100% cruise method to determine the number of platforms per acre.

2.1.1 Sample Plot Method

1. Locate 8 to 30 plot points on the photo using an appropriate systematic grid from a random starting point. (Depending on the variability of the occurrence of large trees and platforms in individual stands, a greater number of plots, up to 30, may yield greater precision in the sampling results.)
2. Locate plot centers at least 75 feet from the edge of the potential habitat being sampled.
3. The starting location and plot centers should be flagged for future relocation.
4. At each plot record the following within a 75-foot radius area (0.4 acre plot):
   - Plot number
   - For all trees ≥32 inches dbh (24 inches for western hemlock)
     - Species
     - dbh
     - Number of platforms by height and type. Only count platforms ≥ 50 feet in height from the base of the tree.
5. Within each plot record the number of platforms per conifer tree ≥32 inches dbh or western hemlock tree > 24 inches dbh. Follow the forest practices rule definitions for "Marbled murrelet nesting platforms" found in WAC 222-16-010.
6. After the stand is delineated (see habitat delineation section below), conduct a single tailed t-test to determine if the platform density is significantly less than 2, 5, or 7 platforms per acre. The example below shows how a t-test is used in conjunction with a marbled murrelet platform assessment.

Single tailed t-test formula: $t = \frac{\bar{x}-p}{s/\sqrt{n}}$

$\bar{x}$ = the average number of platforms/acre
p = minimum number of platforms required in assessment area
s = the standard deviation
n = the number of plots taken in the field
t = the calculated t-test valuie

Example: $\bar{x} = 1.25$; $p = 2$; $s = 2.5$; *and* $n = 8$, $t = \frac{1.25-2}{2.5/\sqrt{8}}$ $t = -0.848$

Once the t-test value is determined compare it to the critical value associated with the number of plots taken in the survey on the table below.

Table 15.1 Critical Value Table

Number of Plots	Critical Value	Number of Plots	Critical Value	Number of Plots	Critical Value
8	-1.895	16	-1.753	24	-1.714
9	-1.860	17	-1.746	25	-1.711
10	-1.833	18	-1.740	26	-1.708
11	-1.812	19	-1.734	27	-1.706
12	-1.796	20	-1.729	28	-1.703
13	-1.782	21	-1.725	29	-1.701
14	-1.771	22	-1.721	30	-1.699
15	-1.761	23	-1.717		

If the value of the t-test is greater than the critical value indicated on the Critical Value Table, then the results are not significant and the 2, 5, or 7 platforms per acre requirement is met, even if the average used in the calculation shows that the unit does not have sufficient platforms. In the example above, the negative t-test value of -0.848 is greater than the listed critical value of -1.895. Therefore, the platform density is not significantly less than 2, and a marbled murrelet protocol survey is required. The more variability in plot results, the more likely it is that this forest stand may not pass the t-test. In cases where there will be a great deal of variability between plots, it is generally better to increase the number of plots taken. If the t-test value is less than the applicable listed critical value, the delineated stand is not suitable murrelet habitat.

7. Additional plots maybe installed and added to the analysis to improve the sensitivity of the statistical t-test. However, current data suggests that more than 30 plots will not improve the test sensitivity enough to justify the effort.

<u>2.1.2 100% Cruise Method:</u>

1. Overlay belt transects onto an aerial photo or stand map at one-acre spacing (i.e., transect centerlines are 208 feet apart or narrower if canopies obscure visibility) to ensure that 100% of the delineated stand is sampled. Transects should be uniquely identified and beginning and end points flagged in the field.
2. The observer should:
   a. Traverse the centerline of each transect and record and map all trees ≥ 32 inches dbh (≥24 inches for western hemlock) with platforms that are within 104 feet of the transect centerline.
   b. Use multiple vantage points per tree <u>to thoroughly assess</u> the number of platforms present. Apply platform descriptions in Forest Practices Rules "Marbled murrelet nesting platforms" (WAC 222-16-010).
   c. A "Marbled murrelet nesting platform" means any horizontal tree structure such as a limb, an area where a limb branches, a horizontal surface created by multiple leaders, a deformity created by mistletoe infection, a branch break, a debris/moss platform, or a stick nest equal to or greater than 7 inches in width including associated moss if present, that is 50 feet or more above the ground in Western hemlock trees 24 inches dbh and greater or in other conifer trees 32 inches dbh and greater, and capable of supporting nesting by marbled murrelets.

3. After the stand is delineated via the MCP methodology (see habitat delineation section below), determine the average number of platforms per acre by dividing the total number of observed platforms by the number of acres in the delineated stand.

2.2 Inventory Model Method

Assumption: The landowner has a stand inventory of trees per acre for trees with 32 inches or larger diameter at breast height (dbh) and wishes to estimate the number of platforms per acre. This method does not include western hemlock inventory of 24 to 31.9 inches dbh. This method does not capture unique characteristics within the stand such as deformities or the occurrence of mistletoe.

Table 15.2 Inventory Model Calculation Worksheet

dbh Classes		Inventory Stand Tree Count per dbh Class (Average/Acre)	Platform Units per Tree	Platform Units per Class (trees/dbh class) (Platform Units/tree)
dbh Classes	Diameter Range			
32”	32”,<33”		0.37	
34”	33”,<35”		0.34	
36”	35”,<37”		0.33	
38”	37”,<39”		0.34	
40”	39”,<41”		0.39	
42”	41”,<43”		0.47	
44”	43”,<45”		0.56	
46”	45”<47”		0.69	
48”	47”,<49”		0.84	
50”	49”,<51”		1.03	
52”	51”,<53”		1.26	
54”	53”,<55”		1.53	
56”	55”,<57		1.86	
58”	57”,<59”		2.26	
60”	59”,<61		2.75	
(Total of all Platform Units for all dbh Classes) = Platforms/Acre				

Procedure: Using a typical forest inventory, query for stands that are likely to contain murrelet habitat characteristics. For these stands, apply the Platform Units per Tree from the table above to the number of eligible trees per acre in each dbh class. The accumulated total represents the number of platforms per acre in the stand. If the platform density meets or exceeds the threshold for probable occupancy, conduct a field inspection to confirm the presence of murrelet platform stand characteristics and conduct protocol marbled murrelet survey. If the platform density does not meet the threshold for probable occupancy, a protocol marbled murrelet survey is not required.

Example:

If a stand inventory shows 5 trees per acre (tpa) in the 32 inches dbh class, 4 tpa in the 38 inches dbh class, 3 tpa in the 42inches dbh class, and 1 tpa in the 48 inches dbh class, the estimated platforms per acre would be calculated as shown below:

(5 * 0.37) + (4 * 0.34) + (3 * 0.47) + (1 * 0.84) = 5.46 platforms per acre

Note: This inventory model was developed using a sample of habitat stands in southwest Washington on private commercial timber lands. Although the model correctly identified most of the known occupied sites in a test sample, some occupied sites were missed by the model. Therefore, some caution is warranted when applying this model.

2.3 Delineation of Suitable Marbled Murrelet Habitat

When using the methods described herein, the area sampled can be delineated from an aerial photo, a boundary flagged and mapped (by GPS) in the field, or the mapped extent of an inventoried stand. Results from all three methods need to be field checked. The most accurate boundary, where the change in stand characteristics is evident, can be obtained from the 100% Cruise method data. To delineate suitable habitat from the 100% Cruise data:

1. All eligible trees ≥32 inches dbh (24 inches dbh for western hemlock) that contain platforms in a stand. This includes the area outside of a proposed harvest unit wherever the forest structure is contiguous. Count all platforms in eligible trees.
2. In the office, upload tree waypoints and identify eligible platform trees that occur within ≥300-feet of one other.
3. Using GIS, draw a minimum convex polygon (MCP) around the perimeter of the eligible platform trees identified. An MCP identifies the smallest bounded area around a set of points. In this case, trees that are within 300 feet of one another. The polygon is convex because all of the angles are less than 180 degrees, and the vertices point away from the center. A vertex is where two-line segments in a polygon meet (Figure 15.3).
4. The area of the MCP is used to calculate platforms per acre. If the MCP of platforms trees is less than 5 acres, then the stand is not suitable murrelet habitat, and no further work is needed. If the stand is greater than 5 acres, divide the number of platforms observed within the MCP by its area.
5. The required number of platforms per acre for the subject area is either 2, 5, or 7 depending on the site's proximity to a known marbled murrelet detection area (WAC 222-16-010) or within the marbled murrelet special landscape WAC 222-16-087 (Figure 15.4). Proposed forest practices activities in stands meeting these platform density thresholds are suitable habitat, subject to SEPA, and require a protocol survey.
6. If suitable murrelet habitat is determined to be present, then the first 300-feet of adjacent timber with similar stand characteristics is added to the MCP. This is not necessarily a continuous buffer around the MCP. The addition only includes areas of similar stand age and structure (Figure 15.2). This additional acreage is assumed to be necessary for buffering a potentially occupied stand and subject to SEPA policies per WAC 222-12-042 without survey information of the suitable habitat.

Without protocol marbled murrelet survey information, all harvest activities (other than removal of down trees) and road construction within 300 feet of suitable habitat has the potential to have a significant adverse impact on the environment.

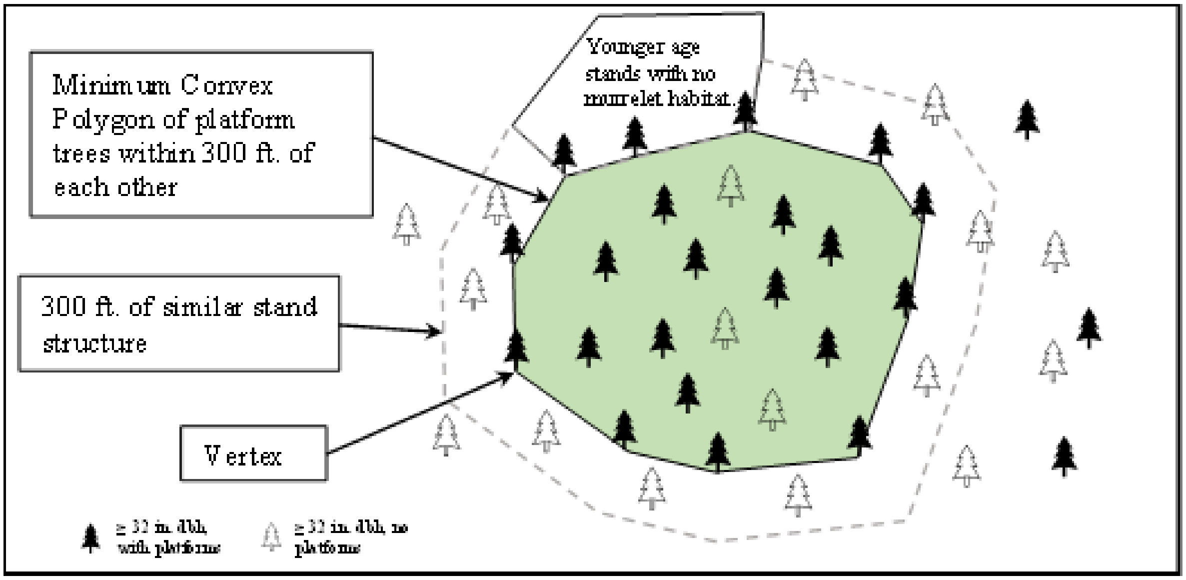


Figure 15.3. Determining the outer perimeter of suitable marbled murrelet habitat. Modified from Ramsdell and Ritchie 1998.

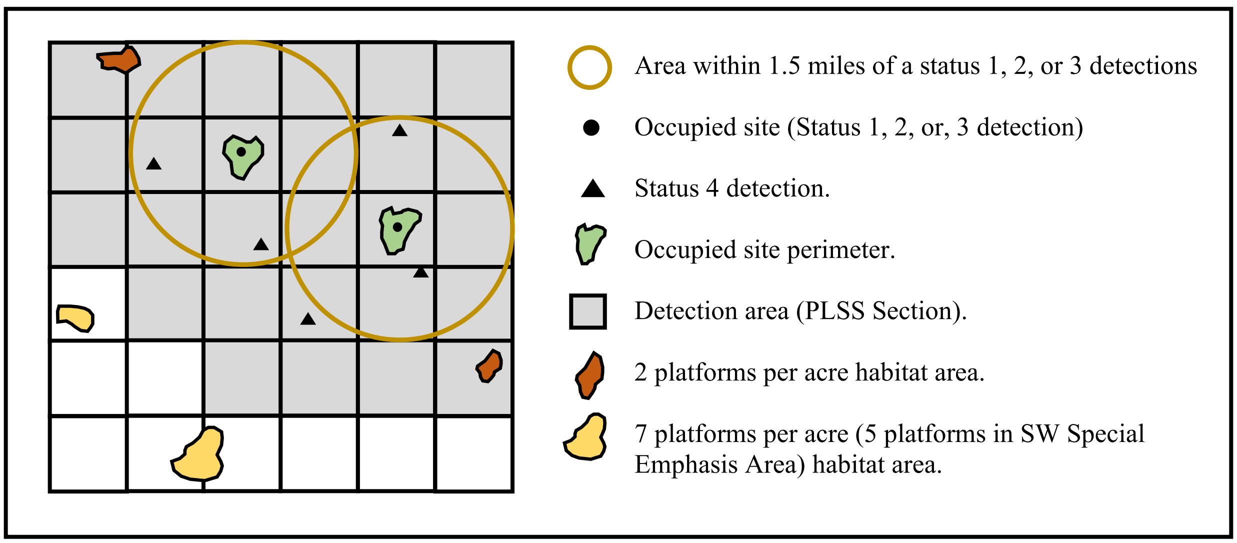


Figure 15.4. Target areas for conducting nesting platform assessments within one township and range. Modified from Ramsdell and Ritchie 1998.

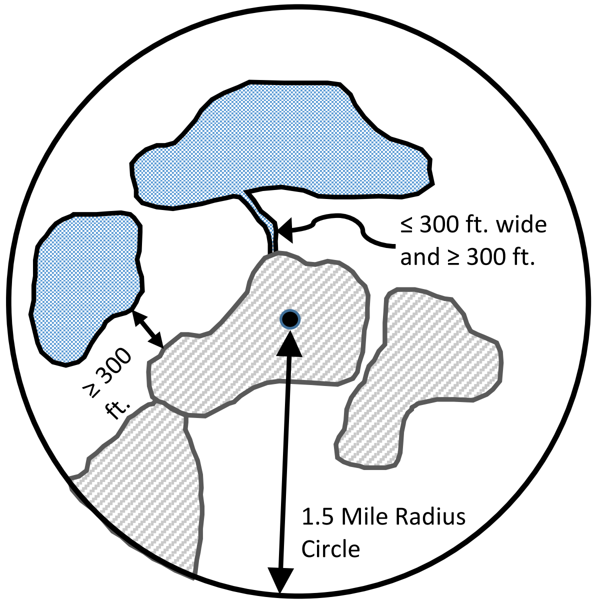
2.4 Delineating Occupied Marbled Murrelet Habitat

If occupancy is detected, you are required to establish the "Occupied Marbled Murrelet Site" boundary as defined in WAC 222-16-010. Contiguous occupied habitat needs to be delineated in the field and confirmed in consultation with WDFW. While the MCP is designed to capture the minimum area needed to trigger a protocol survey, the occupied site may not be a convex polygon. Figure 15.5 illustrates the requirements outlined in rule.

Determining Occupied Sites

The outer perimeter of an "Occupied marbled murrelet site" is presumed to be the closer of the following:

1. 1.5 miles from the point where the occupied behaviors occurred.
2. The beginning of any gap greater than 300 feet that lacks any of the vegetative characteristics listed under "suitable marbled murrelet habitat."
3. The beginning of any narrow area of "suitable marbled murrelet habitat" less than 300 feet wide and more than 300 feet in length.



Contiguous occupied habitat. Non-contiguous suitable habitat.
Land not meeting suitable habitat criteria. Site where occupied behaviors observed.

Figure 15.5 Determining the outer perimeter of occupied marbled murrelet habitat.

PART 3. HARVEST METHODOLOGY FOR OCCUPIED MARBLED MURRELET SITE BUFFERS

3.1 Additional Preparation and Harvest Requirements:

Once occupancy has been confirmed (or assumed), a 300-foot average buffer zone surrounding the MCP delineated occupied marbled murrelet site is necessary for minimizing harvest edge effects WAC 222-16-080 (1)(h)(v)). This is the same area identified in step 6 under delineation of suitable murrelet habitat described above. The 300-foot average managed buffer contains a no-harvest inner zone and a managed outer zone. Specific forest practices on lands adjacent to designated Marbled Murrelet Critical habitat (state) have been determined to have potential for a substantial impact on the environment and have been classified by the department to be Class IV-Special Forest Practices.

Figure 15.5 describes the process for determining the outer perimeter of occupied marbled murrelet habitat.

The following two forest practices activities have been so classified as Class IV-Special Forest Practices under WAC 222-16-080 (1) (h) (v) (see Figure 15.6 for classing flow chart):

1. Harvesting within the150-foot no-cut inner zone buffer of a 300-foot managed buffer zone adjacent to an occupied marbled murrelet site.
2. Harvesting within the 150-foot outer zone managed buffer of a 300-foot managed buffer zone adjacent to an occupied marbled murrelet site that results in less than a residual stand relative density of 35 (Douglas-fir or red alder dominant species group) or a residual stand relative density of 50 (Western hemlock dominant species group).

The total width of the 300-foot managed buffer zone may be reduced in some areas to a minimum of 200 feet and extended to a maximum of 400 feet as long as the average of 300 feet is maintained;

however, a 150-foot no-cut inner zone buffer adjacent to the occupied marbled murrelet habitat must be maintained in these reduced or extended buffer zones. The landowner is required to consult with WDFW on managed buffer prescriptions.

Per WAC 222-16-080 (1)(h)(v), the primary consideration for the design of managed buffer zone widths and leave tree retention patterns is to help minimize edge effects, including effects from prevailing wind patterns.

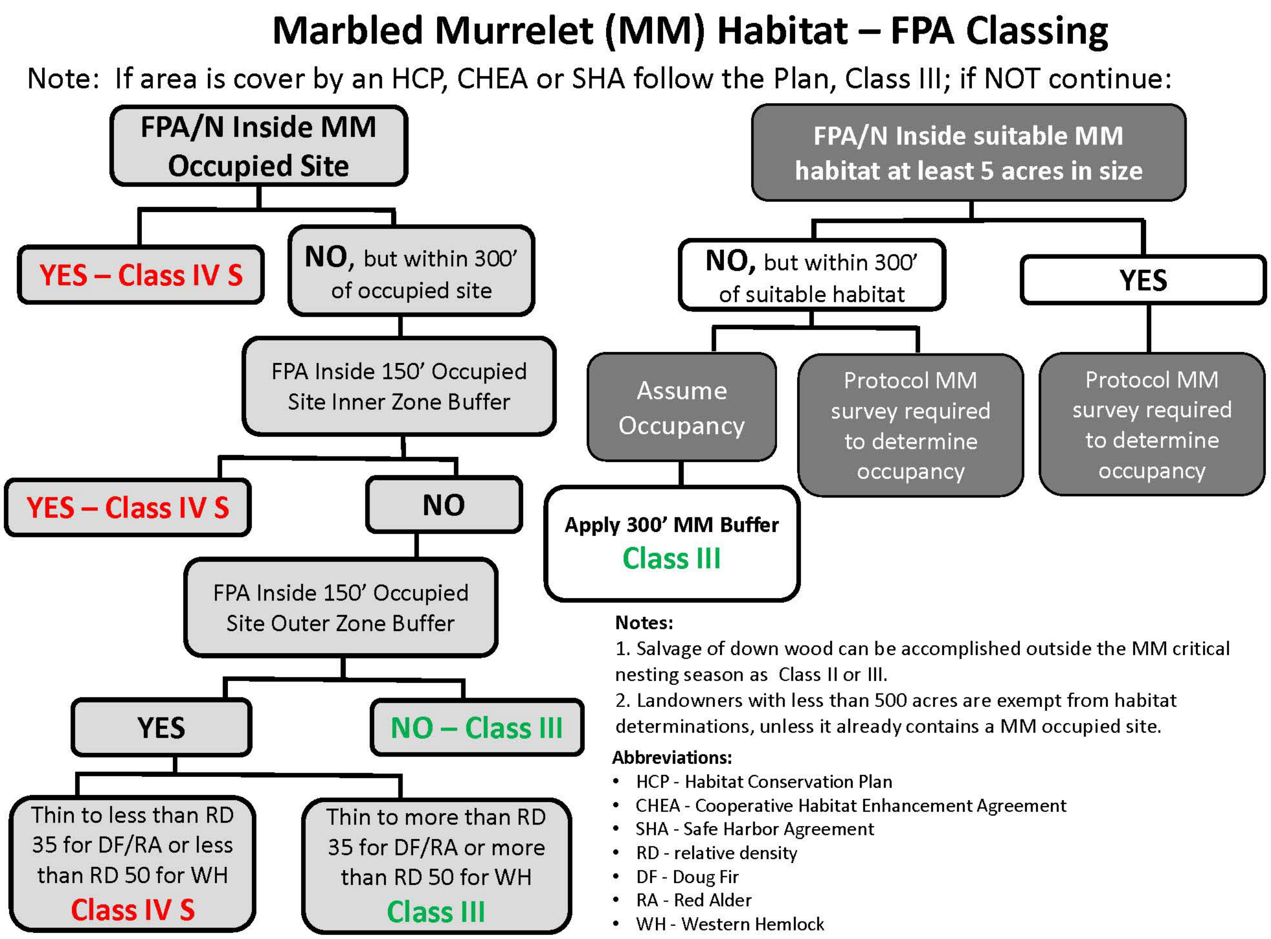


Figure 15.6 Classing flow chart (T. Allison, Olympic Region)

3.2 Simplified Guidance for field layout and conducting harvest within a Marbled Murrelet outer zone managed buffer:

The following is simplified guidance for:

1. Field layout of an outer zone managed buffer within a 300-foot managed buffer adjacent to an occupied marbled murrelet site to produce a residual stand relative density of at least 35 (Douglas-fir or red alder dominant species group) or a residual stand relative density of at least 50 (Western hemlock dominant species group) following harvest and,
2. Conducting the harvest within the outer zone managed buffer.

If you intend to harvest within the outer zone of the managed 300-foot buffer adjacent to an occupied marbled murrelet site, first determine the outer edge of the occupied site, then determine the 150-foot no cut inner zone. Subsequently, determine the inner and outer edges of the proposed 150-foot managed buffer zone. Mark all boundary locations in the field.

The tree retention requirements (the target leave tree stocking levels following harvest) are determined by calculating the quadratic mean diameter (QMD) of the stand within the managed buffer zone and by knowing the dominant species group (see "Dominant species group" information box below) within your proposed managed buffer zone. The QMD method works well in even-aged stands where the dominant and codominant trees are of uniform diameter.

Quadratic mean diameter (QMD) formula (Appendix B):

$$\text{quadratic mean diameter} = \sqrt{(\Sigma d_i^2) / n}$$

d_i=diameter at breast height of an individual tree
n=total number of trees

Figure 15.7 Quadratic mean diameter is the measure of average tree diameter conventionally used in forestry, rather than arithmetic mean diameter. (Abstract: West. J. Appl. For. 15(3):137-139).

Table 15.3 Example of a quadratic mean diameter calculator (tight diameter distribution)

Measured DBHs (inches)	Calculated DBH^2
14.7	216.09
13.3	176.89
14.0	196.00
14.7	216.09
13.7	187.69
14.3	204.49
15.0	225.00
13.3	176.89
14.3	204.49

Marbled Murrelet 150' Managed Outer Zone Cruise Plot Card

Plot Number: ____________ Basal Area Factor (BAF): ____________

1 Tree Number	2 Species	3 Diameter (inches)	4 BA per acre	5 BA per tree	6 Trees per acre
		TOTAL			

Column Descriptions:
1. Number sample (tally)trees sequentially
2. Tree species
3. Tree diameter (record to nearest whole inch)
4. Basal area (BA) per acre (each tally tree is same amount of BA / acre as BAF value)
5. BA per tree (calculate Pi * (DBH/24)^2
6. Tree per acre (TPA) = BA per acre (column4) / BA per tree (column 5)
7. Plot QMD = (Total BA/Total TPA)^.5 * 13.54 **Plot QMD=**
8. After determining QMD, use the modified Curtis Relative Desnsity (RD) calculator found in FP BM 15 for the dominant tree species in the 150' managed outer zone buffer. Use of this calculator will produce the number of leave trees per acre and the spacing between leave trees in feet. Mark a representative sample of the leave tree prescription for review. Ensure legacy or residual trees are all marked for leave prior to harvest.

Figure 15.8 Example plot card.

Use a sample cruise (using fixed-radius or variable plots) to determine the QMD of the trees within your delineated managed buffer zone, as well as the dominant species group (Douglas-fir, western hemlock, or red alder) within this buffer.

Measure the dbh (diameter at breast height, i.e., 4.5 feet above the ground) of each sampled tree and note the dominant species group (Douglas-fir, western hemlock, red alder, or other conifers) of each tree that falls within cruise area. Determine for each tree you have measured whether it is a residual tree (see description in Appendix A) or not a residual tree. The vast majority of managed buffer zone stands adjacent to occupied marbled murrelet sites will likely be even-aged but may have some remnant conifer trees, but identifying which trees are remnant trees is *critically* important to the proper calculation of QMD for the trees within the managed buffer.

As you measure each tree, either:

a) Directly enter the diameter and species group you have measured into the appropriate category ("Residual" tree category or "Non-Residual" tree category) or
b) Record (on any paper form of your choice) the diameter and species group of each measured tree, again making sure to note whether the tree is a Residual or Non-Residual and then input your data into the "QMD Calculator" computer application (Forest Practices Forms and Instructions | WA - DNR).

"**Dominant species group"**: Dominant species group is determined by majority stem count of trees greater than or equal to 6 inches dbh. There are three choices for a dominant species group: Douglas fir; red alder; and western hemlock. If Douglas fir is the majority species choose Douglas fir as the dominant species group. If western hemlock or other conifer is the majority species, choose western hemlock as the dominant species group. If red alder or other hardwood is the majority species, choose red alder as the dominant species group.

The QMD Calculator will provide the calculated QMD for the Non-Residual trees within your managed buffer zone stand, as well as the estimated number of Residual trees within your managed buffer zone, based on your sample cruise. It will also provide the "Dominant species group", Douglas-fir/red alder or western hemlock.

Use the identified "Dominant species group" category to determine which Modified Curtis Relative Density Calculator" table (Tables 15.4 or 15.5) you should use (Douglas-fir/red alder or western hemlock). Using the appropriate species table and the calculated non-Residual QMD for your managed buffer zone, find the stand QMD in the table and determine the calculated number of conifers "Leave Trees/Acre (Minimum)" to retain after partial harvest.

Use this calculated minimum number of residual trees (Leave Trees/Acre (Minimum)) to determine the actual trees you must retain within your managed buffer zone.

If there are no residual conifer trees within your managed buffer zone, merely use this calculated minimum number of residual trees for your field layout of leave trees within your managed buffer zone, using the appropriate "Average Tree Spacing (Feet)" figure from the table as a guide.

If you have *any* residual conifer trees within your managed buffer zone, all such residual conifer trees within your managed buffer zone must be retained as leave trees. Once these residual conifer trees have been identified for leave, the remaining minimum number of residual trees to retain within the managed buffer zone should be calculated and then those remaining leave trees must be identified for leave during field layout. Strive to maintain pre-harvest levels of species diversity.

See the **Additional Preparation and Harvest Requirements** section below for marking leave trees on site.

Table 15.4 Modified Curtis Relative Density (RD) Calculator for Douglas-fir / red alder (RD 35)

QMD Quadratic Mean Diameter (Inches)	Leave Trees/Acre (Minimum)	Average Tree Spacing (Feet)
30	39	38
29	41	37
28	43	36
27	46	35
26	48	34
25	51	33
24	55	32
23	58	31
22	62	30
21	67	29
20	72	28
19	77	27
18	84	26
17	92	25
16	100	24
15	110	22
14	123	21
13	137	20
12	154	19
11	176	18
10	203	17
9	238	15
8	284	14

Table 15.5 Modified Curtis Relative Density Calculator for western hemlock (RD 50)

QMD Quadratic Mean Diameter (Inches)	Leave Trees/Acre (Minimum)	Average Tree Spacing (Feet)
30	56	32
29	59	31
28	62	30
27	65	29
26	69	28
25	73	28
24	78	27
23	83	26
22	89	25
21	95	24
20	102	23
19	111	22
18	120	22
17	131	21
16	143	20
15	158	19
14	175	18
13	196	17
12	221	16
11	251	15
10	290	14
9	340	13
8	405	12

Additional Preparation and Harvest Requirements:

1. A representative sample of the proposed managed buffer zone must be laid out on the ground with leave trees marked prior to harvest and before the Forest Practices Application (FPA) is submitted to demonstrate how the managed buffer zone harvest will be implemented.
2. Reasonable care shall be taken to avoid damage to the stems and root systems of all residual trees within the managed buffer zone from falling, skidding, or yarding. Leave trees with bole diameter damage of more than one half tree diameter will not count towards the residual retention requirements should mortality occur post-harvest. If damage is likely during falling and yarding, leave additional trees within the buffer zone to ensure the adequate density of retention trees are met post-harvest.
3. Within the managed buffer zone, ground-based systems shall not be used on slopes where in the opinion of the department, this method of operation would cause actual or potential material damage to a public resource. When transporting logs in or through the managed buffer zone with ground-based equipment, the number of routes through the zone shall be minimized. Logs shall be transported to minimize damage to leave trees and vegetation in the managed buffer, to the extent practical and consistent with good safety practices.
4. Cable yarding within the managed buffer zone is subject to requirements listed in WAC 222-30-060 Cable Yarding.

APPENDIX A CROWN CLASSIFICATION DESCRIPTIONS

A tree crown classification system is useful in discussing stand development. Figure 15.9 illustrates a commonly used system, which has the following six classes:

1. **Dominant**. Trees with the crown extending above the general level of the crown canopy receive full sunlight from above and some from the sides. The sides of the crowns are well developed but (possibly) somewhat crowded. Live crown ratios generally greater than 50%.
2. **Codominant**. Trees with crowns forming the general level of the crown cover receive full light from above but little from the sides. The tree crowns are medium size and more crowded on the sides than are dominant crowns. Live crown ratios generally greater than 40%,
3. **Intermediate**. These trees usually are shorter than those in the two preceding classes. They have small, crowded sides. The crowns extend into the canopy formed by dominant and codominant trees; they receive a little direct light from above but none from the sides. Live crown ratios generally below 40%.
4. **Suppressed** (overtopped). The crowns on these trees are below the level of the crown canopy. They receive no direct light from above or from the sides. Live crown ratios generally less than 33%.
5. **Remnant (older residual or wolf trees).** These are generally trees in which grew in the open without competition from neighboring trees, or are trees which were not harvested during previous harvest(s). Their diameters are generally significantly larger than the diameters of the rest of the stand. They often have full crowns on all sides, with branches well above or below the general canopy level of the rest of the stand. The crowns are uncrowded on two or more sides and receive full light from above and well down on two or more sides. Live crown ratios often exceed 75%.
6. **Mortality**. These are dead trees within the stand. Suppressed trees usually die, and trees of any crown class may die from disease or insect attack.

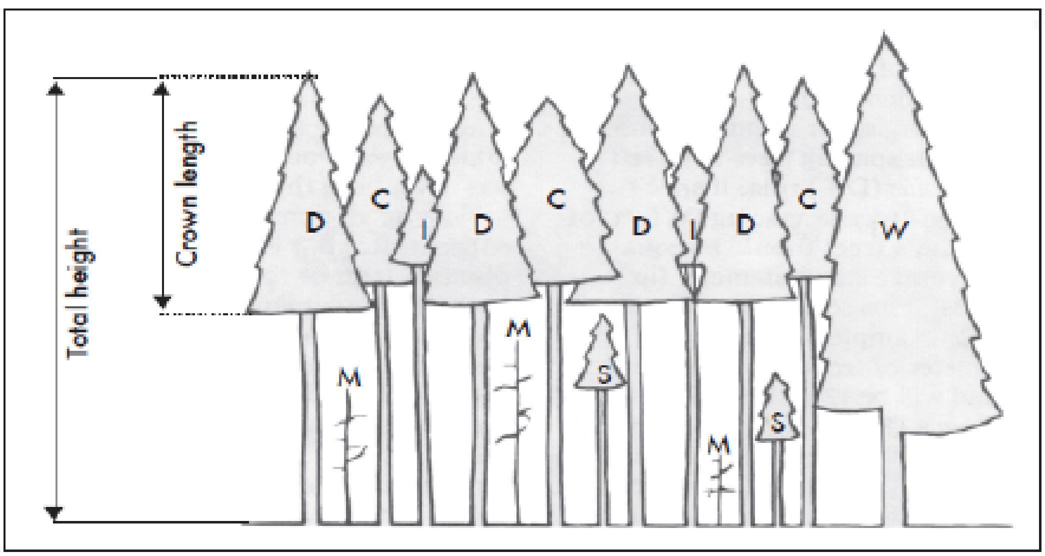


Figure 15.9 Crown type classifications of trees in even-age stands. D = Dominant, C = Codominant, I = Intermediate, S = Suppressed, M = Mortality, and W = Wolf or Remnant Trees. The "crown ratio" is the proportion of total tree height that is occupied by live crown. In this illustration, the dominants have a 50 percent crown ratio; the residual tree has an 80 percent crown ratio. (Adapted from: W.H. Emmingham and N.E. Elwood, 1983 "Thinning: An Important Timber Management Tool", Oregon State University, PNW 184)

APPENDIX B QUADRATIC MEAN DIAMETER FORMULA

Technical Note

Why Quadratic Mean Diameter?

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ABSTRACT: *Quadratic mean diameter is the measure of average tree diameter conventionally used in forestry, rather than arithmetic mean diameter. The historical and practical reasons for this convention are reviewed. West. J. Appl. For. 15(3):137–139.*

Average diameter is a widely used stand statistic that appears in virtually all yield tables, simulator outputs, stand summaries, and much inventory data. To most people, "average" is synonymous with the arithmetic mean, defined as

$$\text{arithmetic mean} = \bar{x} = (\Sigma \;\; x_i) / n$$

where the x_i are the individual measurements and n is the total number of measurements.

But there are in fact some half dozen different kinds of averages (= means = measures of central tendency), each appropriate to specific uses. One of these is the quadratic mean (Kendall and Buckland 1967, Iles and Wilson 1977), defined as

$$\text{quadratic mean} = \sqrt{(\Sigma x_i^2) / n}$$

which is the square root of the arithmetic mean of squared values. Other generally recognized means sometimes encountered in forestry are the geometric mean, harmonic mean, median, and mode.

The expression of average stand diameter conventionally used in forestry is not the arithmetic mean of diameters, but the quadratic mean,

$$\text{quadratic mean diameter} = \sqrt{(\Sigma d_i^2) / n}$$

where d_i is the diameter at breast height of an individual tree, and n is the total number of trees. Quadratic mean diameter is commonly symbolized as *QMD*, *Dq*, or *Dg*. *Dg*, in which the subscript stands for "Grundfläche," German for basal area, is widely used in Europe and is the symbol recommended by the International Union of Forest Research Organizations (Van Soest et al. 1959) .

QMD is often calculated by the equivalent equation:

$$QMD = \sqrt{B / (k * n)}$$

where B is stand basal area, n is corresponding number of trees, and k is a constant that depends on the measurement units used (0.005454 for B in square feet and *QMD* in inches; 0.0000785 for B in square meters and *QMD* in centimeters).

In angle-gauge sampling, it can also be calculated directly (Buckingham 1969) as:

$$QMD = \sqrt{[n_s / \Sigma(1 / d_1^2)]}$$

where the d_i are the diameters and n_s is the number of "in" trees in the angle-gauge sample.

Past usage of the phrase "average diameter" has often been very loose, and unwary readers often take it to mean the arithmetic mean, when in fact the value given is the quadratic mean. It is therefore good practice for authors to be specific (Curtis 1968). The quadratic mean gives greater weight to larger trees and is equal to or greater than the arithmetic mean by an amount that depends on the variance according to the relationship

$$(QMD)^2 = \bar{d}^2 + s^2$$

where $\bar{d}$ is arithmetic mean diameter and s^2 is the variance of diameters.

In stands of small diameter and narrow range in diameters, the differences are slight. In stands with large diameters and a wide range of diameters present or with strongly skewed diameter distributions, the differences between arithmetic mean and quadratic mean diameters can be substantial (Figure 1).

People not strongly grounded in forest mensuration are often unaware of the distinction between arithmetic and quadratic means. When this distinction is pointed out, they naturally wonder how and why such a strange "average" came to be adopted and why it is still used. After all, it is rarely mentioned in introductory statistics courses.

The answer is partly a matter of custom and historical precedent, but *QMD* also has certain practical advantages that still hold true.

Use of the quadratic mean of diameters is a very old practice in forestry, which goes back to 19th century Germany and possibly earlier. It has been standard practice in the United States from the earliest days of North American forestry. Most standard U.S. mensuration texts,

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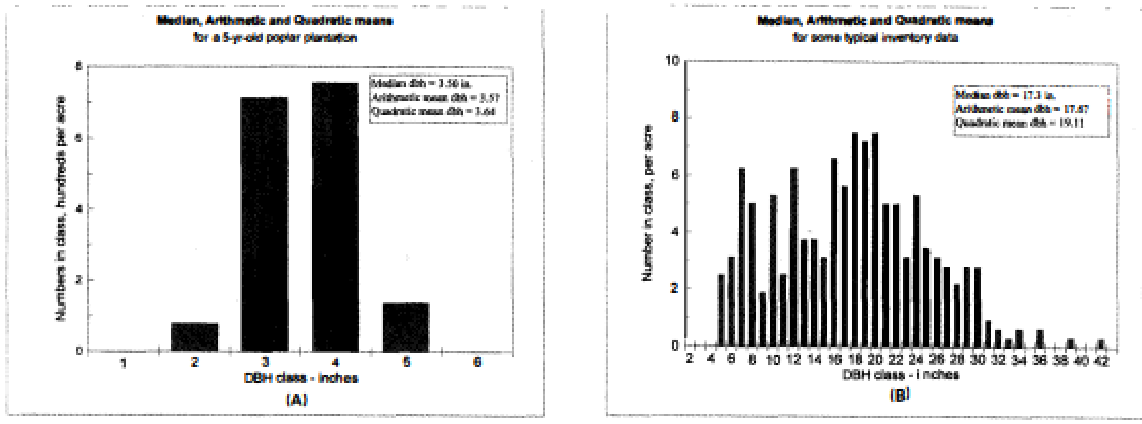

Figure 1. Median, arithmetic mean, and quadratic mean diameters for stands with (A) small diameters and nearly symmetrical diameter distribution, and (B) larger diameters and somewhat asymmetrical diameter distribution.

starting with Graves (1908), define average stand diameter as the diameter corresponding to the tree of arithmetic mean basal area, which *is* the quadratic mean diameter. Braathe's (1957) summary of European thinning literature specifically defines average diameter as the quadratic mean. *QMD* is commonly used in silviculture research data summaries and reports. Virtually all normal yield tables prepared in the United States in the period from around 1920 through the mid-1960s use quadratic mean diameters (Schnur 1937, McArdle et al. 1961, Barnes 1962), sometimes referred to in older publications as "average diameter by basal area." This usage of *QMD* is also common in current stand simulation programs (Curtis et al. 1981, Hann et al. 1997). Reineke's (1933) SDI is based on *QMD*, as are the various relative density measures and stand management diagrams derived from the Reineke relationship (Curtis 1982, Long et al. 1988).

In the Germany of some 150 or more years ago, there were a number of so-called mean tree methods in use for estimating volume of wood in forest stands. These also had some limited use in the early days of North American forestry (Graves 1908, p. 224ff.). The basic idea, in simplest form, was that the forester would select a tree(s) considered average for the stand, cut it and measure its wood content, and then multiply by the number of trees. The obvious difficulty was in selecting an average tree(s), whose volume would approximate overall arithmetic mean volume / tree. In regular even-aged stands, diameter of the tree of arithmetic mean volume is generally close to that of the tree of arithmetic mean basal area (which is also the tree of quadratic mean diameter). Thus, a basis was provided for selecting sample trees for analysis.

Such procedures are now ancient history. But justification for use of *QMD* also arises from the general relationship between stand volume and other, directly measurable, stand attributes.

In any reasonably regular stand, there is a general relationship

$$\text{volume / unit area} = f * N * B_{mn} * H$$

where f = stand form factor, which for a given species and stand condition has only a very limited range of variation and can often be treated as constant.

N = number of trees / unit area

B_{mn} = arithmetic mean basal area / tree, and

H = some "average" height.

In an existing stand we cannot directly measure either total stand volume or mean volume/tree, but must estimate these from measurements of their components. It is often convenient to describe stands in terms of means of these components: namely, number of trees, arithmetic mean basal area, and some average height.

People do not usually think in terms of basal area of a tree (cross-sectional area at breast height). It is much easier to visualize a tree of 19 in. dbh than one of 2.0 ft^2 cross-sectional area. It is therefore common to describe stands by *QMD* (a surrogate for arithmetic mean basal area) rather than by arithmetic mean basal area. In these terms,

$$\text{Volume / unit area} = f * N * [k * (QMD)^2] * H$$

The correct average height in these equations is not the arithmetic mean, but Lorey's height (H_L, named after a 19th century German forester). This is a weighted mean,

$$H_L = \Sigma b_i h_i \,/\, \Sigma b_i = \Sigma d_i^2 h_i \,/\, \Sigma d_i^2$$

where, b_i is the basal area of an individual tree and d_i is the diameter of an individual tree.

H_L is somewhat inconvenient to calculate from a fixed area sample or stand table, although with angle-gauge sampling it can be easily obtained as the arithmetic mean of heights of the count trees. A common approximation is the height corresponding to *QMD*, as estimated by a height-diameter curve or equation for the individual stand. (Stand average height is of course a different statistic from the top height or dominant height used for other purposes, though highly correlated with these in unthinned stands.)

Expressions of the above form are not commonly used today to calculate stand volumes, although they are valid and are sometimes used in stand simulation programs. We generally apply tree volume equations directly and sum over all trees, rather than first calculating these means. But there is another strong reason for using *QMD*. This stems from the relationship

$$B = k * N * (QMD)^2$$

This is an exact relationship. Therefore, knowledge of any two of the variables automatically confers knowledge of the third. In contrast, there is no equivalent exact relationship for the arithmetic mean, and conversions using the arithmetic mean also require knowledge of the variance. It is a great deal easier to make consistent estimates and projections for two variables than for three, and the exact relationship that exists when *QMD* is used markedly simplifies construction of yield tables and stand simulators, stand projections, and some inventory computations.

This direct convertibility also simplifies the construction and use of stand management diagrams based on number of trees, basal area, and average diameter (Long et al. 1988, Gingrich 1967, Ernst and Knapp 1985). Because of this convertibility, they can be expressed in terms of any two of the three variables *N*, basal area, and *QMD*.

The arithmetic mean is the measure of central tendency most widely used in general statistics, and is essential to a few procedures (such as defining a normal probability distribution). But most procedures in common use in forestry do not specifically require the use of the arithmetic mean. Both the mensurational advantages mentioned above and long-standing precedent make the quadratic mean of diameters the preferred "average diameter" for expressing stand attributes. In any case, users should be conscious of the difference between quadratic and arithmetic mean diameters (which usually is not large) and be specific in defining the value used.

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