



United States Department of Agriculture

# Sampling and Measurement Protocols for Long-term Silvicultural Studies on the Penobscot Experimental Forest

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Forest  
Service

Northern  
Research Station

General Technical  
Report NRS-147

April 2015

## Abstract

The U.S. Forest Service, Northern Research Station has been conducting research on the silviculture of northern conifers on the Penobscot Experimental Forest (PEF) in Maine since 1950. Formal study plans provide guidance and specifications for the experimental treatments, but documentation is also needed to ensure consistency in data collection and sampling protocols. This guide details current sampling and measurement protocols for three of the longest running Forest Service experiments on the PEF: (1) the management intensity demonstration (1950 to present), (2) the compartment management study (1952 to present), and (3) the auxiliary selection cutting study (1953-present). Each of these long-term stand-scale experiments use plot-based measurements of trees taken at periodic intervals. Additional data collected vary and include regeneration, recruitment, and mortality; amount, size, and decay of dead wood; and stand structural characteristics such as heights, crown dimensions, and spatial locations of trees. Descriptions provided here are the basis for data collection in the relevant studies on the PEF, inform interpretation of the published databases, and serve as a model for silvicultural studies elsewhere.

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## Quality Assurance

This publication conforms to the Northern Research Station's Quality Assurance Implementation Plan which requires technical and policy review for all scientific publications produced or funded by the Station. The process included a blind technical review by at least two reviewers, who were selected by the Assistant Director for Research and unknown to the author. This review policy promotes the Forest Service guiding principles of using the best scientific knowledge, striving for quality and excellence, maintaining high ethical and professional standards, and being responsible and accountable for what we do.

## Cover Photo

University of Maine students Brittany Ross (left) and Elizabeth Lewis (right) assist with field work in a U.S. Forest Service study on the Penobscot Experimental Forest, 2012. Photo by Laura S. Kenefic, U.S. Forest Service.

Manuscript received for publication 9 July 2014

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Published by:  
U.S. FOREST SERVICE  
11 CAMPUS BLVD SUITE 200  
NEWTOWN SQUARE PA 19073

April 2015

For additional copies:  
U.S. Forest Service  
Publications Distribution  
359 Main Road  
Delaware, OH 43015-8640  
Fax: (740)368-0152  
Email: [nrspubs@fs.fed.us](mailto:nrspubs@fs.fed.us)

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## INTRODUCTION

Since 1950, the Penobscot Experimental Forest (PEF) in Maine has been the site of U.S. Forest Service, Northern Research Station (formerly the Northeastern Forest Experiment Station) research on silviculture of northern conifer (previously called spruce-fir) forests (Kenefic and Brissette 2014). Long-term data collected and maintained over many decades at the PEF are an invaluable resource in efforts to improve and advance northern conifer forest management and inform policymaking. Data collected in the field are used in scientific publications, presentations, workshops, and tours that reach national and international audiences.

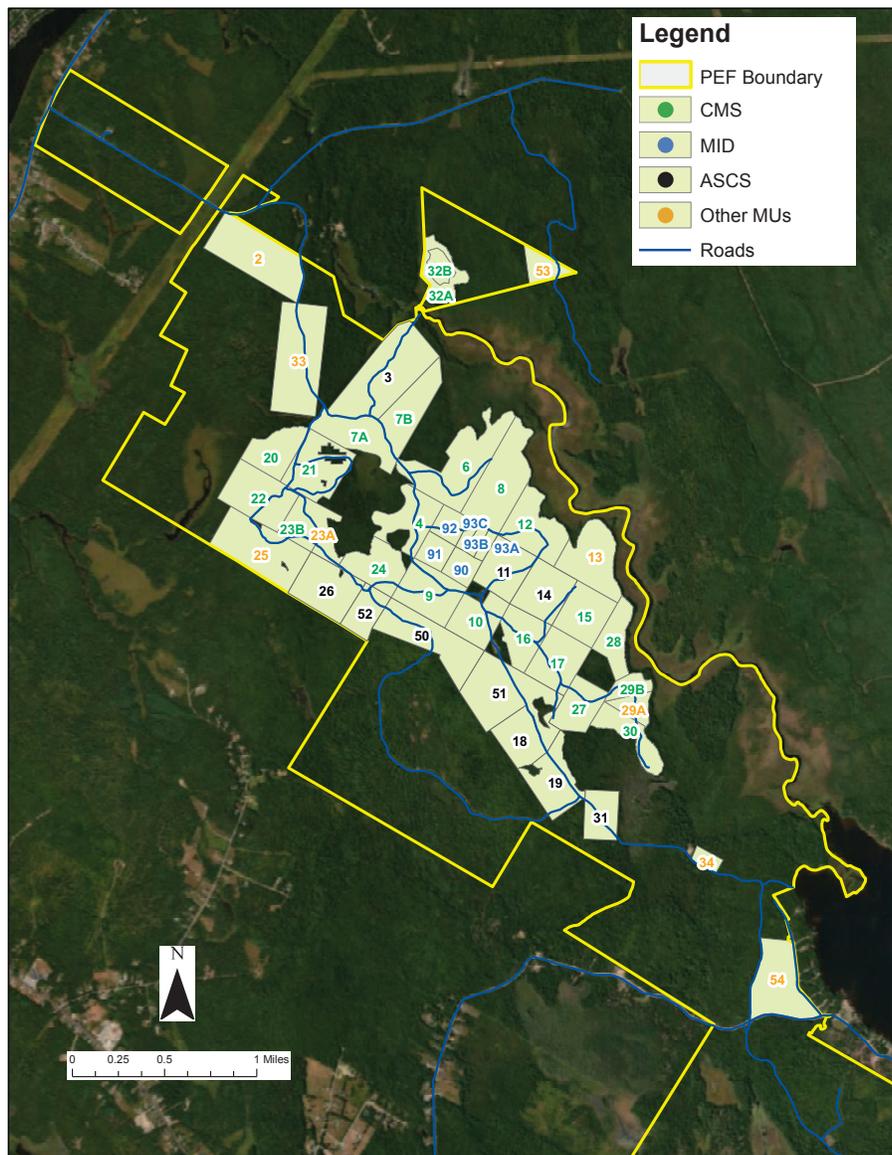
The PEF is one of 80 experimental forests and ranges (EFRs) maintained by the Forest Service nationwide (Stine 2014). Each of these sites was designated by the Chief of the Forest Service for long-term forest ecology and management research. Although the EFR network includes studies with more than 100 years of data, many of the historical databases are locally stored and lack metadata; they are thus difficult to access and understand. In a partnership with the Forest Service's Research Data Archive (<http://www.fs.usda.gov/rds/archive/>), scientists at the PEF recently published a number of long-term databases and metadata. This is the first time historical silvicultural (vegetation management) data from the EFR network have been fully documented and made available to the public. To maintain and continue to build this valuable long-term data resource, it is essential that measurements taken in the field be precise, accurate, and consistent within studies and across years.

This document describes current (as of 2015) data collection procedures for the three oldest ongoing PEF studies: (1) the management intensity demonstration (MID), (2) the compartment management study (CMS), and (3) the auxiliary selection cutting study (ASCS). Combined with the appropriate study plans and job hazard analyses, this manual provides guidance for field work in these studies at the PEF. Scientists working with data from the long-term studies should refer not only to this guide, but also to the metadata and supplemental files associated with individual study databases (e.g., Brissette et al. 2012b, Waskiewicz et al. 2014). The latter provide specific information about procedures that have changed over time (e.g., plot sizes, measurement intervals, and tree condition codes; Appendix I).

## Study Site

The 3,855-acre PEF (44°53' N, 68°39' W) is located near Bangor, Maine, within the Acadian forest, an ecotone between eastern broadleaf and boreal forests (Halliday 1937). Tree composition is dominated by red spruce (*Picea rubens* Sarg.), balsam fir (*Abies balsamea* (L.) Mill.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), northern white-cedar (*Thuja occidentalis* L.), and eastern white pine (*Pinus strobus* L.). Important hardwoods include red maple (*Acer rubrum* L.) and paper birch (*Betula papyrifera* Marsh.). Detailed descriptions of the climate and soils of this site may be found in Sendak et al. (2003) and Kimball (2014).

Figure 1.—Management units on the Penobscot Experimental Forest, including those in the compartment management study (CMS), the management intensity demonstration (MID), and the auxiliary selection cutting study (ASCS).



## Management Units

There are 48 management units (MUs) on the PEF, ranging in size from 3 to 56 acres (Fig. 1, Table 1). Eighteen MUs are part of the CMS described in Study Plan FS-NRS-07-08-01, “Silvicultural Effects on Composition, Structure, and Growth of Northern Conifers in the Acadian Forest Region: Revision of the Compartment Management Study on the Penobscot Experimental Forest” (Brissette et al. 2012b, Brissette and Kenefic 2014, Sendak et al. 2003). MUs 6, 7A, 7B, and 10 are also compartments, although not described in the Study Plan. MUs in the CMS represent 10 different silvicultural treatments (two MUs in each treatment—see Appendix II) that have been maintained and remeasured since 1952. Treatments include variants of even-age and uneven-age silviculture, exploitative cutting, and no harvest.

Six MUs are part of the MID, also known as the cutting practice level (CPL) study, described in Working Plan RS-NE “Cutting Practice Level Plots” and its addendum, dated December 21, 2012 (Waskiewicz et al. 2014). The MID MUs were established in 1950; four treatments have

**Table 1.—Attributes of management units (MUs)<sup>a</sup> at the Penobscot Experimental Forest, as of March 2015**

MU	Acres	Cruise line azimuth	no. of lines	no. of PSPs	Study <sup>b</sup>	MU	Acres	Cruise line azimuth	no. of lines	no. of PSPs	Study <sup>b</sup>
03	55.3	330	9	25	ASCS	24	23.2	50	4	12	CMS
04	25.1	320	4	13	CMS	26	31.3	230	6	22	ASCS
06 <sup>c</sup>	48.5	320	7	21	CMS	27	20.2	140	6	23	CMS
07A <sup>c</sup>	26.2	50	28	21	CMS	28	18.0	140	8	20	CMS
07B <sup>c</sup>	27.0	155	25	21	CMS	29B	8.8	50	3	8	CMS
08	43.4	140	7	21	CMS	30	18.2	230 & 180	8	20	CMS
09	27.0	230	4	13	CMS	31	17.5	24 & 294	9	21	ASCS
10 <sup>c</sup>	21.9	50	3	10	CMS	32A	12.8	289	5	10	CMS
11	25.4	50	3	9	ASCS	32B	7.1	289	6	10	CMS
12	30.9	50	4	14	CMS	50	37.8	228	4	13	ASCS
14	26.2	50	3	13	ASCS	51	48.9	230	3	10	ASCS
15	25.5	50	4	20	CMS	52	15.6	230	3	12	ASCS
16	16.3	230	5	20	CMS	90	9.9	50	5	6	MID
17	26.4	230	3	14	CMS	91	9.8	50	5	6	MID
18	20.8	73	6	22	ASCS	92	9.9	230	5	6	MID
19	27.4	73	6	22	ASCS	93A	3.3	230	1	2	MID
20	21.8	50	5	21	CMS	93B	3.6	230	1	2	MID
21	28.0	230	3	10	CMS	93C	3.0	230	1	2	MID
22	33.5	230	5	20	CMS						
23B	12.4	50	3	9	CMS						

<sup>a</sup> MUs 02A, 02B, 13, 25, 33, 34, 53, and 54 contain inactive or other studies. MUs 23A and 29A were previously part of the compartment management study and are now part of the Commercial Thinning Research Network (Seymour et al. 2014). None of these MUs are covered by this guide.

<sup>b</sup> MUs are in the compartment management study (CMS), management intensity demonstration (MID), or auxiliary selection cutting study (ASCS).

<sup>c</sup> MUs 06, 07A, 07B, and 10 are compartments containing PSPs of both extensive and intensive measurement as described in this document; however, they are not explicitly included in the compartment management Study Plan.

been represented and maintained since that time (Hart 1964). In 1972, two treatments were added in subdivisions of one of the original MID MUs. Treatments include variants of even-age and uneven-age silviculture, and exploitative cutting.

Ten MUs are part of the ASCS. This study was established in 1953 and includes uneven-age silviculture (selection cutting on 10-year and 15-year cutting cycles).

The remaining MUs contain inactive studies or current studies that do not use the same sampling structure as the three studies described here, e.g., the precommercial thinning x fertilization study (also called Study 58) (Brissette et al. 1999, 2012a; Weiskittel et al. 2011) and the rehabilitation study (Kenefic et al. 2014).

## Inventory Schedule

Study MUs are inventoried at 10-year intervals; different MUs are inventoried in different years, unless a harvest is scheduled. In MUs with a scheduled harvest, inventories are conducted before and after harvest, in addition to the regular schedule. Inventory scheduling is a duty of the PEF Forester with approval of the lead scientist.

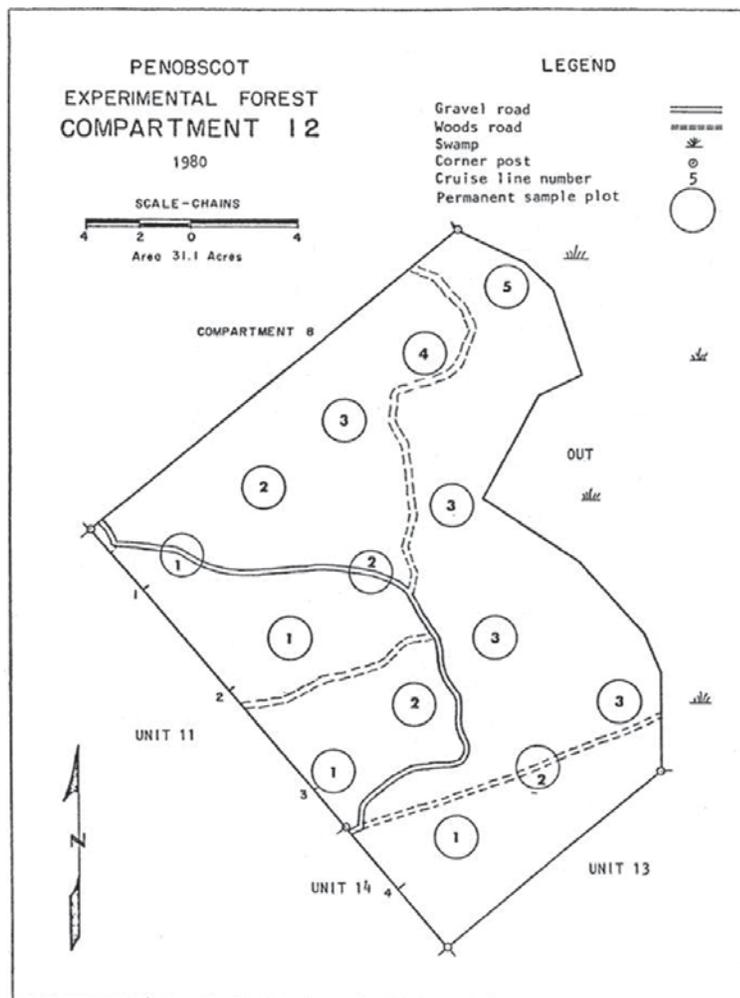


Figure 2.—Location of PSPs on an example MU (MU 12, a CMS MU) with four cruise lines and 14 PSPs.

## PERMANENT SAMPLE PLOTS

In each MU, permanent sample plots (PSPs) have been established for collection of data over time. The number of PSPs per MU is between 2 and 25. The PSPs are located at randomly selected points on a systematic grid with a random start; orientation and spacing between plots varies by MU. In the CMS and MID, PSPs within each MU are nested plots for sampling overstory trees, saplings, and regeneration. In the ASCS, PSPs are used to sample overstory trees only; there are no nested plots. Details of PSP sampling are described in following sections of this document.

In the CMS, additional measurements are taken on a subset of plots (called intensive PSPs). Approximately one-third of the PSPs in the CMS are intensive. Detailed procedures for measurements on intensive PSPs are described in the Field Procedures section on page 8.

## Locating Permanent Sample Plots

Within each MU are 2 to 10 cruise lines, along which lie one to five PSPs (Fig. 2). The location of a PSP within an MU is signified by a two-digit code. The first digit represents the cruise line and the second represents the plot number. For example, the third plot on the fourth cruise line



Figure 3.—PSP marking. Left: PSP marker post. Center: PSP number (4/6). Right: PSP center stake, next to post. Photos by Justin D. Waskiewicz, University of Vermont, used with permission.

would be PSP 4/3 (in the databases, often appearing without the /, thus: 43). All cruise lines are parallel within an MU, with the exception of MUs 30 and 31, which each have two separate cruise line orientations (Table 1). Spatial data describing location of MUs and PSPs can be found in Rogers et al. 2014.

When locating PSPs in the field, it is important to know that direction in the Forest Service studies at the PEF is based on magnetic north, not true north. The declination, or difference between true and magnetic north, has changed since 1950 and will continue to change into the future. In CMS and ASCS MUs, most PSPs were established in the mid-1950s when approximate declination was 19.8° W. Tree numbers and associated PSP sectors, as described later in this document, were established in the middle to late 1970s when the approximate declination was 19.1° W. On MID MUs, PSPs were established in 2000, at which time approximate declination was 18.1° W.

## Permanent Sample Plot Marking and Layout

### Plot Center

The center of each PSP is marked by: (1) a short metal stake, approximately 0.5 inch diameter and 10 to 12 inches long, and (2) a tall wooden post, painted blue, approximately 3 x 3 inches in thickness and 5 to 6 feet long. The blue posts are highly visible and are marked with the PSP number in the form x/y, where x is the cruise line number and y is the plot number, e.g., 3/4 (Fig. 3). The precise location of plot center, from which measurements are taken, is at the metal stake. The stakes are usually right next to and often touching the posts.

### Plot Sectors

Permanent sample plots are divided into ten 36° sectors. Sectors are numbered from zero to nine, where sector one is between 0° and 36°, sector two is between 36° and 72°, etc., to sector

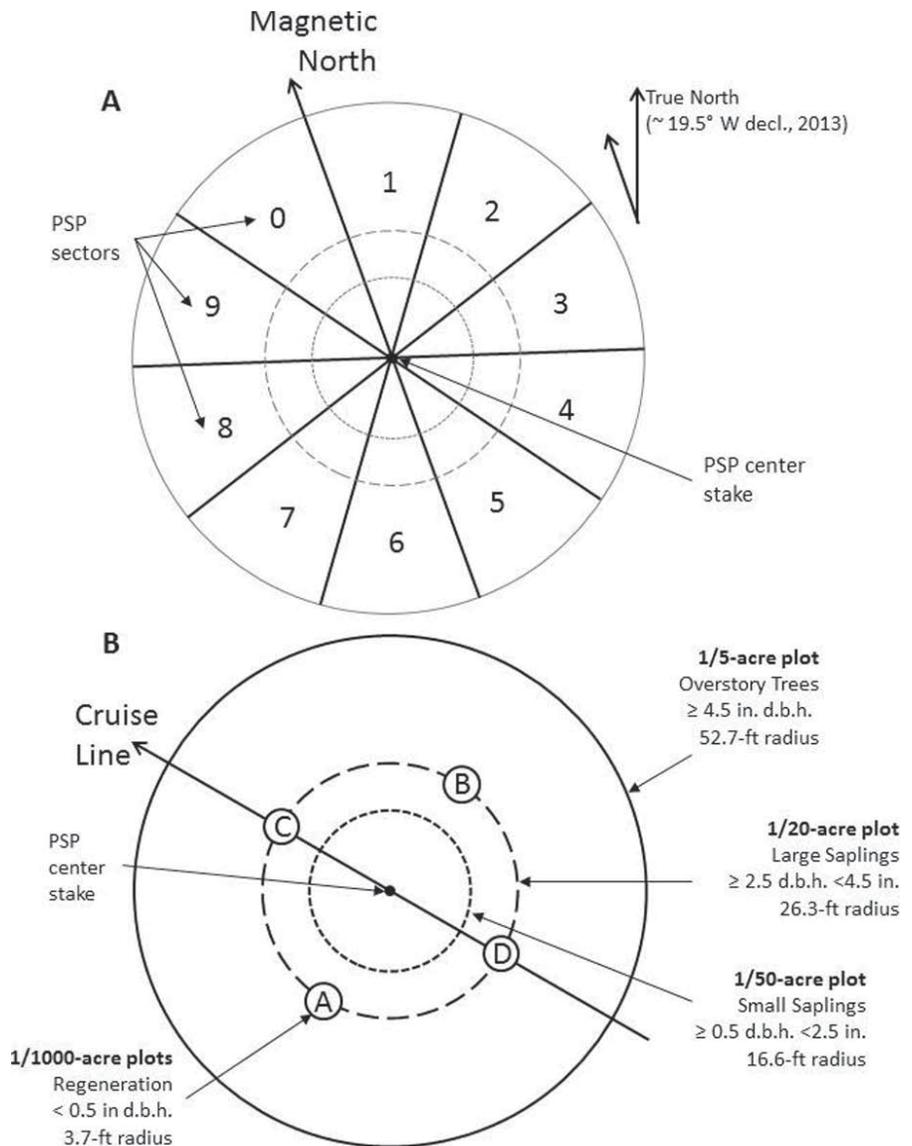


Figure 4.—Layout of a CMS or MID PSP. A: location of tree numbering sectors relative to magnetic north; B: locations and sizes of nested subplots relative to cruise line. Cruise line orientation may vary among MUs (see Table 1). Tree measurements on ASCS MUs use only the 1/5-acre plot.

nine between 288° and 324° and sector zero between 324° and 360° (Fig. 4A). Fieldworkers can orient themselves within a plot by use of surrounding trees numbers which reference sector location (exceptions exist; see the Field Procedures section on page 8).

### Nested Plot Design

Permanent sample plots are 1/5-acre in size, with a 52.7-foot radius. On MUs within the CMS and MID, PSPs are in a nested design to sample overstory trees, large saplings, small saplings, and regeneration (Fig. 4B). Overstory trees with a diameter at breast height (d.b.h) ≥ 4.5 inches are measured on the entire 52.7-foot radius PSP; large saplings, 2.5 ≤ d.b.h < 4.5 inches, are measured on a 26.3-foot radius subplot (1/20 acre); and small saplings, 0.5 ≤ d.b.h < 2.5 inches, are measured on a 16.6-foot radius subplot (1/50 acre). Regeneration subplots, described in the next section of this document, are used to record trees < 0.5 inches d.b.h. Sapling and regeneration subplots are not present in the ASCS study: only overstory trees are measured on the 52.7-foot radius PSP.



Figure 5.—Regeneration plot stake marking center of one of three milacre plots in PSP. Photo by Justin D. Waskiewicz, University of Vermont, used with permission.

### **Regeneration Plot Design**

Regeneration is sampled in each PSP in the CMS and MID using four milacre (0.001-acre) plots labeled A, B, C, and D (Fig. 4B). Regeneration plots are centered 26.3 feet from the PSP center and are oriented relative to the cruise line, as follows: milplot A to the left of the cruise line, B to the right, C forward along the cruise line, and D backward along the cruise line (Fig. 4B). Each milplot is circular with a radius of 3.7 feet. All four milplots are used in MUs 32A and 32B; only milplots A, B, and C are used in the other CMS and MID MUs.

Milplot centers are marked with a 12-inch metal stake, driven into the ground with 2 inches showing, and flagged with blue tape (Fig. 5). The milplot designation is stamped on the side of the stake or is written on a yellow cap topping the stake. In addition, blue flagging is hung from a branch above the milplot. Regeneration plots may have been moved away from their prescribed locations to avoid obstacles (e.g., stumps, large rocks, logs; see Field Procedures).

If a new regeneration milplot must be located due to loss or destruction of an existing milplot, it is placed as close as possible to the prescribed location, along the prescribed direction (0°, 90°, or 270° from cruise line direction), where the plot stake can be driven down to 2 inches showing. The stake is labeled and flagged as described above, and a note is made of any deviation from the prescribed location. Milplots are not located on or within 6 feet of a maintained road. If a milplot in need of relocation cannot be positioned anywhere along its prescribed bearing, a different bearing may be substituted with the change noted.

## **FIELD PROCEDURES**

### **Data Forms**

Before workers go to the field, the database manager produces data entry forms (paper or electronic) for the plots to be remeasured. The layout of these forms varies depending on the study and PSP measurement intensity. For the CMS and MID PSPs, each plot's forms provide the number, diameter, and condition code for every tree recorded during the previous inventory. For each numbered tree, there are entry blanks for the current condition and measurement(s) to be recorded; there is also space for new trees (ingrowth or previously missed trees) to be entered, usually on a separate form, and a list of numbers ineligible for assignment to new trees.

Several different forms may be involved in a given inventory on a single PSP, especially for intensive PSPs. Data collection is neat and organized, and each form's heading information (e.g., date, fieldworker names, MU, plot and inventory numbers, start and end times) is filled out completely. Summary sheets for field reference are provided in Appendix III.

### **Permanent Sample Plot Maintenance**

Upon arriving at a PSP to be inventoried, fieldworkers check the PSP number on the post and the metal stake. If either the stake or post is missing, damaged, or decayed, this is noted and brought to the attention of the PEF Forester so that the items may be repaired or replaced. If the PSP is in a CMS or MID MU, fieldworkers locate the regeneration milplots, flag their location with blue flagging (if not already prominent), and note if the stakes or caps need to be replaced. Workers strive to avoid unnecessary trampling in the regeneration milplots while taking other measurements.

### **Tree Numbering**

Each measured tree on a PSP in the CMS and MID MUs is assigned a unique three-digit number (trees just outside the edge of the PSP may be marked with a 0 to indicate that they are not to be sampled). The first digit of a tree number corresponds to the sector (0 to 9) in which the tree is located (Fig. 4A); the second two digits correspond to the approximate distance of the tree from plot center, creating a system for easy tree location in the field. For example, tree 043 would be in sector 0, 43 feet from PSP center. No two trees on the same plot may share the same number, even when this requires deviations from the general numbering rule.

Where clusters of trees are at the same approximate distance from PSP center, each tree must be assigned a nonduplicated number, even if the number is not a precise representation of the tree's actual position. The number assigned should be as close as possible to the originally intended number; i.e., three trees in the same sector, an equidistance from the plot center, may have the numbers 052, 053, 054 (all in sector 0, about 52 feet from plot center).

Tree numbers are never more than three digits, and the first digit is always the sector number; thus, if there are more than 99 trees in a sector, the numbering rules must be modified. If a tree is close to a sector boundary, the adjacent sector number can be used as the first digit to prevent duplication. If this is done, a number not used in the adjacent sector is chosen and fieldworkers make a note of this action on the data forms.



Figure 6.—D.b.h.-marked and numbered trees on an example PSP. Left: saplings, with tags; Right: overstory trees. Photos by Justin D. Waskiewicz, University of Vermont, used with permission.

Overstory trees  $\geq 4.5$  in. d.b.h. on PSPs in CMS and MID MUs are marked with a unique number and a horizontal line at breast height (b.h.), 4.5 feet from the ground or as described below, using tube paint. Instructions for determining d.b.h. are provided in the Overstory Tree Sampling section on this page. Tree numbers are written horizontally or vertically depending on tree size. Stamped metal tags may also be used to number trees (Fig. 6).

During inventories, new numbers and d.b.h. lines are applied to ingrowth trees not measured before. Ingrowth trees are categorized as small trees that have grown into the overstory or sapling size class since the last inventory. Additionally, trees not captured in previous inventories due to error, i.e., missed trees, are numbered and marked with a d.b.h. line. Care must be taken not to repeat any previously used numbers, using the list of ineligible numbers provided by the database manager.

## Standard Measurements for Permanent Sample Plots in Compartment Management Study and Management Intensity Demonstration MUs

### Overstory Tree Sampling

Overstory trees sampled are those with a d.b.h.  $\geq 4.5$  inches and the center of the base of the trunk  $\leq 52.7$  feet from plot center (Fig. 7). Overstory trees are measured at d.b.h. and assigned a condition code (Table 2). The majority of overstory trees have been numbered, measured, and recorded in previous inventories; however, fieldworkers check that each tree was correctly identified in the previous inventory. New trees, not previously recorded, occur because of ingrowth. Ingrowth is recorded separately and missed trees noted in comments to ensure status is clear in the data. New trees are assigned a numerical species code (Table 3). Species in question are verified by the PEF Forester.

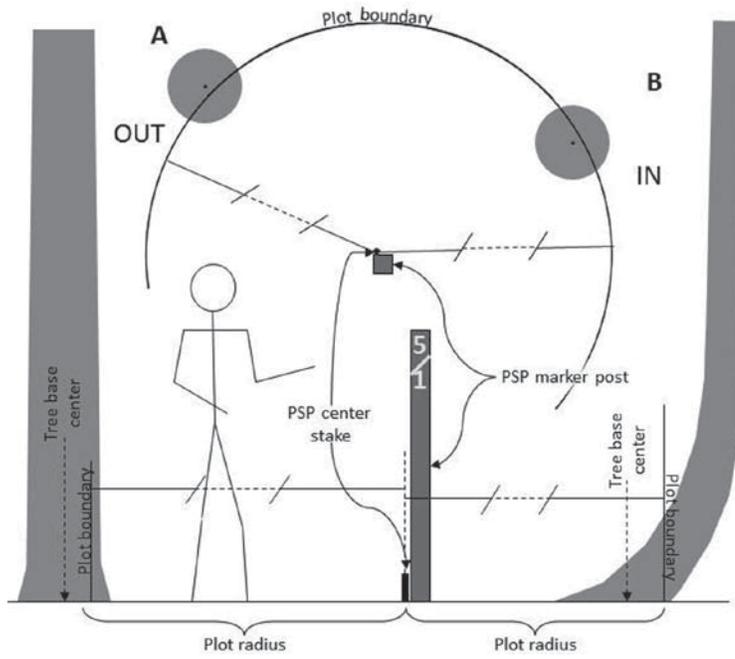


Figure 7.—Trees are in or out of a plot based on the distance from the PSP center stake to the center of the tree stem at its base. A: tree is out because tree base center is beyond plot boundary; B: tree is in at base, even though upper stem, including d.b.h. line, is outside of boundary.

**Table 2.—Codes used to describe tree conditions in U.S. Forest Service studies on the Penobscot Experimental Forest, 2015**

Tree Condition

1st Field:

1	Sapling 0.5 to <4.5 inches d.b.h.
2	Tree $\geq$ 4.5 inches d.b.h. and merchantable
3	Tree $\geq$ 4.5 inches d.b.h. and cull
4	Ingrowth to pole class ( $\geq$ 4.5 inches d.b.h.) and merchantable
5	Ingrowth to pole class ( $\geq$ 4.5 inches d.b.h.) and cull
7	Ingrowth to small sapling class (0.5 to <2.5 inches d.b.h.)
8	Mortality: cut or killed during harvest
9	Ingrowth to large sapling class (2.5 to <4.5 inches d.b.h.)
A	Mortality: animal damage, e.g., beaver or porcupine
B	Mortality: breakage
D	Deadwood: recorded as mortality or deadwood in previous inventory
S	Mortality: suppression
L	Could not be located
T	Mortality: sapling (0.5 to <4.5 inches d.b.h.) cut in PCT
U	Mortality: uprooted by wind
W	Mortality: spruce budworm
X	Mortality: other or undetermined cause of death

Tree Condition

2nd Field:

C	Sapling (0.5 to <4.5 inches d.b.h.) released in PCT since last inventory
R	Tree released by PCT prior to last inventory
N	Deadwood; previously recorded stump or downed snag that is indistinguishable from forest floor
D	Downed snag touching ground or another downed snag at some point
S	Standing snag; $\geq$ 4.5 feet tall
P	Stump; <4.5 feet tall
0	None of the above

continued

**Table 2 continued.—Codes used to describe decay of snags and stumps**

Standing Snags

3rd Field:

- 
- |   |                                                                                                                                                                               |
|---|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | Tree recently died. Top intact or freshly snapped. Most fine twigs and branches still present. Some foliage may be attached. Bark intact. Wood hard.                          |
| 2 | Top intact or snapped at time of death. Most fine branches absent; more than 50% of coarse branches remain. Foliage absent. Bark may begin to loosen. Wood hard.              |
| 3 | Top intact or snapped at time of death. Fewer than 50% of the coarse branches remain. Bark may or may not have sloughed off. Wood mostly hard.                                |
| 4 | Top broken. Usually no coarse branches remain, but some of the largest branches may be present. Bark may or may not have sloughed off. Some softening of the wood detectable. |
| 5 | Top repeatedly broken. No coarse branches remain. Bark may or may not have sloughed off. Wood soft. Height of tree substantially reduced from its original height.            |
| 0 | None of the above                                                                                                                                                             |

Downed Snags

3rd Field:

- 
- |   |                                                                                                                                                                                            |
|---|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | Wood intact and hard. All bark intact. Twigs (<1 inch in diameter) present. Cross-sectional shape is round. Tree may be elevated by supporting branches. No invading roots.                |
| 2 | Wood intact and hard. Bark has begun to detach. Twigs absent. Shape is round. Tree elevated or sagging slightly. No invading roots.                                                        |
| 3 | Wood is hard to partially soft. Some bark may remain attached. Shape is round. Tree sagging or near the ground. Roots invade sapwood.                                                      |
| 4 | Wood substantially decayed and pieces easily slough off. Inner heartwood, if present, may be soft but is intact. Shape elliptical. Tree usually on the ground. Roots invade the heartwood. |
| 5 | Wood decayed throughout. May be soft or punky and partially incorporated into forest floor. Shape elliptical to flattened. Tree is on the ground, partially sunken into the organic layer. |
| 0 | None of the above                                                                                                                                                                          |

Stumps

3rd Field:

- 
- |   |                                                                                                                                                                              |
|---|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | Recently formed. Wood intact and hard. Bark mostly intact. No invading roots.                                                                                                |
| 2 | Wood intact and hard. Bark has begun to detach. No invading roots.                                                                                                           |
| 3 | Wood hard to partially soft; sapwood beginning to decay. Bark fully or partially detached. Roots may invade sapwood.                                                         |
| 4 | Wood is substantially decayed and pieces easily slough off. Bark absent or completely detached. Inner heartwood, if present, is soft but intact. Roots may invade heartwood. |
| 5 | Wood is decayed throughout. May be soft or punky and partially incorporated into forest floor.                                                                               |
| 0 | None of the above                                                                                                                                                            |

*Diameter at Breast Height.* The d.b.h. of each overstory tree is located 4.5 feet from the ground on the uphill side of the tree. Deviation from the 4.5 foot rule may occur in circumstances such as forked trees, curved or leaning trees, or trees with wounds, swellings, or growths at the d.b.h. location (See text box, “Locating d.b.h.” and Fig. 8). D.b.h. is measured with a diameter tape. The tape is wrapped tightly, perpendicular to the tree trunk at the top of the d.b.h. line (Fig. 9). D.b.h. is recorded to the nearest 0.1 inch, at the point where the initial mark (0 line) on the tape comes closest to the numerical value.

Trees classified as cull (<50 percent merchantable by volume) are marked with an additional paint line approximately 3 inches long, applied vertically above the d.b.h. line. The appropriate condition code is recorded on the data form.

*Condition Codes.* Each overstory tree is given a three-field condition code (K-code; Table 3). The first digit of the K-code reflects a tree’s status (e.g., living, ingrowth, cull, mortality, or previously dead). The second and third fields of the K-code are zeroes, unless the tree has been released by precommercial thinning (PCT) or is dead. Saplings released by PCT operations receive a second-field K-code of C when this condition is first noted and an R each following inventory unless released again—then a C is used. Ingrowth trees are added to the plot data, with a first-digit K-code of 4 (merchantable) or 5 (cull). K-coding for dead trees is described on page 16.

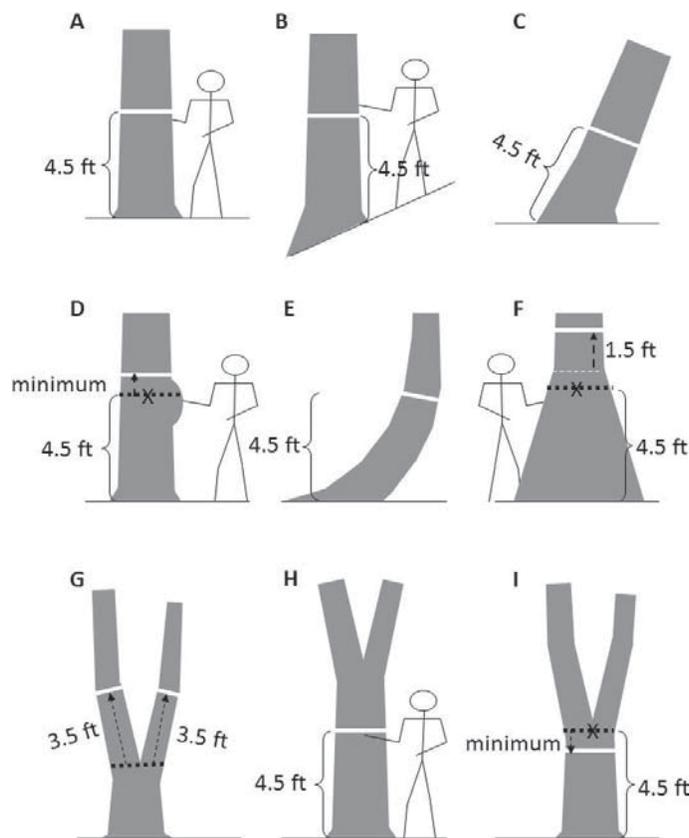


Figure 8.—Locations of d.b.h. on tree boles. A: normal tree; B: tree on sloping ground; C: leaning tree; D: tree with deformity at 4.5 feet; E: curving tree; F: buttressed tree; G: tree forked below 4.5 feet; H: tree forked above 4.5 feet; I: tree forked above 4.5 feet, but deformed at 4.5 feet.



Figure 9.—D.b.h. is measured just above the marked line, with the tape perpendicular to the trunk and tight against the bark. Photo by Justin D. Waskiewicz, University of Vermont, used with permission.

### Locating d.b.h

Diameter at breast height (d.b.h) is located at 4.5 feet from the ground on the uphill side of a tree stem (Fig. 8A and B). This rule applies to most trees, but some trees present circumstances demanding rule modification.

Trees that lean should be marked and measured at 4.5 feet along the stem, and the measurement should be taken perpendicular to the tree's stem (Fig. 8C).

Some trees have scars, knots, burls, or other deformities at b.h.; in those cases, the mark and measurement should instead be made at the minimum distance necessary to clear the obstacle, above or below b.h.\* (Fig. 8D).

A tree that curves, or “sweeps” up from the ground is treated differently from one that leans; curved stems are marked and measured at 4.5 vertical feet from the ground (although it is still important to be sure the measurement is made perpendicular to the stem at the point of measurement) (Fig. 8E). If the tree trunk is straight for the first 4.5 feet or more before curving upward, the tree is treated as leaning, not curving.

Buttressed or swollen-butted trunks are another special case, if the swelling affects trunk diameter at d.b.h. line. In this case, the mark and measurement are 1.5 feet above the top of the swelling\* (Fig. 8F).

Forked trees are treated as two separate trees, with two separate marks and measurements (and tree numbers, if applicable) if they fork below 4.5 feet. In this case, marks and measurements should be made 3.5 feet above the fork\* (Fig. 8G).

If a fork occurs above 4.5 feet, it is one tree, with one d.b.h. measurement (Fig. 8H). Forks just above 4.5 feet may cause a distortion of the trunk shape and size at 4.5 feet; in this case, mark and measure at the minimum distance below 4.5 feet necessary to obtain an undistorted reading (Fig. 8I).

\* Between inventories, wounds, forks, or other abnormalities may change as the trees grow. It may be necessary to relocate d.b.h. points accordingly.

**Table 3.—Numeric tree species codes used in the Penobscot Experimental Forest management units**

Code	Common name	Scientific name
01	balsam fir	<i>Abies balsamea</i>
02	spruce species <sup>a</sup>	<i>Picea</i> spp. <sup>a</sup>
04	red or black spruce	<i>Picea rubens</i> or <i>P. mariana</i>
05	white spruce	<i>Picea glauca</i>
06	eastern hemlock	<i>Tsuga canadensis</i>
07	northern white-cedar	<i>Thuja occidentalis</i>
09	red pine	<i>Pinus resinosa</i>
10	eastern white pine	<i>Pinus strobus</i>
11	tamarack/eastern larch	<i>Larix laricina</i>
15	red maple	<i>Acer rubrum</i>
16	paper birch	<i>Betula papyrifera</i>
17	black ash	<i>Fraxinus nigra</i>
18	quaking aspen	<i>Populus tremuloides</i>
19	basswood	<i>Tilia americana</i>
20	gray birch	<i>Betula populifolia</i>
21	black cherry	<i>Prunus serotina</i>
22	pin cherry	<i>Prunus pensylvanica</i>
23	elm species	<i>Ulmus</i> spp.
24	bigtooth aspen	<i>Populus grandidentata</i>
26	balsam poplar	<i>Populus balsamifera</i>
31	white ash	<i>Fraxinus americana</i>
32	American beech	<i>Fagus grandifolia</i>
33	yellow birch	<i>Betula alleghaniensis</i>
34	hophornbeam/ironwood	<i>Ostrya virginiana</i>
35	sugar maple	<i>Acer saccharum</i>
36	oak species	<i>Quercus</i> spp.
37	serviceberry species <sup>b</sup>	<i>Amelanchier</i> spp. <sup>b</sup>
38	striped maple	<i>Acer pensylvanicum</i>
99	other or unknown	

<sup>a</sup> Code 02 is used only for regeneration plots; among sapling and overstory trees, spruce species are distinguished as code 04 (red or black) or code 05 (white)

<sup>b</sup> Code 37 is used only for arborescent serviceberries, i.e. Alleghany (*A. laevis* Wieg.) and downy serviceberry (*A. arborea* (Michx.f.) Fern.), not for shrub species such as eastern serviceberry (*A. canadensis* (L.) Medik.)

### Sapling Sampling

Saplings are tallied by 1-inch d.b.h. classes and are not individually numbered (except on intensive PSPs, see below), although they do receive a d.b.h. line with blue paint. Any numbers present on large or small saplings not within intensive PSPs are remnants of previous fieldwork and are no longer maintained. Dead saplings are not recorded in the tally.

### Regeneration Sampling

*Seedling Classification and Measurement.* Seedlings are defined as live trees <0.5 inches d.b.h., including new germinants, and are tallied by species and height class on milplots in the CMS.

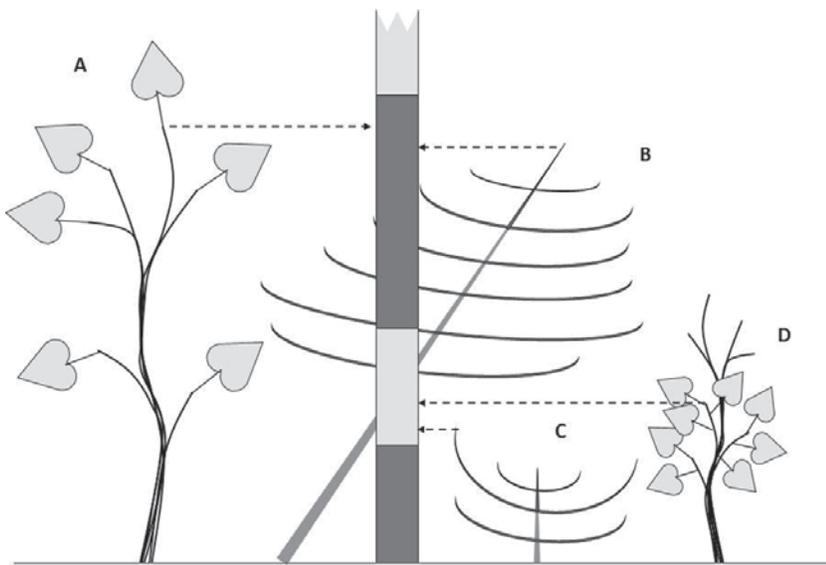


Figure 10.—Categorizing seedling heights on regeneration plots. A: measure to highest live stem, not leaf; B: do not straighten leaning stems; C: measure to the highest live stem, even if it is not the leader; D: do not measure any dead top.

Height classes are defined as  $\geq 6$  inches to  $< 12$  inches,  $\geq 12$  to  $< 24$  inches,  $\geq 24$  to  $< 54$  inches (4.5 feet), and  $\geq 54$  inches tall but  $< 0.5$  inches at d.b.h.. Trees  $< 6$  inches tall are recorded by species only as present (1) or absent (0) (number of stems is not counted). Seedling height is measured using a marked rod, held vertically at the tree's base. Seedling height is the highest living stem point, with no attempt to straighten the stem (Fig. 10). Counted seedlings may be lightly marked, as with chalk, to prevent double-counting on dense plots.

In the MID, species are recorded as present (stocked) if there is at least one stem  $< 0.5$  inches d.b.h. with a secondary branch. Density and height class are not measured.

Tallying on milplots is facilitated by a set of crossed PVC pipes or dowels extending 3.7 feet from the milplot center; this helps visually break up the plot (Fig. 11). Distance from milplot center is checked for seedlings that are borderline.



Figure 11.—PVC frame to aid seedling tally. Photo by Justin D. Waskiewicz, University of Vermont, used with permission.

*Seedlings.* All seedlings are recorded to species except for the three spruce species, which are recorded as “spruce”—species code 02. Fieldworkers must familiarize themselves with the appearance of young seedlings of different species, because the cotyledons and juvenile foliage of many species can be quite different from adult foliage for up to several years.

*Inventory Timeline.* Regeneration inventories are not conducted before June 15, because many germinants may not yet be visible before that date. Regeneration inventories also are not conducted after October 15, because leaf loss may make live deciduous seedlings difficult to find and distinguish from dead.

*Seedlings not Tallied.* Dead seedlings are not tallied, and seedlings buried under slash are not tallied if slash must be moved for them to be visible (no woody debris is moved on the milplots).

## **Dead Wood**

Overstory trees are tracked and measured for as long as they can be detected following mortality. The dead wood is classified as a standing snag, downed snag, or stump (Fig. 12). A standing snag is a dead tree  $\geq 4.5$  feet in height. A downed snag is a snag that has fallen to the ground (i.e., tipped over) but remains attached to the stump and is  $\geq 4.5$  feet long. A stump is a dead tree  $< 4.5$  feet in height; it is the bottom part of the tree left after the stem has been harvested, or after a living tree, standing snag, or downed snag has broken off. Measurements of standing snags, downed snags, and stumps are associated with the portion of the tree that remains attached to the ground, i.e., if the tree breaks apart, the stump rather than the detached stem is measured. Any pieces of the stem that break off, i.e., downed logs, are not measured. Standing and downed snags are numbered in the same manner as live trees, with a line at breast height. Stumps are marked with a tagged metal pin or flag.

Dead wood measurements collected during PSP sampling include d.b.h., if applicable, and K-code. Diameter at breast height is measured following the procedures for live trees. K-codes assigned to dead wood reflect cause of mortality, if known, and condition of decay. Trees that were dead during the previous inventory are assigned first-field K-code D. When the first digit of the K-code reflects mortality (8, A, B, S, T, U, W or X) or previously dead status, the second digit of the K-code may be 0, D, N, P, or S, and the third digit is a number between 0 and 5 (Table 3).

Additional measurements collected on standing snags include height and lean. Height of standing snags is recorded following the same steps used to measure height of live trees (see Tree Heights, page 18). If the top of the snag is broken off at an angle, i.e. “splintered,” it receives a second height measurement at the base of the splinter (Fig. 13A). If a standing snag is splintered below breast height (4.5 feet), the tree is recorded as a stump rather than a snag even if the top of the snag extends much higher.

Lean of standing snags is recorded in the same manner as lean of live trees. Standing snags leaning  $> 5^\circ$  from vertical receive an additional measurement: horizontal displacement of top from stump (Fig. 13B).

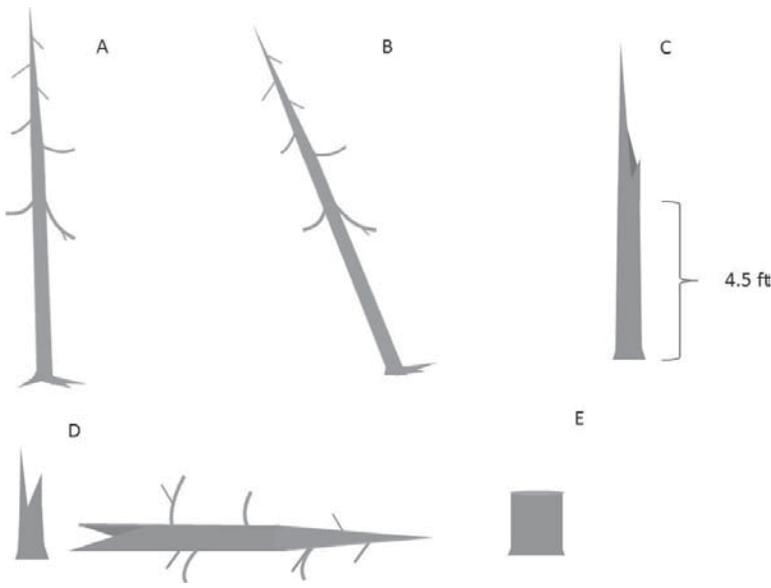


Figure 12.—Classification of snags and stumps. A) standing snag ( $\geq 4.5$  feet tall); B) standing snag, leaning ( $\geq 4.5$  feet tall); C) standing snag, splintered (bottom of splinter is at or above breast height); D) stump resulting from stem breakage below breast height (top of splinter may extend above breast height; the portion of the stem detached from the tree is not measured); E) stump created during harvest ( $< 4.5$  feet tall).

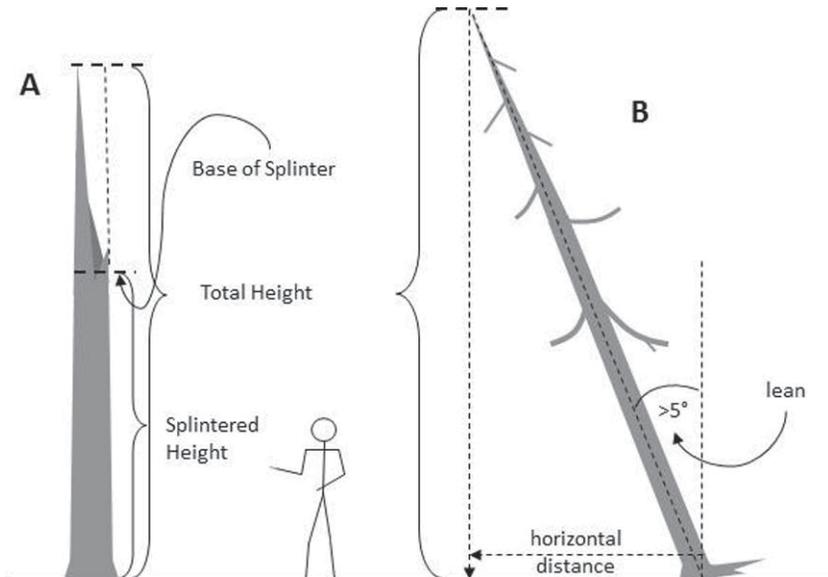


Figure 13.—Snag measurements. A: broken snag with a splintered bole; B: leaning snag ( $> 5^\circ$  from vertical).

Prior to 1996, dead wood was not tracked after overstory tree mortality was recorded. Between 1996 and 2013, snags and stumps that resulted from new mortality were tracked in subsequent inventories. Since 2013, all snags  $\geq 4.5$  inches d.b.h. have been measured and tracked, regardless of whether the tree died prior to or since 1996. This transition from tracking recruited snags to measuring and tracking all snags means that until inventories have been conducted in all MUs, snags that recruited before 1996 will be added to dead wood inventories. These snags receive first-field K-code D. If the previously assigned tree number is still visible, it is used. If not, a new tree number is assigned following the protocol for live trees.

## Additional Procedures on Intensive Permanent Sample Plots

Approximately one-third of the PSPs within the CMS are categorized as intensive. In addition to the measurements described in preceding sections, the following measurements are taken on intensive PSPs:

### Overstory Tree Coordinates

Coordinates are measured for all overstory trees using a hand compass, to a precision of  $\pm 2^\circ$  true (geodetic north) azimuth, and a tape measure or other measuring device to the nearest 0.1 foot. Measurements are based on true north. Coordinate measurements are always from the PSP center stake to the centers of tree stems at their bases (Fig. 7), and reflect horizontal distance, not distance along the slope. In most cases, tree locations were already measured in a previous inventory, so coordinate measurements are only made for ingrowth to the overstory class, or for trees missed in earlier inventories.

### Tree Heights

Heights are measured only for overstory trees ( $\geq 4.5$  inches d.b.h.), using a height-measuring instrument approved by the PEF Forester (e.g., a sonic hypsometer or height pole). Heights are measured to the highest live point of the crown, with precision to the nearest 0.1 foot. Most height-measuring equipment is based on trigonometry and assumes the sighted high point is directly above the tree base, not closer or farther from the observer, as could happen with a leaning tree or broad crown (Fig. 14). To avoid error, the observer stands perpendicular to the lean.

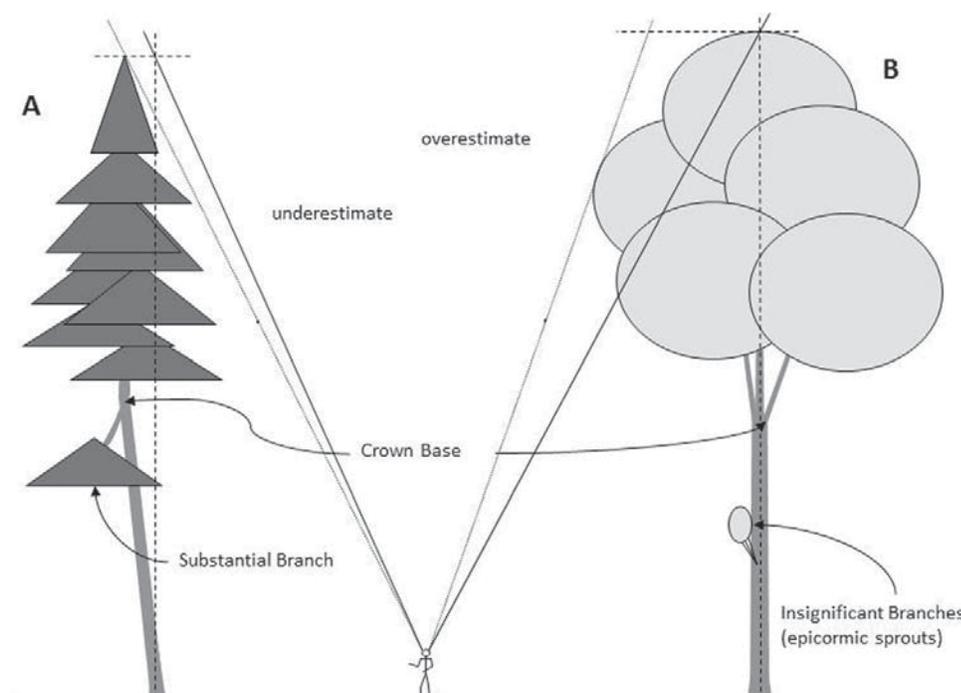


Figure 14.—Measurement of total height and height to live crown base of overstory trees on intensive plots. A: leaning tree; observer views from a location neutral relative to lean; B: wide branches obscure crown apex. Observer stands back farther from tree. In both, base of live crown occurs at point of branch attachment, whether above (A) or below (B) foliage.

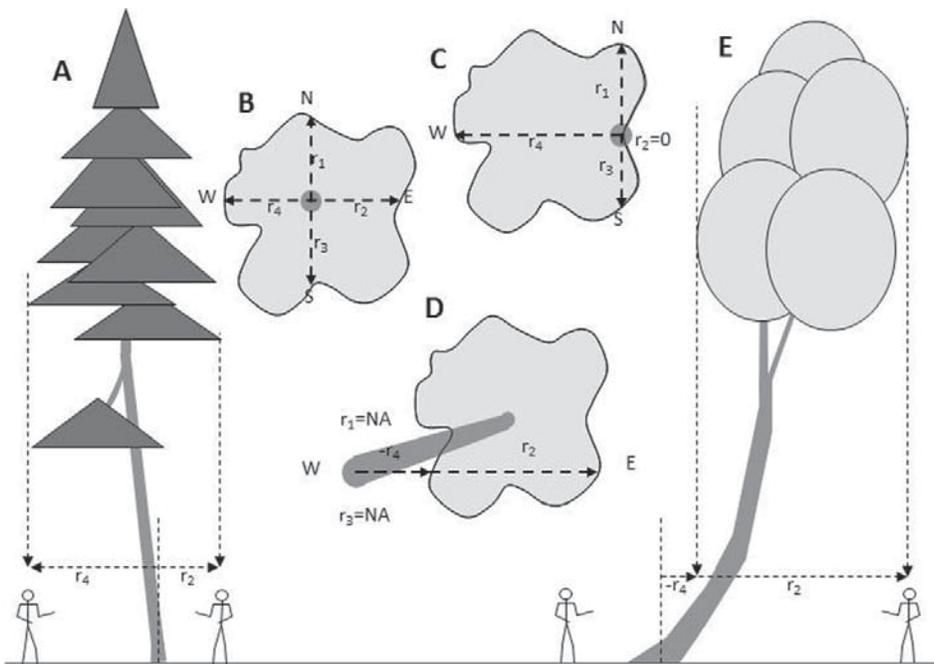


Figure 15.—Crown measurements on intensive PSPs. A: radii are measured from center of stem base to point 90° below crown edge; B: radii are measured to crown edge along cardinal radius—not necessarily widest point on a side; C: lopsided crowns can receive radii measurements of zero; D and E: leaning trees may have crown edges at a negative distance from stem base along some radial directions and may receive an NA value if no measurement is possible.

### Height to Live Crown Base

The live crown base is measured with the same equipment as height and to the same precision, with the same precautions (Fig. 14). The live crown base is defined as the point on the stem where the lowest significant live branch attaches, whether this is above or below the lowest foliage. A branch is defined as significant if it appears to be contributing to the tree's growth. Epicormic shoots, i.e., shoots arising from adventitious buds along the tree stem, are not considered significant. Nor are some of the sparsely foliated and deeply shaded sprigs that sometimes appear low on the stems of conifers.

### Crown Radii

Crown radii are measured to the nearest 0.1 foot in four cardinal directions, 0°, 90°, 180°, and 270° (magnetic), using a tape measure. Radii measurements are from the center of the tree stem at the base to the vertical projection of the crown edge over the radial line (Fig. 15). A clinometer is used to ensure that the observer is directly below the crown edge. Lopsided or leaning trees may have measurements of 0, negative, or NA along some radial lines if the crown is sufficiently displaced from the stem base (Fig. 15 C, D, and E).

### Sapling Measurements and Marking

On intensive PSPs, additional measurements are made on saplings, and ingrowth to the 0.5- and 2.5-inch d.b.h. classes are tracked. Saplings are individually numbered with paint or tagged with metal tags, and measured to the nearest 0.1 inch with a diameter tape. Overstory ingrowth recruited from the sapling class already have numbers and previous inventory records; they are

simply updated on the data form (including receiving a first-digit K-code 4 or 5). Ingrowth into the sapling classes are also recorded on intensive plots, with K-code 7 used for ingrowth into the small class (0.5 in. d.b.h.), and K-code 9 used for ingrowth into the large class (2.5 in. d.b.h.). Dead saplings are given a final d.b.h. measurement and assigned a cause-of-mortality K-code (with second and third fields 0), but are not followed as deadwood in subsequent inventories. Saplings that were recorded as mortality in the previous inventory are confirmed dead.

### **Understory Vegetation**

Understory vegetation is measured on the same milacre plots as regeneration in intensive PSPs. First, the milplot's substrate is evaluated by percent undisturbed and percent disturbed; these two categories total 100 percent. Second, substrate is categorized by percentages of mineral soil, deciduous or coniferous litter, coarse woody material, logging slash, rock, or flooded condition; these total 100 percent. Percent cover of nontree vegetation on the milplots is visually estimated and categorized as woody shrubs; forbs; grasses, sedges, or rushes; ferns; and moss or lichen. For plants, categories of cover are provided on the data forms: none, less than 5 percent and rare ( $\leq 5$  individuals), less than 5 percent and occasional ( $> 5$  individuals, but clumped together in  $\leq 2$  quadrants of the milplot), less than 5 percent and common ( $> 5$  individuals distributed through  $\geq 3$  quadrants),  $> 5$  percent to 25 percent, 26 percent to 50 percent, 51 percent to 75 percent, and 76 percent to 100 percent. Each category of plants is assessed independently of the others, within the column of space above the milplot to a height of 4.5 feet (for example, there may be both 76 to 100 percent cover of woody shrubs and 76 to 100 percent of moss or lichen).

### **Standard Measurements for Permanent Sample Plots in Auxiliary Selection Cutting Study MUs**

PSPs in the ASCS MUs receive fewer measurements than PSPs in the CMS and MID MUs. In ASCS MUs, overstory trees are sampled, but not numbered. No saplings are measured. Instead, trees  $\leq 52.7$  feet from the PSP center and with a d.b.h.  $\geq 4.5$  inches are marked with a horizontal line at b.h. and tallied by 1-inch size classes. A tree measured to X.5 inches is placed in the X+1 size class; a tree measured to X.4 inches is in the X size class. Ingrowth and mortality are not recorded and dead wood is not followed.

### **Installing New Permanent Sample Plots**

If the lead scientist decides that a new PSP must be installed, plot layout follows the specifications described in the preceding sections. The coordinates of plot center are provided by the database manager, and installation is conducted under the supervision of the PEF Forester. First, the metal stake and blue post used to designate plot center are set. Next, azimuths relative to magnetic north are taken using a hand-held compass to designate individual plot sectors. Distance to the edge of each plot is determined and flagging is hung at distances of 16.6 feet, 26.3 feet, and 52.7 feet to distinguish the radius of the 1/50-acre, 1/20-acre, and 1/5-acre plots as appropriate. Milplots are established at the periphery of the 1/20-acre plot in the CMS and MID. Once plot boundaries have been determined, d.b.h. lines are painted and the trees are numbered as appropriate and measured as described in the preceding sections. Note that ingrowth and mortality K-codes are not used in an initial inventory; all snags  $\geq 4.5$  inches d.b.h. in the CMS and MID are assigned K-Code D (previous mortality) and stumps are not measured.

## **OFFICE PROCEDURES**

### **Data Entry and Quality Assurance/Quality Control (QA/QC)**

Once data collection is completed in the field, data are converted to or entered into digital spreadsheets as soon as possible. Each spreadsheet is given a file name that includes the MU, the inventory number, status of the file, and version number (i.e., 1, 2, 3, etc...). For example: MU24\_INV15\_Draft1.xls contains data from MU 24, inventory 15, and is in first draft status.

The spreadsheet and original data forms are checked for consistency by the PEF Forester. The Forester may return a list of errors to field crew; they re-enter data as needed and rename the revised spreadsheet to reflect its updated status, i.e., MU24\_INV15\_Draft2.xls.

After second review by the PEF forester, the electronic file is provided to the database manager, who analyzes the data for outliers, negative growth, or other illogical changes in the data that may represent errors. Required actions may include entering the data again or revisiting the plot(s). After final review, the data manager updates the file name to indicate the corrected status, i.e., MU24\_INV15\_Final.xls. The final draft of the data is then incorporated into the PEF database. Once a year or as needed, the published database for each study (e.g., Brissette et al. 2012b, Waskiewicz et al. 2014) is updated with new or corrected data.

### **File Management**

All data forms are scanned as .pdf files, with the images saved in their appropriate electronic folders, by MU. Final spreadsheets submitted to the database manager are also electronically filed. Paper data forms, memos, and pertinent notes (i.e., records) are filed appropriately within file cabinets at the U.S. Forest Service facility associated with the PEF.

## **CONCLUSIONS**

The sampling and measurement protocols and data collection and management procedures described in this publication relate to the three longest running U.S. Forest Service experiments on the Penobscot Experimental Forest: the management intensity demonstration, compartment management study, and auxiliary selection cutting study. Data from these studies represent many acres and span many decades, highlighting the importance of accurate, precise, and consistent data collection and management across space and time. The information presented here aims to ensure the addition of sound data to the PEF archive in the future and supports appropriate interpretation of the findings. The protocols and procedures presented here serve as a model for similar studies, inform interpretation of published databases, and ensure that U.S. Forest Service research on the PEF will continue to be an important resource for science and policy in northern conifer forests.

## ACKNOWLEDGMENTS

This work was conducted in partnership with the University of Maine, School of Forest Resources, with funding from the U.S. Department of Agriculture, Forest Service, Research Data Archive and the Northern Research Station. We appreciate the support of Dave Rugg (U.S. Forest Service) and Aaron Weiskittel (University of Maine). Helpful reviews of an earlier version of this document were provided by Mohammad Bataineh (University of Arkansas at Monticello), John Kabrick (U.S. Forest Service, Northern Research Station), Nicole Stark (U.S. Forest Service, Forest Products Laboratory), John Kershaw (University of New Brunswick), Shawn Fraver (University of Maine) and two anonymous reviewers.

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## APPENDIX I: IMPORTANT CHANGES TO SAMPLING AND MEASUREMENT PROTOCOLS, 1950 TO 2014

### 1950

- Inventories were conducted before and after harvest and at 5-year intervals.
- Species codes:
  - 01- balsam fir
  - 04- red and black spruce
  - 05- white spruce
  - 06- eastern hemlock
  - 07- northern white-cedar
  - 10- eastern white and red pine
  - 11- tamarack
  - 15- red maple
  - 16- paper birch
  - 25- other soft hardwoods
  - 40- other hard hardwoods
- K-codes:
  - 1- 0.6 to 4.5 in. d.b.h.
  - 2-  $\geq 4.6$  in. d.b.h. and merchantable
  - 3-  $\geq 4.6$  in. d.b.h. and cull
- DCLASS was recorded for trees  $\geq 0.6$  in. d.b.h., as follows: 1 in. DCLASS = 0.6 to 1.5; 2 in. DCLASS = 1.6 to 2.5; 3 in. DCLASS = 2.6 to 3.5; etc.
- 100 percent inventories were conducted in the MID; PSPs were inventoried in the CMS and ASCS.
- Regeneration inventories were conducted in the MID; stocking by species was recorded on systematically located milplots if at least one seedling with a secondary branch was present (density and height class were not measured).

### 1955

- K-codes were added:
  - 4- ingrowth into the pole class ( $\geq 4.6$  in. d.b.h.) and merchantable
  - 5- ingrowth into the pole class ( $\geq 4.6$  in. d.b.h.) and cull
  - 6- mortality (cause not specified)

### 1962

- DCLASS was redefined as 1 in. DCLASS = 0.5 to 1.4; 2 in. DCLASS = 1.5 to 2.4; 3 in. DCLASS = 2.5 to 3.4, etc.

## 1964

- Regeneration inventories began in the CMS; red pine (09) and eastern white pine (10) were differentiated on milplots.

## 1974

- Tree numbering began for all trees  $\geq 0.5$  in. d.b.h. in the CMS; d.b.h. was recorded to the nearest 0.1 in. and DCLASS was office assigned.
- D.b.h. of new mortality was measured during the inventory in which mortality was first observed.

## 1976

- K-code 7 was introduced for ingrowth to the sapling (0.5 to 4.5 in. d.b.h.) class in the CMS.

## 1977

- K-code 8 was introduced for trees cut or killed during harvest in the CMS.

## 1981

- New K-codes were introduced to specify cause of mortality in the CMS, replacing K-code 6:
  - W- spruce budworm
  - U- uproot
  - B- breakage
  - S- suppression
  - X- other /unknown cause of mortality

## 1982

- MUs 23 and 29 in the CMS were each subdivided into two new management units: 23A and 23B; 29A and 29B.

## 1987

- K-code T was introduced for saplings (0.5 to 4.4 in. d.b.h.) cut during precommercial thinning in the CMS.

## 1992

- K-code A was introduced for mortality caused by animal damage in the CMS.

## 1994

- K-code C was introduced for saplings (0.5 to 4.4 in. d.b.h.) released through precommercial thinning in the CMS.

## 1995

- Regeneration data collection was discontinued in the MID.

## 1996

- K-code 8 was introduced in the MID for trees cut or killed during harvest.
- Species codes 25 (other soft hardwoods) and 40 (other hard hardwoods) were discontinued; species codes 09 and 10 were applied to red and eastern white pine  $\geq 0.5$  in. d.b.h. in addition to seedlings. Additional species codes were introduced in all studies:
  - 17- black ash
  - 18- quaking aspen
  - 19- basswood
  - 20- gray birch
  - 21- black cherry
  - 22- pin cherry
  - 23- elm species
  - 24- bigtooth aspen
  - 26- balsam poplar
  - 31- white ash
  - 32- American beech
  - 33- yellow birch
  - 34- eastern hophornbeam/ironwood
  - 35- sugar maple
  - 36- oak species
  - 37- serviceberry species (tree)
  - 38- striped maple
  - 99- other or unknown species
- Tracking of stumps and snags recruited from mortality of trees  $\geq 4.5$  in. d.b.h. began in the CMS. Second- and third-field K-codes were introduced for classifying dead wood.

1<sup>st</sup> Field: Tree Type

W- Mortality: Spruce budworm

U- Mortality: Uproot

B- Mortality: Breakage

S- Mortality: Suppression

X- Mortality: Other/Unknown

A- Mortality: Animal damage

T- Mortality: Sapling removed for TSI work

2<sup>nd</sup> Field: Dead Wood type

S- Standing snag

L- Leaning snag

D- Down snag

P- Stump

N- No evidence

0- Zero: no information

3<sup>rd</sup> Field: Decay Class- Snags

- 1- Recent; tight bark; fine branches
- 2- Some peeling bark; large limbs only
- 3- Heavy bark peeling; branch stubs
- 4- Little or no bark; <50% original height
- 5- No evidence
- 0- Zero: no information

3<sup>rd</sup> Field: Decay Class- Stumps

- 1- Sound outside wood; bark intact; splinters
- 2- Partially rotted outside wood; bark loose
- 3- Mostly rotted outside wood; some lichen
- 4- Outside wood very rotted, fluffy or doughy
- 5- No evidence
- 0- Zero: no information

## 1998

- Second field K-code R was introduced for trees released by PCT prior to last inventory.

## 2000

- In the MID, 100% inventories were replaced by 6 PSPs in MUs 90, 91, and 92, and 2 PSPs in 93A, 93B, and 93C. Sampling protocols (including the use of tree numbers, k-codes, and tracking of stumps and snags) followed those used in the CMS.
- Inventory cycle was changed to before and after harvest, and at 10-year intervals.
- 1/50-acre PSPs were added to the CMS and MID for inventorying small saplings (0.5 to 2.4 in. d.b.h.). Large saplings (2.5 to 4.4 in. d.b.h.) continued to be measured on 1/20-acre PSPs.
- One-third of PSPs within the CMS were designated as intensive; measurements of height, crown radii, height to live crown, and stem mapping were initiated for trees  $\geq 4.5$  in. d.b.h. and estimates of understory vegetation cover were introduced. Crown radii were measured as distance from crown edge to center of the tree. Where crown edge did not extend past center of the tree, crown radius was recorded as zero.

## 2001

- CMS MU 23A became part of a University of Maine commercial thinning study.

## 2005

- Ingrowth K-codes were revised for the sapling classes in the CMS:
  - 7- Ingrowth into small sapling class (0.5 to 2.4 in. d.b.h.)
  - 9- Ingrowth into large sapling class (2.5 to 4.4 in. d.b.h.)

## 2009

- CMS MU 29A became part of a University of Maine commercial thinning study.

## 2010

- Measurement of d.b.h. to the nearest 0.1 inch for trees 0.5 to 4.4 inches d.b.h. was discontinued and replaced by DCLASS measurements on all except intensive PSPs in the CMS.
- K-code 6 was discontinued in the ASCS.

## 2012

- Crown radii measurements changed for lopsided or leaning trees to reflect a zero, negative, or NA distance if crown is sufficiently displaced from stem base.

## 2013

- Measurement of all (not just recruited) snags  $\geq 4.5$  inches d.b.h. began on PSPs in the CMS and MID. D.b.h. was measured to 0.1-inch; mortality K-code or K-code D (existing deadwood) was applied. Second- and third-field deadwood K-codes were revised.

### Second Field:

0: Zero, no information

D- Downed snag; touching ground at some point

N- No evidence

P- Stump;  $< 4.5$  feet tall

S- Standing snag;  $\geq 4.5$  feet tall

L- Leaning snag; no part touching ground

### Third Field:

0: Zero, no information

1- Snags: Recent; tight bark; fine branches

Stumps: Outer wood sound; bark intact; wood will splinter

2- Snags: Bark somewhat peeling; large limbs only

Stumps: Outer wood partially rotted; loose bark

3- Snags: Bark heavily peeling; branch stubs

Stumps: Outer wood mostly rotted; some lichen present

4- Snags: Little to no bark;  $< 50\%$  of original height

Stumps: Outer wood very rotted (fluffy or doughy); lichens present

5- No evidence

## 2014

- Inventories of regeneration stocking by species were reinitiated in the MID using the original (1950) protocol.

## 2015

- Updated dead wood sampling protocol, including revision to second- and third-field K-codes (Table 2).
- Added first-field K-code L: could not be located

## APPENDIX II: SILVICULTURAL TREATMENTS

The long-term, large-scale U.S. Forest Service experiments on the Penobscot Experimental Forest include a range of even-age and uneven-age silvicultural treatments and exploitative cuttings. The specifics of these treatments are detailed in the relevant study plans, which are available with the archived databases (e.g., Brissette et al. 2012b, Waskiewicz et al. 2014), or in publications associated with the studies (e.g., Brissette and Kenefic 2014, Hart 1964, Sendak et al. 2003). Generally, the MUs described in this guide fall into the following treatment categories (as of March 2015):

### Uneven-age silviculture

- Single-tree selection cutting applied using a  $BDq$  target structure (residual basal area [B], maximum diameter [D], and distribution of trees across diameter classes defined by the mathematical  $q$  factor)
  - 5-year cutting cycle: CMS 9, 16; MID 90
  - 10-year cutting cycle: CMS 12, 20
  - 15-year cutting cycle: MID 91; ASCS 3, 11, 14, 18, 19, 26, 31, 50, 51, 52
  - 20-year cutting cycle: CMS 17, 27
- Irregular shelterwood cutting to create and maintain multi-cohort structures
  - Partial overstory removal with thinning of midstory trees: CMS 6, 10

### Even-age silviculture

- Uniform shelterwood regeneration
  - Two-stage overstory removal: CMS 7A, 7B
  - Two-stage overstory removal, with retention of unmerchantable trees and commercial thinning: CMS 21, 30
  - Three-stage overstory removal: CMS 23B, 29B
  - Three-stage overstory removal with precommercial and commercial thinning: CMS 23A, 29A

### Exploitative cutting

- Removal of all merchantable or the largest commercially valuable trees
  - Fixed diameter-limit cutting: CMS 4, 15; MID 92
  - Modified (flexible) diameter-limit cutting: CMS 24, 28
  - Commercial clearcutting: CMS 8, 22; MID 93A, 93B

### Rehabilitation

- Treatments to restore species composition and production potential of stands degraded by exploitative cutting
  - Commercial clearcutting followed by overstory removal and precommercial thinning: MID 93C

## APPENDIX III: SUMMARY SHEETS FOR FIELD REFERENCE

Plot Sizes			
Overstory	d.b.h. $\geq$ 4.5 inches	52.7 feet	1/5 acre
Large Saplings	$2.5 \leq$ d.b.h. < 4.5 inches	26.3 feet	1/20 acre
Small Saplings	$0.5 \leq$ d.b.h. < 2.5 inches	16.7 feet	1/50 acre
Regeneration	d.b.h. < 0.5 inches	3.7 feet	1/1000 acre

Plot Sectors		Species Codes		
1	0° - 36°	Code	Common Name	Scientific Name
2	36° - 72°	01	balsam fir	<i>Abies balsamea</i>
3	72° - 108°	02	spruce species	<i>Picea</i> spp.
4	108° - 144°	04	red or black spruce	<i>Picea rubens</i> or <i>P. mariana</i>
5	144° - 180°	05	white spruce	<i>Picea glauca</i>
6	180° - 216°	06	eastern hemlock	<i>Tsuga canadensis</i>
7	216° - 252°	07	northern white-cedar	<i>Thuja occidentalis</i>
8	252° - 288°	09	red pine	<i>Pinus resinosa</i>
9	288° - 324°	10	eastern white pine	<i>Pinus strobus</i>
0	324° - 360°	11	tamarack/eastern larch	<i>Larix laricina</i>
		15	red maple	<i>Acer rubrum</i>
		16	paper birch	<i>Betula papyrifera</i>
		17	black ash	<i>Fraxinus nigra</i>
		18	quaking aspen	<i>Populus tremuloides</i>
		19	basswood	<i>Tilia americana</i>
		20	gray birch	<i>Betula populifolia</i>
		21	black cherry	<i>Prunus serotina</i>
		22	pin cherry	<i>Prunus pennsylvanica</i>
		23	elm species	<i>Ulmus</i> spp.
		24	bigtooth aspen	<i>Populus grandidentata</i>
		26	balsam poplar	<i>Populus balsamifera</i>
		31	white ash	<i>Fraxinus americana</i>
		32	American beech	<i>Fagus grandifolia</i>
		33	yellow birch	<i>Betula alleghaniensis</i>
		34	hophornbeam/ironwood	<i>Ostrya virginiana</i>
		35	sugar maple	<i>Acer saccharum</i>
		36	oak species	<i>Quercus</i> spp.
		37	serviceberry species	<i>Amelanchier</i> spp.
		38	striped maple	<i>Acer pensylvanicum</i>
		99	other or unknown	

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Condition Codes

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Tree Condition

1st Field:

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- 1 Sapling 0.5 to <4.5 inches d.b.h.
- 2 Tree ≥4.5 inches d.b.h. and merchantable
- 3 Tree ≥4.5 inches d.b.h. and cull
- 4 Ingrowth to pole class (≥4.5 inches d.b.h.) and merchantable
- 5 Ingrowth to pole class (≥4.5 inches d.b.h.) and cull
- 7 Ingrowth to small sapling class (0.5 to <2.5 inches d.b.h.)
- 8 Mortality: cut or killed during harvest
- 9 Ingrowth to large sapling class (2.5 to <4.5 inches d.b.h.)
- A Mortality: animal damage, e.g., beaver or porcupine
- B Mortality: breakage
- D Deadwood: recorded as mortality or deadwood in previous inventory
- S Mortality: suppression
- L Could not be located
- T Mortality: sapling (0.5 to <4.5 inches d.b.h.) cut in PCT
- U Mortality: uprooted by wind
- W Mortality: spruce budworm
- X Mortality: other or undetermined cause of death

Tree Condition

2nd Field:

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- C Sapling (0.5 to <4.5 inches d.b.h.) released in PCT since last inventory
- R Tree released by PCT prior to last inventory
- N Deadwood; previously recorded stump or downed snag that is indistinguishable from forest floor
- D Downed snag touching ground or another downed snag at some point
- S Standing snag; ≥4.5 feet tall
- P Stump; <4.5 feet tall
- 0 None of the above

Standing Snags

3rd Field:

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- 1 Tree recently died. Top intact or freshly snapped. Most fine twigs and branches still present. Some foliage may be attached. Bark intact. Wood hard.
  - 2 Top intact or snapped at time of death. Most fine branches absent; more than 50% of coarse branches remain. Foliage absent. Bark may begin to loosen. Wood hard.
  - 3 Top intact or snapped at time of death. Fewer than 50% of the coarse branches remain. Bark may or may not have sloughed off. Wood mostly hard.
  - 4 Top broken. Usually no coarse branches remain, but some of the largest branches may be present. Bark may or may not have sloughed off. Some softening of the wood detectable.
  - 5 Top repeatedly broken. No coarse branches remain. Bark may or may not have sloughed off. Wood soft. Height of tree substantially reduced from its original height.
  - 0 None of the above.
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continued

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Condition Codes continued

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Downed Snags

3rd Field:

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- |   |                                                                                                                                                                                            |
|---|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | Wood intact and hard. All bark intact. Twigs (<1 inch in diameter) present. Cross-sectional shape is round. Tree may be elevated by supporting branches. No invading roots.                |
| 2 | Wood intact and hard. Bark has begun to detach. Twigs absent. Shape is round. Tree elevated or sagging slightly. No invading roots.                                                        |
| 3 | Wood is hard to partially soft. Some bark may remain attached. Shape is round. Tree sagging or near the ground. Roots invade sapwood.                                                      |
| 4 | Wood substantially decayed and pieces easily slough off. Inner heartwood, if present, may be soft but is intact. Shape elliptical. Tree usually on the ground. Roots invade the heartwood. |
| 5 | Wood decayed throughout. May be soft or punky and partially incorporated into forest floor. Shape elliptical to flattened. Tree is on the ground, partially sunken into the organic layer. |
| 0 | None of the above.                                                                                                                                                                         |

Stumps

3rd Field:

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- |   |                                                                                                                                                                              |
|---|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | Recently formed. Wood intact and hard. Bark mostly intact. No invading roots.                                                                                                |
| 2 | Wood intact and hard. Bark has begun to detach. No invading roots.                                                                                                           |
| 3 | Wood hard to partially soft; sapwood beginning to decay. Bark fully or partially detached. Roots may invade sapwood.                                                         |
| 4 | Wood is substantially decayed and pieces easily slough off. Bark absent or completely detached. Inner heartwood, if present, is soft but intact. Roots may invade heartwood. |
| 5 | Wood is decayed throughout. May be soft or punky and partially incorporated into forest floor.                                                                               |
| 0 | None of the above.                                                                                                                                                           |

Waskiewicz, Justin D.; Kenefic, Laura S.; Rogers, Nicole S.; Puhlick, Joshua J.; Brissette, John C.; Dionne, Richard J. 2015. **Sampling and measurement protocols for long-term silvicultural studies on the Penobscot Experimental Forest.** Gen. Tech. Rep. NRS-147. Newtown Square, PA: U.S. Department of agriculture, Forest Service, Northern Research Station. 32 p.

The U.S. Forest Service, Northern Research Station has been conducting research on the silviculture of northern conifers on the Penobscot Experimental Forest (PEF) in Maine since 1950. Formal study plans provide guidance and specifications for the experimental treatments, but documentation is also needed to ensure consistency in data collection and sampling protocols. This guide details current sampling and measurement protocols for three of the longest running Forest Service experiments on the PEF: (1) the management intensity demonstration (1950 to present), (2) the compartment management study (1952 to present), and (3) the auxiliary selection cutting study (1953-present). Each of these long-term stand-scale experiments use plot-based measurements of trees taken at periodic intervals. Additional data collected vary and include regeneration, recruitment, and mortality; amount, size, and decay of dead wood; and stand structural characteristics such as heights, crown dimensions, and spatial locations of trees. Descriptions provided here are the basis for data collection in the relevant studies on the PEF, inform interpretation of the published databases, and serve as a model for silvicultural studies elsewhere.

**KEY WORDS:** compartment management study, management intensity demonstration, selection cutting, Acadian forest, northern conifers, red spruce, balsam fir

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