

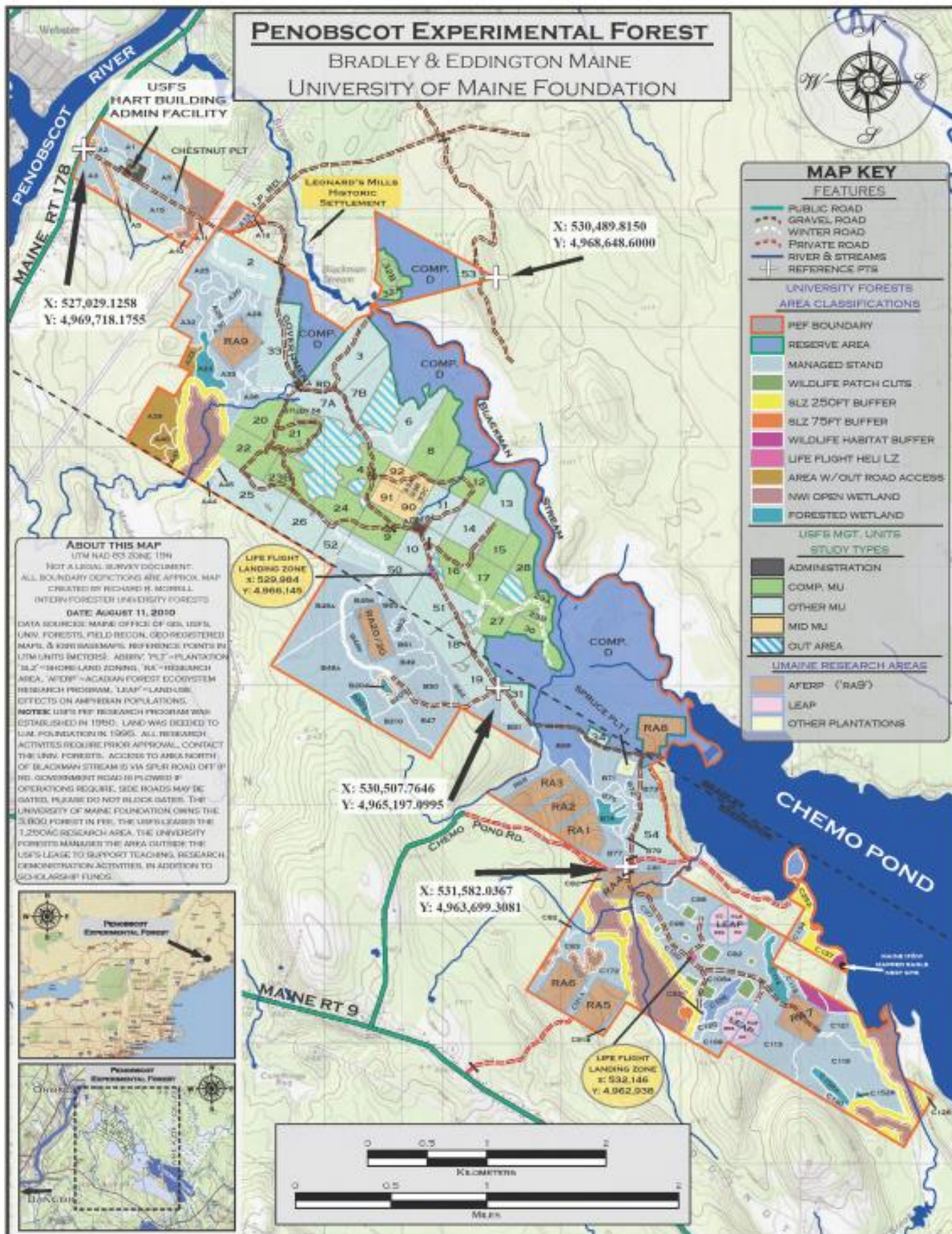
Long-term U.S. Forest Service Research at the Penobscot Experimental Forest

**Silviculture Institute
FIELD TOUR**

June 23, 2017



Laura Kenefic, Research Forester (lkenefic@fs.fed.us)





INTRODUCTION TO THE PEF

Background

Land for the approximately 4,000-acre Penobscot Experimental Forest (PEF) was purchased in 1950 by nine pulp, paper, and land holding companies. It was leased to the U.S. Forest Service, Northeastern Forest Experiment Station (now the Northern Research Station) for long-term research in the northern conifer (previously called spruce – fir) forest. In 1994, the industrial owners of the PEF donated the land to the University of Maine Foundation.

The mission of the PEF is to provide a setting for long-term research conducted cooperatively by the U.S. Forest Service and university researchers, to enhance forestry education of students and the public, and to demonstrate how the timber of needs of society are met from a working forest.

Forest Characteristics

About 10 miles north of Bangor, Maine, the PEF is in the Acadian Forest, a region covering much of Maine and Atlantic Canada. This is an ecotone between boreal and broadleaf biomes dominated by mixed conifers. Red spruce is the signature species. Balsam fir, a boreal species, is at its southern limit, while eastern hemlock and eastern white pine are at their northern limit. Stand-replacing fires are less frequent than in the boreal or other temperate forests. Insect epidemics (e.g. spruce budworm) and windstorms cause sporadic mortality. Most of the forest in the region has been periodically cut since the 1700s.

The climate is cool and humid. Average annual temperature is 43.9 °F; February is the coldest (19.3 °F) and July the warmest (68.0 °F). Normal precipitation is 41.7 in., with 48% falling during the 156-day growing season. Soils are complex and variable because of glacial influences. Till derived from fine grained, sedimentary rock is the principal parent material. Low till “ridges” are well drained, stony, and sandy loams. Flat till areas between ridges are poorly and very poorly drained loams and silt loams. Low areas along watercourses and in depressions have lake and marine sediments that are poorly drained silt and silty clay loams.

The Acadian Forest is more compositionally diverse than commercial spruce – fir forests farther north. The canopy is dominated by conifers, including hemlock, spruce (mostly red but some white and black), balsam fir, northern white-cedar, white pine, and an occasional tamarack or red pine. Common hardwoods include red maple, paper and gray birch, and trembling and bigtooth aspen.



LONG-TERM RESEARCH

Silvicultural Effects on Composition, Structure, and Growth of Northern Conifers in the Acadian Forest Region (1952-present)

Objectives:

1. Quantify tree and stand response to silvicultural treatment in order to develop knowledge and provide information about interaction between natural and human disturbances and their effects on stand dynamics.
2. Provide a variety of forest structures at one location, to be used as the framework for short-term experiments in ecology and silviculture.

Treatments:

Even-aged:

Uniform shelterwood with 2- and 3-stage overstory removal, with and without thinning

Uneven-aged:

Selection cutting on 5-, 10-, and 20-year cutting cycles

Diameter-limit cutting:

Unregulated harvesting (commercial clearcutting)

Fixed diameter-limit cutting

Modified (guiding) diameter-limit cutting

Reference:

No management

In addition to the above treatments, additional selection cutting, clearcutting, thinning, and shelterwood treatments are included in other Forest Service studies on the PEF.



Average Pre-Treatment Stand Condition (Management Units 15, 16, 17, 22, 23)

Management Unit	Total Acres (Hectares)	Inventory Year
15	25.5 (10.3)	1955
16	16.3 (6.6)	1957
17	26.4 (10.7)	1954
22	33.8 (13.7)	1956
23	24.3 (9.8)	1954

Stand Volume

2000 ft³/acre/year (140 m³/ha/year)

Basal Area

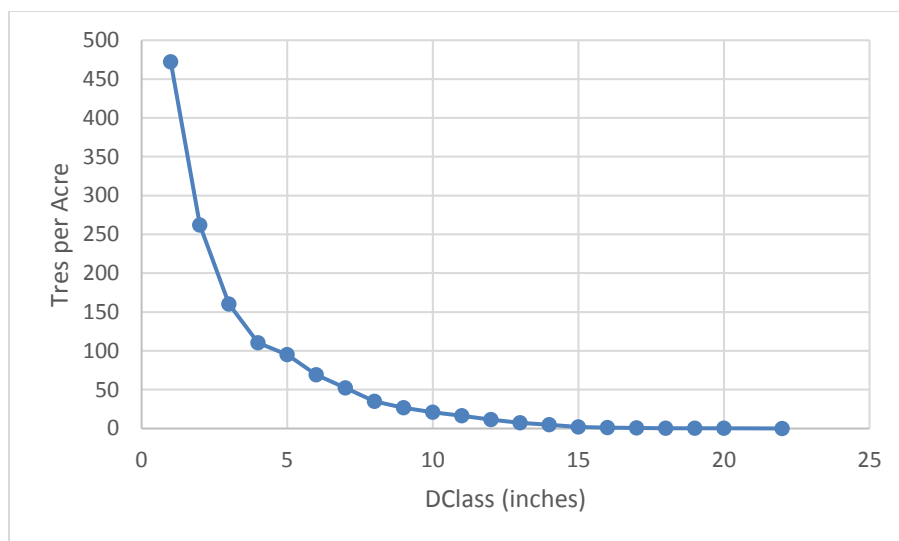
Sapling BA (DBH < 4.5 inches): 25.8 ft²/ acre (5.9 m²/ha)

Overstory Tree BA: (DBH ≥ 4.5 inches): 114.3 ft²/ acre (26.2 m²/ha)

Trees per Acre

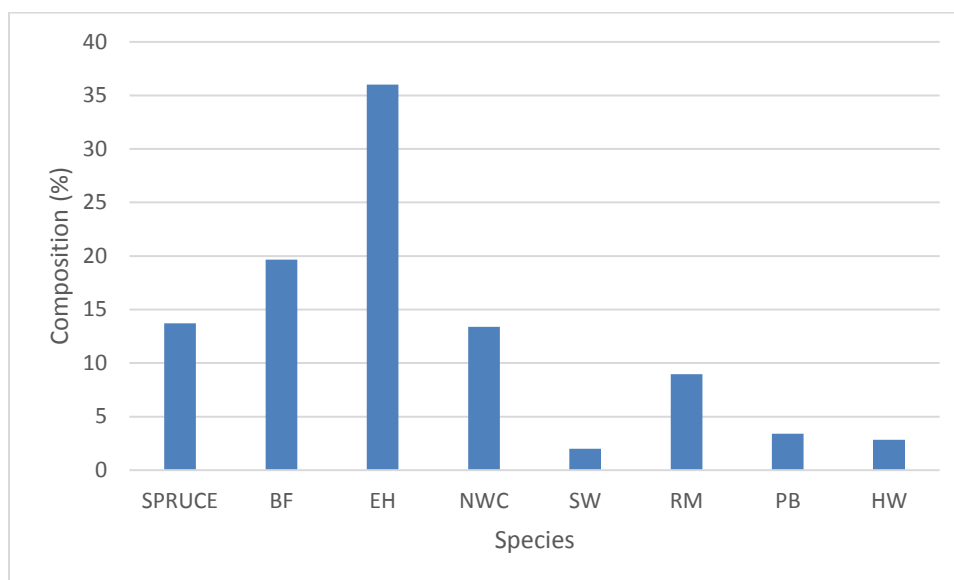
Sapling Total (DBH < 4.5 inches): 1004

Overstory Total: (DBH ≥ 4.5 inches): 343





Species Composition by % of Total Basal Area ≥ 0.5 inches DBH



Regeneration Density and Stocking (1960s)

	Spruce	BF	EH	NWC	OSW	RM	PB	OHW
Density (per acre)	321	2310	1550	77	19	1112	1698	543
Stocking	19%	56%	36%	5%	2%	29%	28%	16%

Note: Spruce refers to all spruce species, BF=balsam fir, EH=Eastern hemlock, NWC=Northern white cedar, RM=red maple, PB=paper birch, OHW=all other hardwoods not specified, and OSW=all other softwoods not specified.



Compartment 33

Strip Clearcut (1-, 2- and 3-chain width)

Whole-tree, Stem-only (Slash Left), and Stem-only (Slash Burned) Harvesting

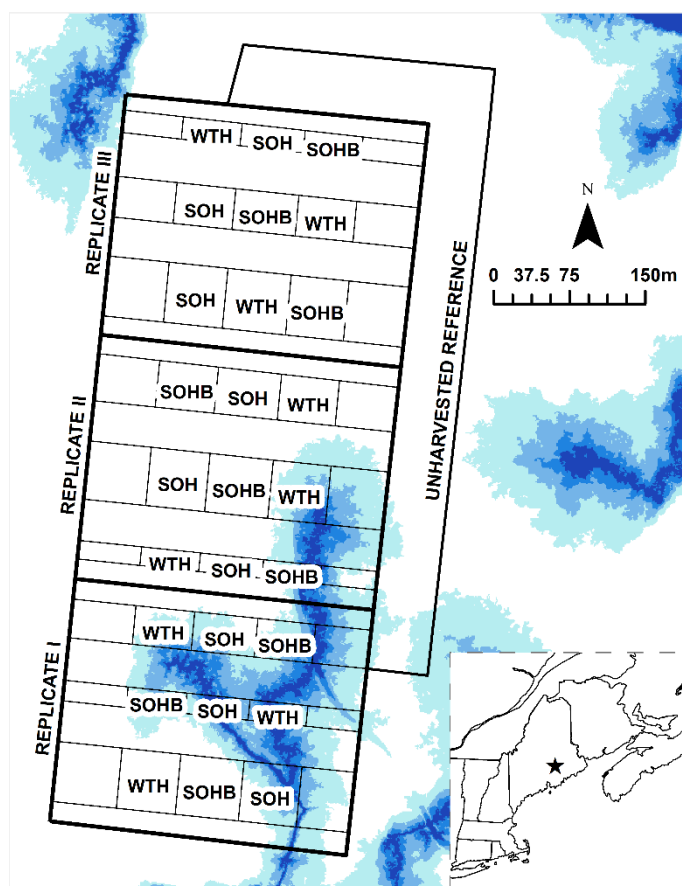
Pre-treatment stand data (1964, trees ≥ 4.5 in. dbh):

Volume: 1860 ft³/acre

Species composition:	Spruce (white and red) and Fir	50%
	Hardwoods	25%
	Eastern white pine	10%
	Eastern hemlock	10%
	Northern white-cedar	5%

Average DBH of merchantable growing stock was 7 inches.

(Czapowskyj et al. 1977)



Eastern hemlock and eastern white pine were more prevalent on well-drained soils, and northern-white cedar and black ash on poorly drained soils.

All areas of the compartment contained red maple, balsam fir, and spruce spp.

Birch and aspen spp. were found in small numbers throughout the study.

(Rinaldi 1970)



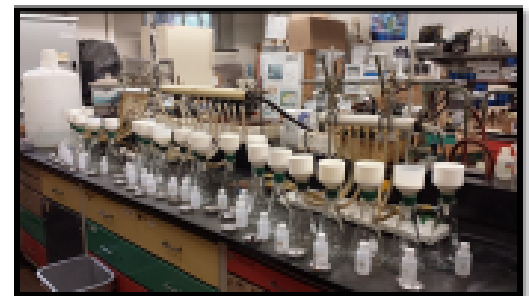
Northern mixedwood forest productivity 50 years after whole-tree and stem-only harvesting

Bethany Muñoz, and Laura Kenefic, U.S. Forest Service; Aaron Weiskittel and Ivan Fernandez, University of Maine

- ☐ We are using a slash-disposal experiment established in 1964 in Maine to address concerns about forest productivity following biomass harvesting.
- ☐ Treatments are clearcutting with stem-only harvesting (SOH), stem-only harvesting and prescribed burning (SOHB), and whole-tree harvesting (WTH).
- ☐ In terms of stand structure and composition 50 years after harvest, intensive biomass removals (WTH and SOHB) did not reduce forest productivity.
- ☐ Analysis of soil and foliar nutrition (ongoing) and planned retreatment will further inform productivity outcomes.
- ☐ This is the longest known study of biomass harvesting in temperate forests worldwide.

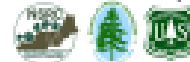


Collecting data on stand structure, composition, and carbon stock



Analyzing foliar and soil nutrition

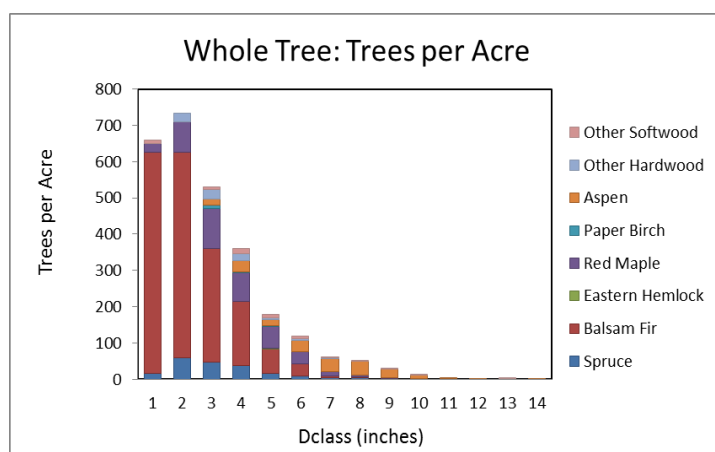
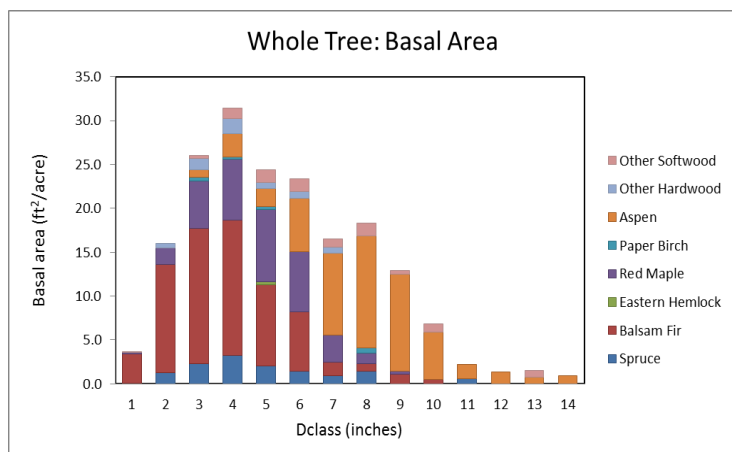
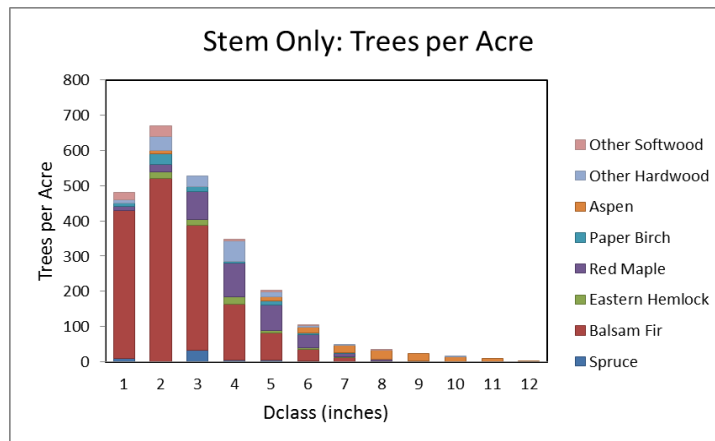
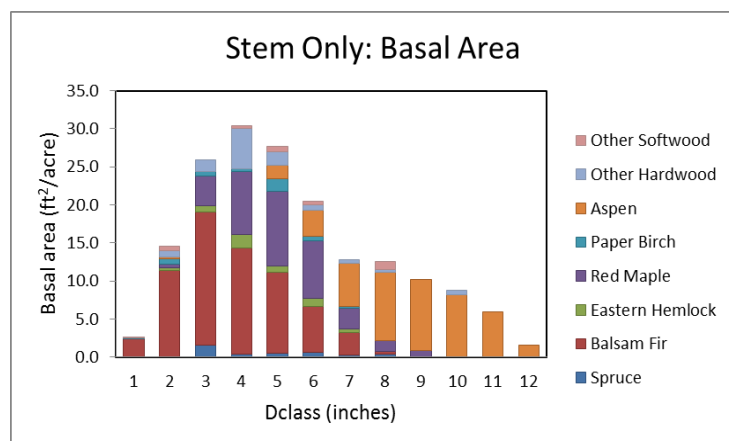
Research Funded By:





Treatment	Total Basal Area (ft ² /acre) ≥ 0.5
STEM-ONLY HARVEST	173.4
WHOLE-TREE HARVEST	185.3

Treatment	Trees per Acre
STEM-ONLY HARVEST	2467.0
WHOLE-TREE HARVEST	2743.3



Author: Bethany Muñoz



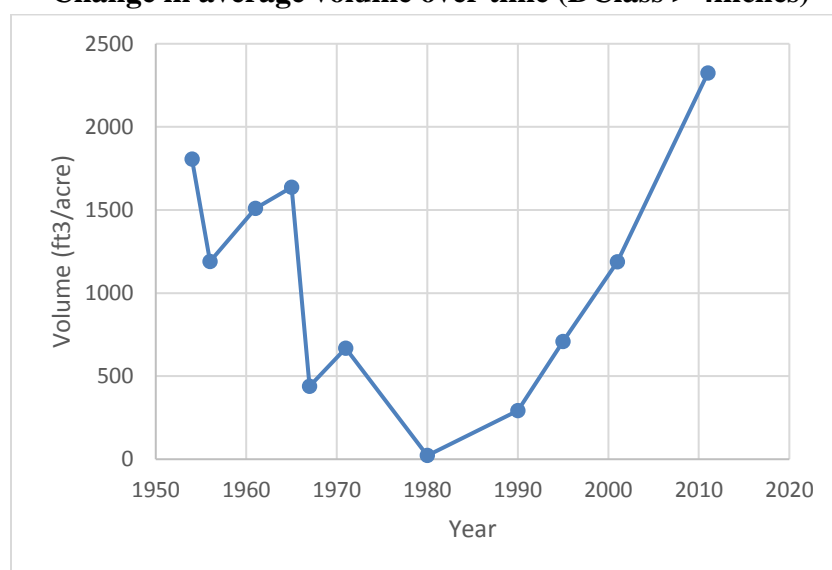
Management Unit 23B 3-Stage Shelterwood System

Acres: 12.4 Hectares: 5.0

Permanent Sample Plots: 9

Treatment: Shelterwood system with three-stage overstory removal. The final overstory removal occurred in 1971. All residuals trees >2 in dbh were removed. No additional management has been applied.

Change in average volume over time (DClass > 4inches)



Basal Area (2011)

Sapling BA (DBH < 4.4 inches):
88.4 ft²/ acre (20.3 m²/ha)

Overstory Tree BA: (DBH ≥ 4.5 inches):
133.3 ft²/ acre (30.6 m²/ha)

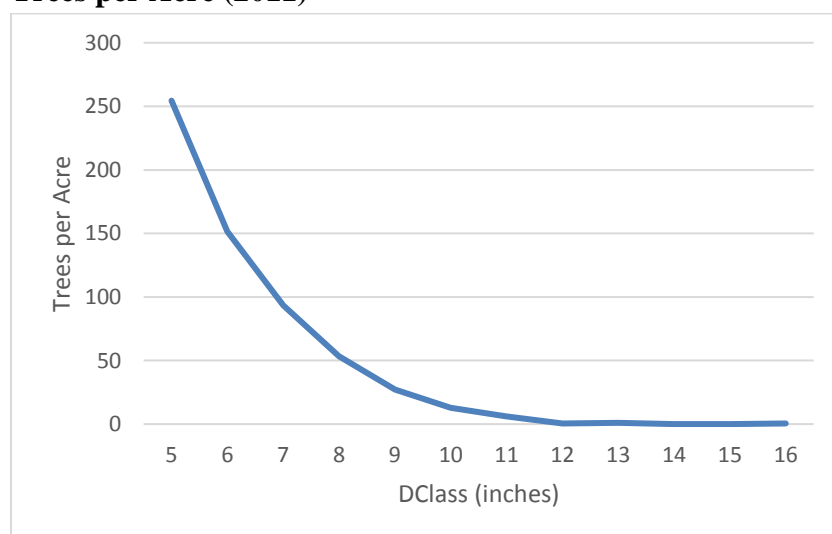
Total Net Volume Growth (From 1954-2011)

52.2 ft³/acre/year (3.6 m³/ha/year)

Average Removal

(Total Harvest/Number of Harvests)
820.2 ft³/acre (57.3 m³/ha)

Trees per Acre (2011)



Percent Cull by Volume

1954: 4.7% (± 1.2 SE)

2011: 1.5% (± 0.7 SE)

Trees per Acre (2011)

Sapling Total (DBH < 4.5 inches): 1967

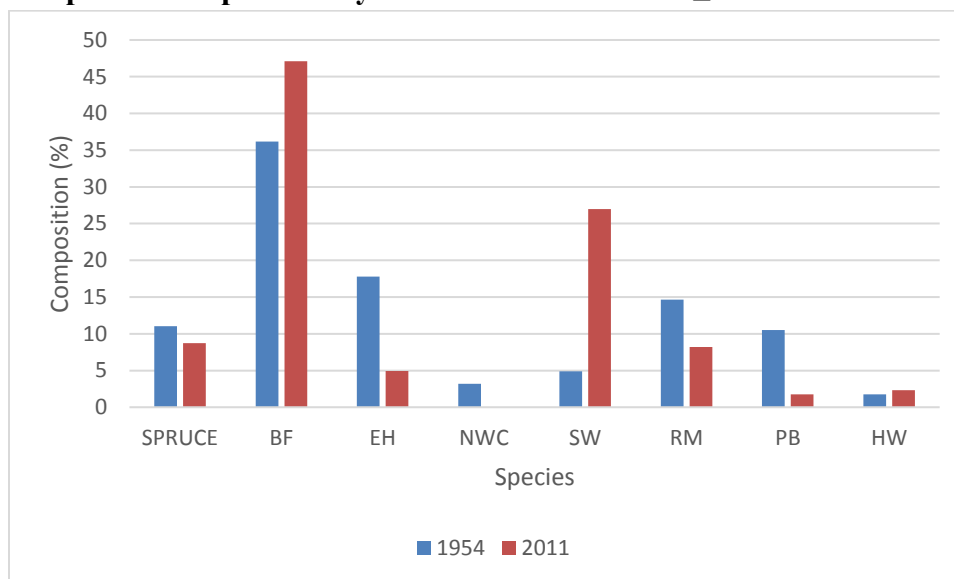
Overstory Total: (DBH ≥ 4.5 inches): 601

Note: TPA × 0.0404 = TPH; ft³/acre × 0.0699 = m³/ha.



Management Unit 23B (continued)

Species Composition by % of Total Basal Area \geq 0.5 inches DBH



Regeneration Stocking and Density (2011)

	Spruce	BF	EH	NWC	OSW	RM	PB	OHW
Density (per acre)	0	556	37	0	0	259	0	0
Stocking	0%	4%	4%	0%	0%	4%	0%	0%

Note: Spruce refers to all spruce species, BF=balsam fir, EH=Eastern hemlock, NWC=Northern white cedar, RM=red maple, PB=paper birch, OHW=all other hardwoods not specified, and OSW=all other softwoods not specified.

Understory Vegetation Cover (2011)

	Woody Shrubs	Herbaceous Vegetation	Grasses, Sedges, Rushes	Ferns	Mosses & Lichens
Percent Cover (%)	0	<1	0	0	14.8

Author: Rachel A. Knapp



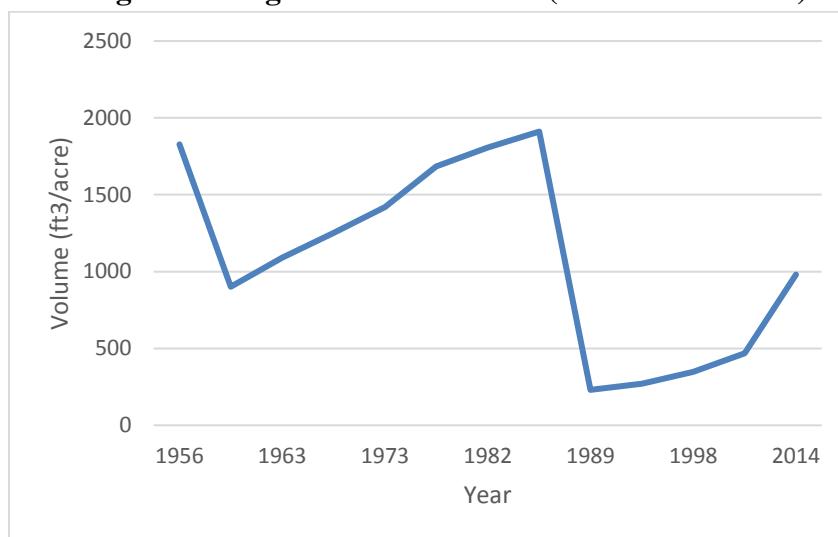
Management Unit 22 Commercial Clearcut

Acres: 33.8 Hectares: 13.7

Permanent Sample Plots: 16

Treatment: Commercial Clearcut, also called Unregulated Harvest. The original harvest was an unregulated “logger’s choice” in 1957. The second entry in 1988 was a commercial clearcut removing all merchantable stems, with no tending or attention to regeneration.

Change in average volume over time (DClass > 4 inches)



Basal Area (2014)

Sapling BA (DBH < 4.5 inches):
76.7 ft²/acre (17.6 m²/ha)

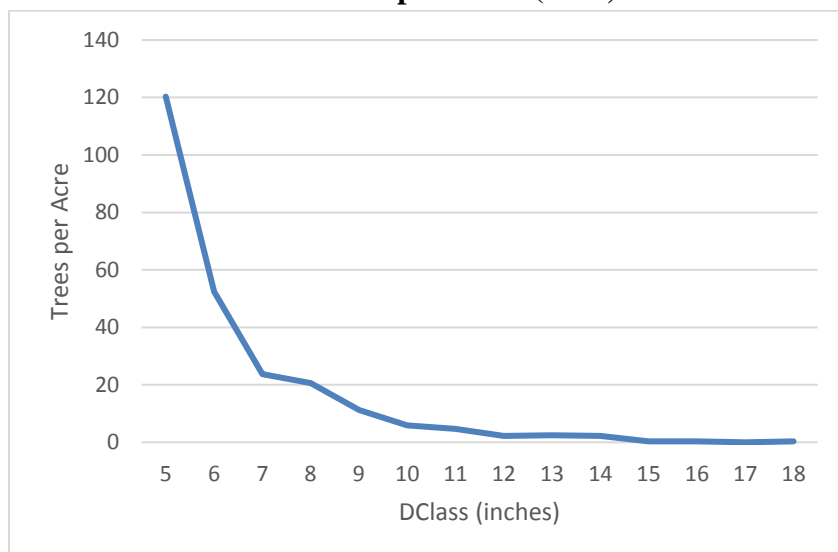
Overstory Tree BA: (DBH ≥ 4.5 inches):
59.3 ft²/acre (13.6 m²/ha)

Net Volume Growth From 1956-2013

30.3 ft³/acre/year (2.12 m³/ha/year)

**Average Removal
(Total Harvest/Number of Harvests)**
1303.1 ft³/acre (91.1 m³/ha)

Trees per Acre (2014)



Percent Cull by Volume

1956: 9.2% (±1.6 SE)

2013: 11.2% (±2.3 SE)

Trees per Acre (2013)

Sapling Total (DBH < 4.5 inches): 2904

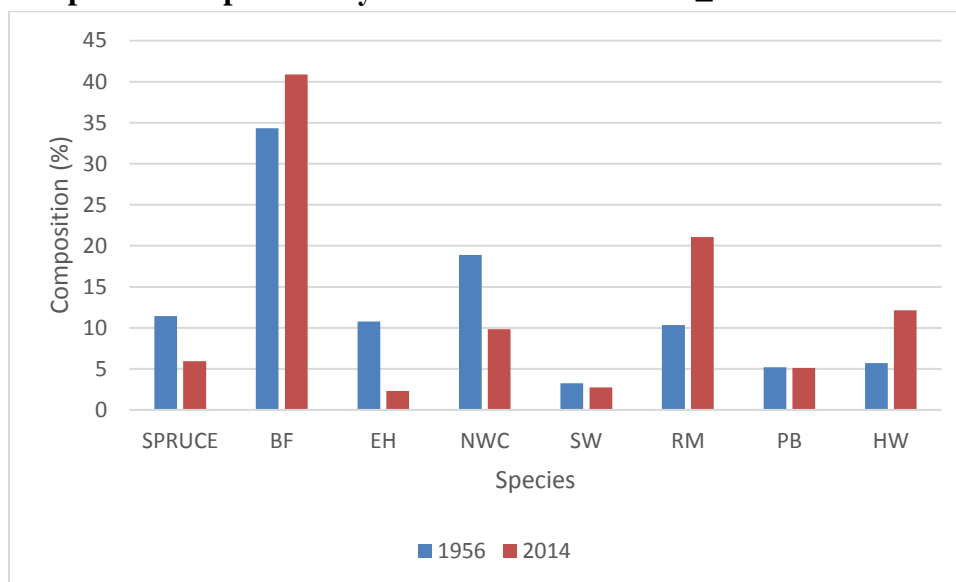
Overstory Total: (DBH ≥ 4.5 inches): 247

Note: $TPA \times 0.0404 = TPH$; $ft^3/acre \times 0.0699 = m^3/ha$.



Management Unit 22 (continued)

Species Composition by % of Total Basal Area ≥ 0.5 inches DBH



Regeneration Density and Stocking (2014)

	Spruce	BF	EH	NWC	OSW	RM	PB	OHW
Density (per acre)	62	2771	42	125	0	369	62	562
Stocking	6%	57%	4%	8%	0	21%	6%	15%

Note: Spruce refers to all spruce species, BF=balsam fir, EH=Eastern hemlock, NWC=Northern white cedar, RM=red maple, PB=paper birch, OHW=all other hardwoods not specified, and OSW=all other softwoods not specified.

Understory Vegetation Cover (2014)

	Woody Shrubs	Herbaceous Vegetation	Grasses, Sedges, Rushes	Ferns	Mosses & Lichens
Percent Cover (%)	6.0	23.7	9.0	13.0	28.8

Author: Rachel A. Knapp



Rehabilitation Silviculture

Treatments

Moderate rehabilitation

- Crop tree release
 - hardwoods: 25 ft
 - softwoods: 15 ft



Intensive rehabilitation

- Crop tree release
- Timber stand improvement
- Fill/under planting



Results

Percent cull

- Pre-treatment stand average 20%
- Post-treatment
 - Moderate: 1%
 - Intensive: 0%





Results

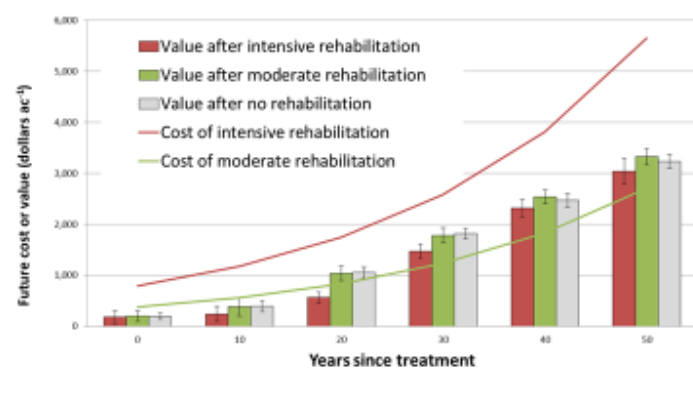
- planted 176 seedling per acre
- 3-yr mortality: 30%
- 90% of surviving seedlings were browsed



Results

Cost of labor:

- Intensive \$603/ac
- Moderate \$231/ac



Kenefic, Laura S.; Bataineh, Mohammad; Wilson, Jeremy S.; Brissette, John C.; Nyland, Ralph D. 2014. Silvicultural rehabilitation of cutover mixedwood stands. *Journal of Forestry*. 112(3): 261-271.

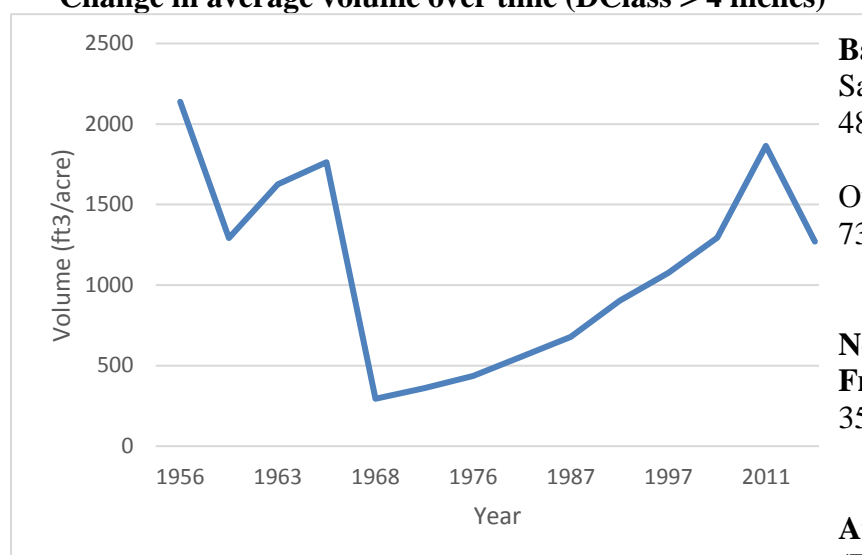


Management Unit 21 2-Stage Shelterwood System

Acres: 24.2 (Hectares: 9.8)
Permanent Sample Plots: 10

Treatment: Shelterwood System, Two-Stage Overstory Removal. Initial overstory removal was completed in 1957 followed by a final incomplete overstory removal in 1967. This resulted in the development of a two-aged stand. The stand was commercially thinned in 2012 to capture mortality, remove poor vigor and unacceptable growing stock, and increase growing space available to acceptable growing stock and potential crop trees.

Change in average volume over time (DClass > 4 inches)



Basal Area (2013)

Sapling BA, DBH < 4.5 inches:
48.0 ft²/acre (11.0 m²/ha)

Overstory Tree BA: (DBH ≥ 4.5 inches):
73.9 ft²/acre (17.0 m²/ha)

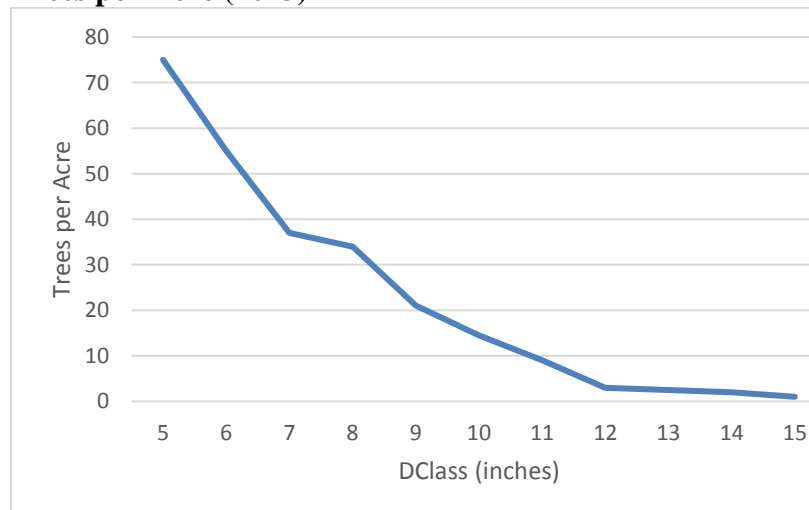
Net Volume Growth From 1956-2013

35.8 ft³/acre/year (2.5 m³/ha/year)

Average Removal

(Total Harvest/Number of Harvests)
969.9 ft³/acre (67.8 m³/ha)

Trees per Acre (2013)



Percent Cull by Volume

1956: 7.4% (± 1.4 SE)

2013: 0.34% (± 0.3 SE)

Trees per Acre (2013)

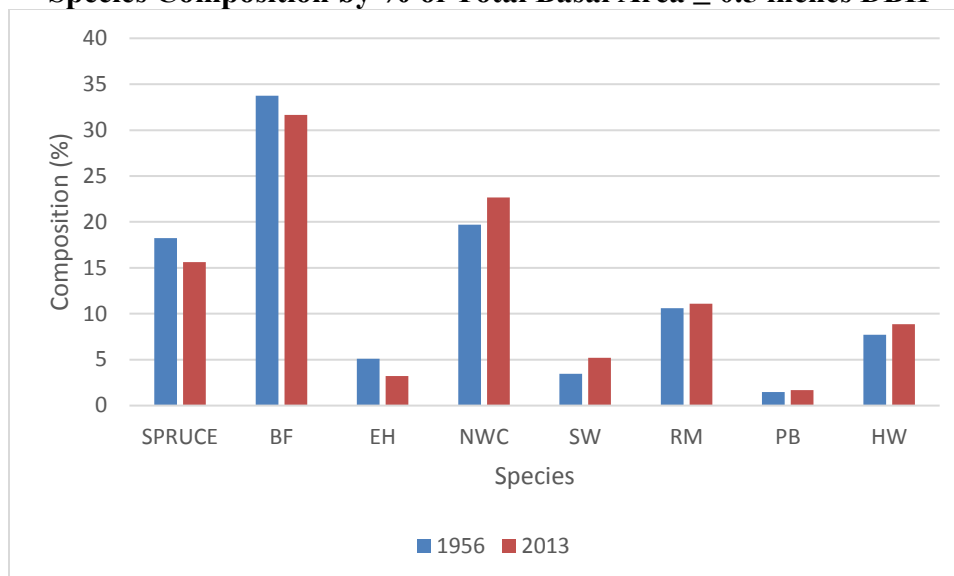
Sapling Total (DBH < 4.5 inches): 1577

Overstory Total: (DBH ≥ 4.5 inches): 254

Note: TPA × 0.404 = TPH; ft³/acre × 0.0699 = m³/ha.



Species Composition by % of Total Basal Area \geq 0.5 inches DBH



Regeneration Stocking and Density (2013)

	Spruce	BF	EH	NWC	OSW	RM	PB	OHW
Density (per acre)	67	700	0	0	0	467	33	1933
Stocking	7%	17%	0	0	0	7%	3%	13%

Note: Spruce refers to all spruce species, BF=balsam fir, EH=Eastern hemlock, NWC=Northern white cedar, RM=red maple, PB=paper birch, OHW=all other hardwoods not specified, and OSW=all other softwoods not specified.

Understory Vegetation Cover (2011)

	Woody Shrubs	Herbaceous Vegetation	Grasses, Sedges, Rushes	Ferns	Mosses & Lichens
Percent Cover (%)	5.1	5.3	15.1	3.1	25.2

Author: Rachel A. Knapp

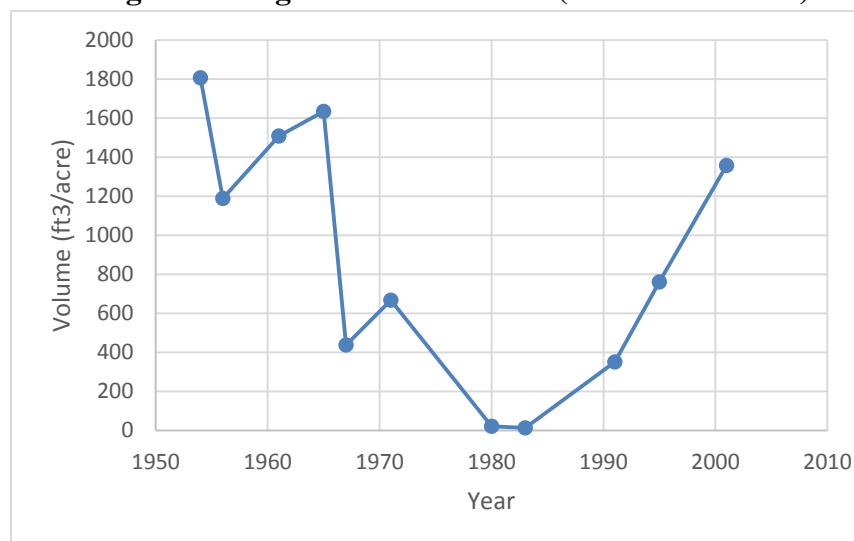


Management Unit 23A 3-Stage Shelterwood System with Precommercial Thinning

Acres: 11.9 Hectares: 4.8
Permanent Sample Plots: 10

Treatment: Shelterwood system with three-stage overstory removal. The final overstory removal occurred in 1971. All residual trees >2 in dbh were removed. Manual PCT to a residual spacing of 2×3 m was applied in 1981; volunteer growth occurred between crop trees. In 2001 this compartment was transferred to the CFRU Commercial Thinning Research Network for management.

Change in average volume over time (DClass > 4 inches)



Basal Area (2001)

Sapling BA (DBH < 4.4 inches):
54.4 ft²/acre (12.5 m²/ha)

Overstory Tree BA: (DBH ≥ 4.5 inches):
76.9 ft²/acre (17.6 m²/ha)

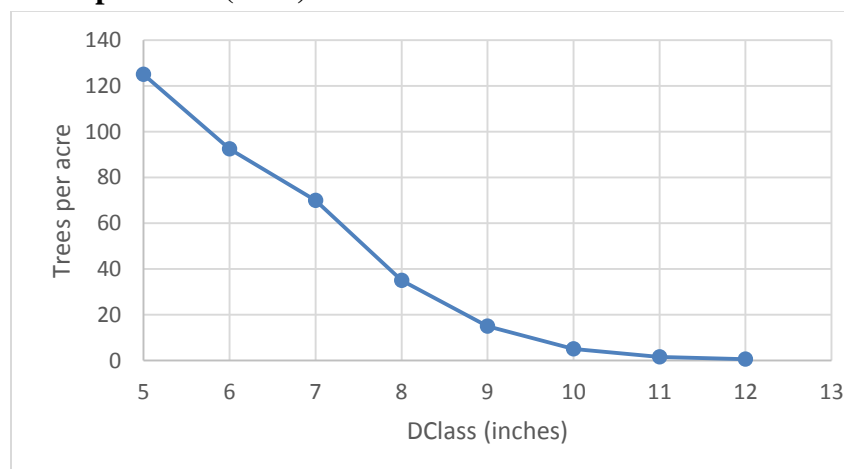
Total Net Volume Growth (From 1954-2001)

43.0 ft³/acre/year (3.0 m³/ha/year)

Average Removal

(Total Harvest/Number of Harvests)
617.5 ft³/acre (43.2 m³/ha)

Trees per Acre (2001)



Percent Cull by Volume

1954: 4.7% (± 1.2 SE)

2001: 0.1% (± 0.1 SE)

Trees per Acre (2011)

Sapling Total (DBH < 4.5 inches): 2789

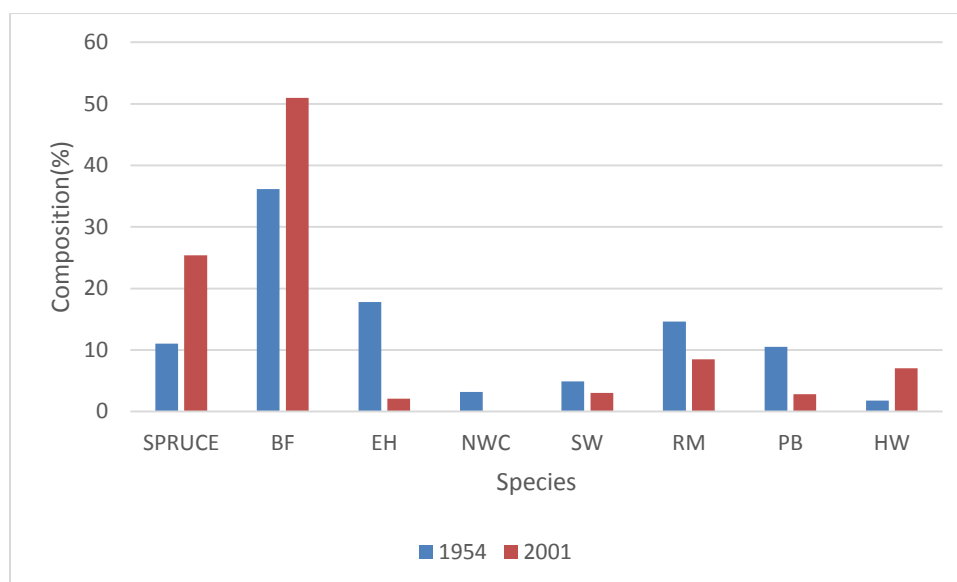
Overstory Total: (DBH ≥ 4.5 inches): 345

Note: $TPA \times 0.0404 = TPH$; $ft^3/acre \times 0.0699 = m^3/ha$.



Management Unit 23A (continued)

Species Composition by % of Total Basal Area ≥ 0.5 inches DBH



Regeneration Stocking and Density (2001)

	Spruce	BF	EH	NWC	OSW	RM	PB	OHW
Density (per acre)	600	1400	333	67	0	200	0	33
Stocking	33%	53%	23%	3%	0%	10%	0%	3%

Note: Spruce refers to all spruce species, BF=balsam fir, EH=Eastern hemlock, NWC=Northern white cedar, RM=red maple, PB=paper birch, OHW=all other hardwoods not specified, and OSW=all other softwoods not specified.

Understory Vegetation Cover (2011)

	Woody Shrubs	Herbaceous Vegetation	Grasses, Sedges, Rushes	Ferns	Mosses & Lichens
Percent Cover (%)	<1	1.9	<1	<1	20.1

Author: Rachel A. Knapp



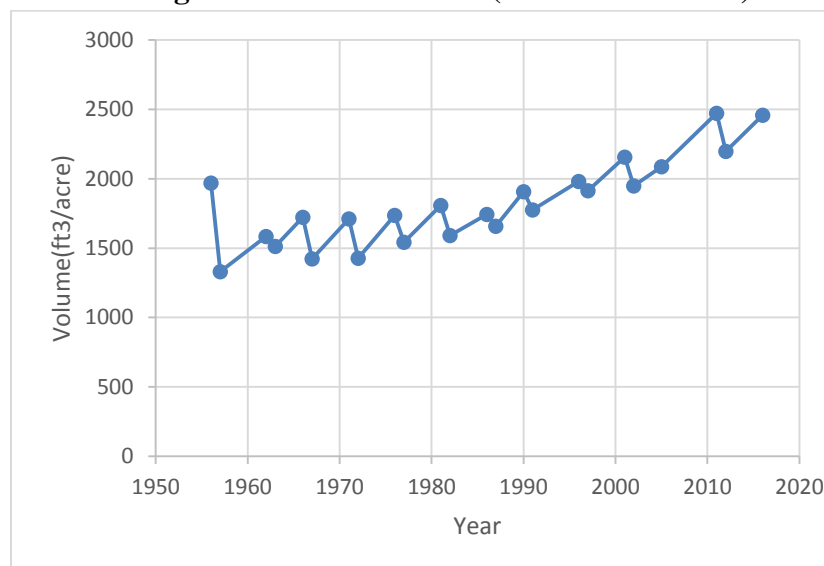
Management Unit 16 Selection Cutting, 5-Year Cycle

Acres: 16.3 (Hectares: 6.6)

Permanent Sample Plots: 20

Treatment: Single-tree selection on a 5-year cutting cycle. Residual stand composition and structure are based on species-specific and BDq (residual BA, maximum DBH, and q -factor) goals. The 11th treatment was applied in 2012. The last inventory was conducted in the summer of 2016 in preparation for the 12th treatment.

Change in volume over time (DClass > 4 inches)



Basal Area (2016)

Sapling BA, DBH < 4.5 inches:
17.8 ft²/ acre (4.1 m²/ha)

Overstory Tree BA: (DBH ≥ 4.5 inches):
118.1 ft²/ acre (27.1 m²/ha)

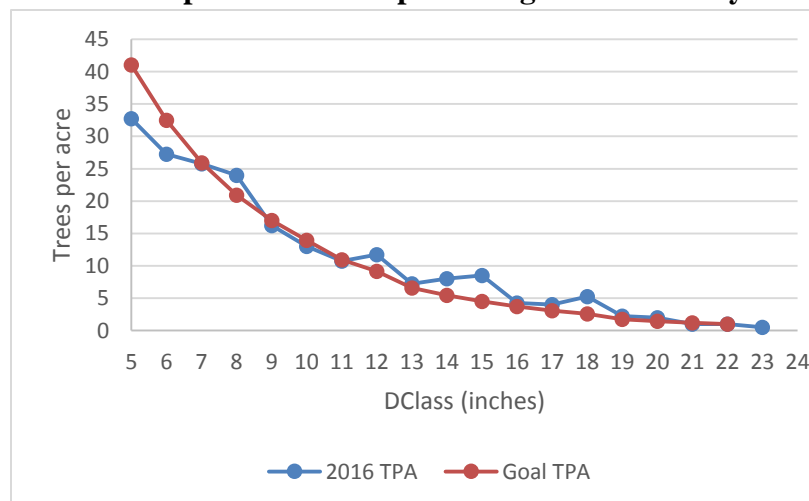
Net Volume Growth (From 1957-2012)

50.1 ft³/acre/year (3.5 m³/ha/year)

Average Removal

(Total Harvest/ Number of Harvests)
205.9 ft³/acre (14.4 m³/ha)

Actual trees per acre as compared to goal set in Study Plan



Percent Cull by Volume

1957: 6.6% (± 1.3 SE)

2016: 1.2% (± 0.6% SE)

Trees per Acre (2016)

Sapling (DBH < 4.5 inches): 876

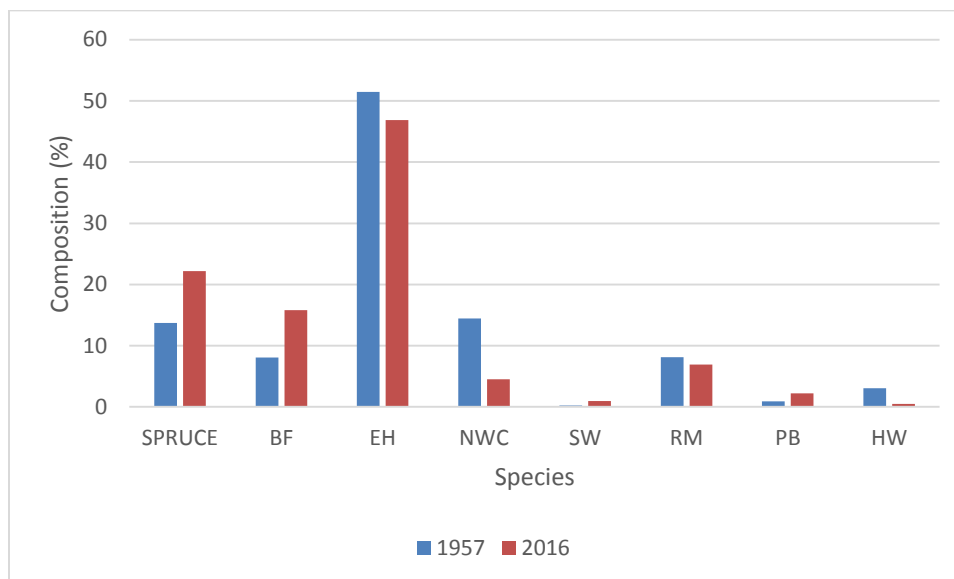
Overstory (DBH ≥ 4.5 inches): 206

Note: $TPA \times 0.404 = TPH$; $ft^3/acre \times 0.0699 = m^3/ha$.



Management Unit 16 (continued)

Species Composition by % of Total Basal Area \geq 0.5 inches DBH



Regeneration Stocking and Density (2016)

	Spruce	BF	EH	NWC	OSW	RM	PB	OHW
Density (per acre)	933	900	2067	0	0	33	50	33
Stocking	30%	37%	50%	0%	0%	2%	2%	2%

Note: Spruce refers to all spruce species, BF=balsam fir, EH=Eastern hemlock, NWC=Northern white cedar, RM=red maple, PB=paper birch, OHW=all other hardwoods not specified, and OSW=all other softwoods not specified.

Understory Vegetation Cover (2016)

	Woody Shrubs	Herbaceous Vegetation	Grasses, Sedges, Rushes	Ferns	Mosses & Lichens
Percent Cover (%)	<1	4.9	1.0	<1	39.7

Author: Rachel A. Knapp



Marking Guidelines
C16, 5-year selection cutting
13th treatment

November 13, 2016

This treatment is prescribed per instructions in the Study Plan entitled “Silviculture Effects on Composition and Structure of Northern Conifers in the Acadian Forest Region: Revision of the Compartment Management Study on the Penobscot Experimental Forest” by J.C. Brissette and L.S. Kenefic (2008).

Section A: Basal Area, Trees \geq 4.5 in. DBH

1. Target BA (trees \geq 4.5 in. DBH)	105 ft ² /ac
2. Observed BA	118 ft ² /ac
3. Prescribed BA removal	13 ft ² /ac
4. Estimated Volume removal ¹	Approximately 2.6 cd-eq/ac

Section B: Species Composition (percent of BA \geq 4.5 in. DBH; asterisks denote excess)

Species	Target	Observed
Spruce	40	24
B. fir	5	13*
E. hemlock	30	47*
N. white-cedar	5	5
E. white pine	5	1
Hardwoods	15	10

Section C: Maximum DBH (in.); Asterisks denote excess

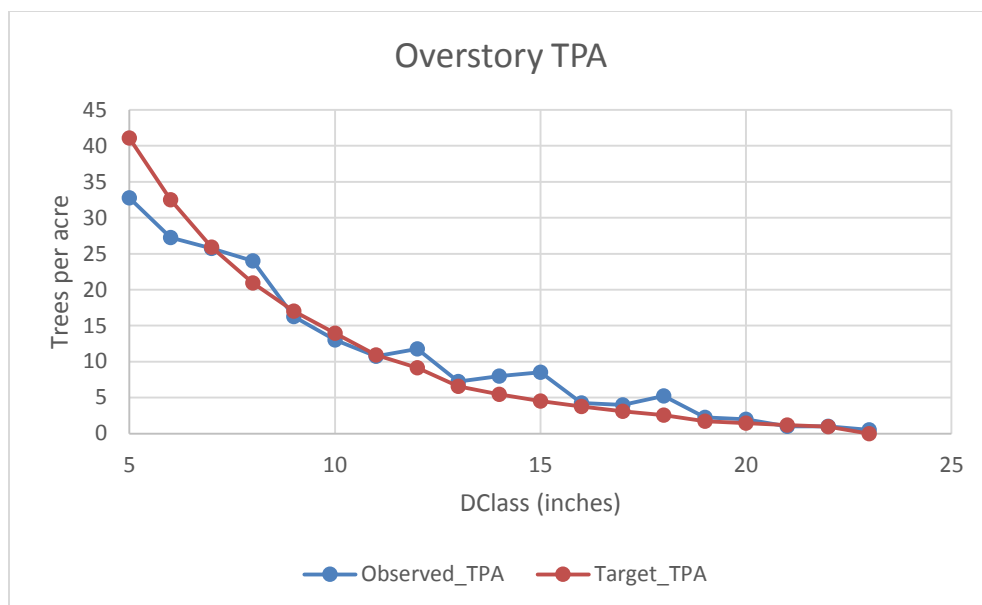
Species	Target	Observed
Spruce	22	23*
B. fir	10	12*
E. hemlock	22	22
N. white-cedar	12	15*
E. white pine	24	20
Hardwoods	18	18

In light of a low rate of white-cedar recruitment across the PEF and our desire to retain seed trees, northern white-cedar will not be cut unless cull, high-risk, or other UGS.

¹ BA (ft²/acre) is divided by 5 to estimate cord-equivalents.



Section D: Diameter Distributions (all species combined)



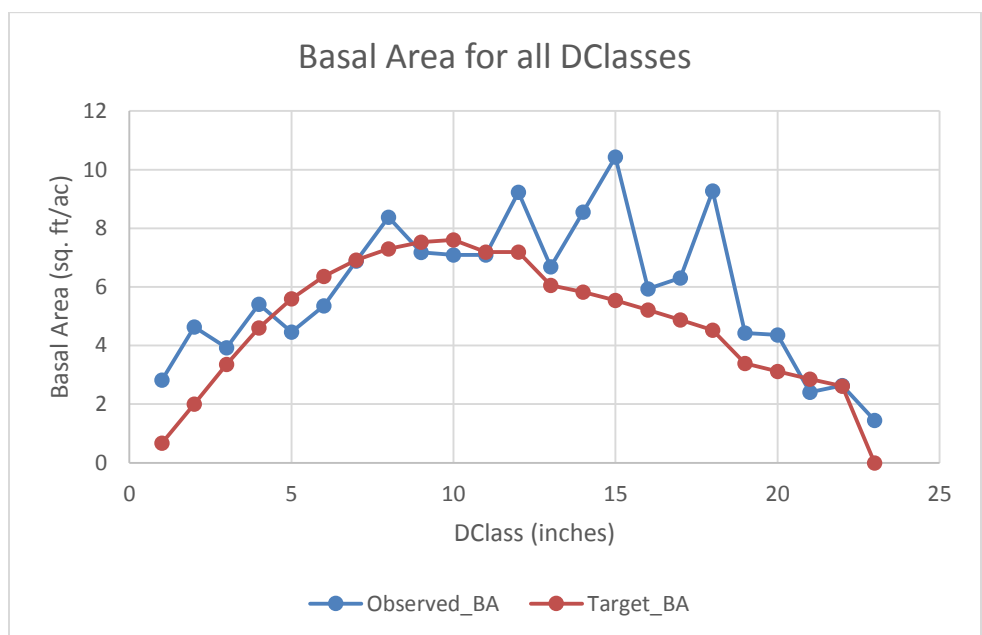
Trees per acre

Slight deficit in small poletimber (5-6 inches DBH).

Close to target in large poled and small sawtimber (7-11 inches DBH).

Excess trees in large sawtimber (12-18 inches DBH)

See: Section G for table of TPA by diameter class and species groups.



Basal Area

Excess basal area in the saplings (<5 inches DBH).

Other deviations from the target are listed above.

See: Section H for table of basal area by diameter class.



Section E; Sapling Density and Species Composition (Trees per acre², 0.5 – 4.5 in. DBH; asterisks denote excess)

Species	Target	Observed
Spruce	85	40
B. fir	130	245*
E. hemlock	22	490*
N. white-cedar	12	8
E. white pine	n/a	1
Hardwoods	45	90*

Eastern hemlock is excessively overstocked with >20 times the desired density. Hardwoods and fir are also overstocked, with twice as many sapling stems as desired.

Section F: Instructions for marking:

Harvest: 13 ft²/ac (this is approximately 11% of current total BA \geq 4.5 in DBH).

Priorities:

1. Remove cull trees (without at least one sound 6-foot log), except northern white-cedar (retain cedar for seed and biodiversity unless competing with a crop tree). Note: < 4% of current stand BA is cull.
2. Remove high-risk trees (expected to die within next 5 years) and unacceptable growing stock (UGS: trees without potential for volume and value increase).
3. Control structure and composition, as follows:
 - a. Reduce proportion of hemlock 12 to 20 inches DBH (see Section G).
4. Remove trees greater than the species-specific MaxD (see Section C).
5. Release or thin potential crop trees in saplings, poles, and small sawtimber.

Notes:

- 1 – 2 trees > maximum diameter may be retained per unit if of exceptional size and quality for their species.
- Dead trees (snags) and trees with active cavities or nests (wildlife trees) should not be harvested.
- When selecting trees to mark based on structure, composition, and quality goals, trees that release sapling and pole-sized spruce should be selected if other considerations are equal.
- Each person marking may retain two trees per stand which would otherwise be harvested, for non-commodity reasons.

Summary: Mark 13 ft²/ac. After cull (which should be rare), high-risk trees and UGS, the top priorities for removal are hemlock 12 to 20 inches DBH.

² Rounded to the nearest 5 stems per acre, unless < 5.



Post-Harvest Precommercial Treatment

Per the 2008 Study Plan, mechanical (brushsaw) release of sapling crop trees (0.5 to 4.4 inches dbh) will be conducted 1-2 years post-harvest. While the study plan suggests release of spruce and hemlock, due to the overabundance of hemlock in this stand, only spruce and rare/understocked desirable species such as white-cedar, pine, and oak will be released. A minimum of 25 well-distributed spruce trees should be released per acre.

A handwritten signature in dark ink that reads "Rachel A. Knapp".

Rachel Knapp, Data Manager

A handwritten signature in dark ink that reads "Laura Kenefic".

Laura Kenefic, Research Forester



Section G: Trees per acre by Major Species Groups

DClass	Spruce_ Target	Spruce_ Obs	BF_ Target	BF_ Obs	Excess	EH_ Target	EH_ Obs	Excess	NWC_ Target	NWC_ Obs	HW_ Target	HW_ Obs	Excess	Total_ Target (no pine)	Total_ Obs (no pine)
1	27.9	25	56.17	112.5	*	20.93	325	*	3.47	2.5	14.33	52.5	*	122.8	517.5
2	23.17	7.5	35.55	65	*	17.38	115	*	3.16	0	11.75	25	*	91.01	212.5
3	19.24	1	22.5	36	*	14.43	31	*	2.87	3	9.63	9		68.67	80
4	15.92	6	14.24	31	*	11.99	18	*	2.61	2	7.89	4		52.65	61
5	13.27	3	9.01	16	*	9.95	7.5		2.37	0.5	6.47	5.5		41.07	32.5
6	11.08	2	5.7	13.5	*	8.27	7.75		2.16	1	5.3	2.75		32.51	27
7	9.15	0.75	3.61	11.25	*	6.86	8.25		1.96	2	4.35	3.5		25.93	25.75
8	7.6	3.25	2.29	10.5	*	5.7	6.5		1.78	1.25	3.56	2.25		20.93	23.75
9	6.31	3	1.45	4.75	*	4.73	4.25		1.62	2.75	2.92	1.25		17.03	16
10	5.24	4	0.92	1.5	*	3.93	4.75	*	1.47	1	2.39	1.75		13.95	13
11	4.35	1.5		1.25		3.27	5.25	*	1.34	1	1.96	1.75		10.92	10.75
12	3.62	2.75		0.75		2.71	6	*	1.22	1	1.61	1.25		9.16	11.75
13	3	3.75				2.25	2.5	*		0.25	1.32	0.5		6.57	7
14	2.49	2				1.87	4	*		0.5	1.08	1.5		5.44	8
15	2.07	3.25				1.55	4	*		0.5	0.89	0.75		4.51	8.5
16	1.72	1				1.29	2.5	*		0.25	0.73	0.25		3.74	4
17	1.43	1.5				1.07	2.25	*			0.59	0.25		3.09	4
18	1.19	1.5				0.89	3.5	*			0.49	0.25		2.57	5.25
19	0.98	0.5				0.74	1.75	*	Shaded cells=Excess to focus on Dark outlined cells=Greater than MaxD					1.72	2.25
20	0.82	0.75				0.61	1	*						1.43	1.75
21	0.68	0				0.51	1	*						1.19	1
22	0.56	0.25				0.42	0.75	*						0.98	1
23		0.25					0.25								0.5



Explanation: Though there are excess balsam fir in the pole and small sawtimber classes, these classes are understocked overall (i.e., all species combined) relative to the target distribution. For this reason, excess fir will not be removed from merchantable classes ≤ 10 in. DBH unless cull, high risk, or UGS. Instead, the cut will focus on hemlock 12 to 20 inches DBH, for structure and composition control. This approach prioritizes structure (the reverse-J diameter distribution goal over species composition goals re: fir.

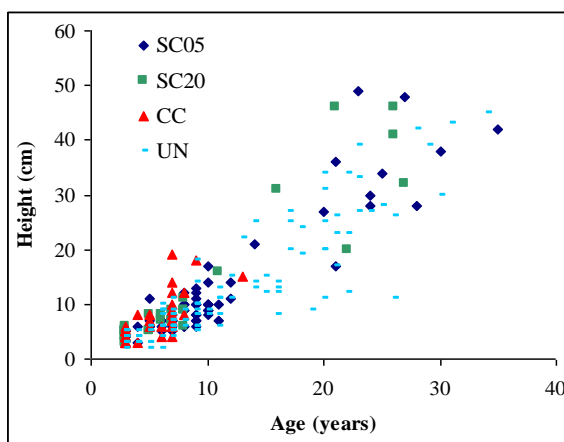
Section H: Basal Area per acre by DClass

DClass	Target_BA	Observed_BA
1	0.67	2.82
2	2	4.64
3	3.36	3.93
4	4.6	5.41
5	5.6	4.47
6	6.36	5.35
7	6.92	6.88
8	7.3	8.38
9	7.53	7.18
10	7.61	7.09
11	7.19	7.09
12	7.19	9.23
13	6.06	6.68
14	5.82	8.55
15	5.54	10.43
16	5.21	5.93
17	4.88	6.30
18	4.53	9.28
19	3.39	4.43
20	3.12	4.36
21	2.86	2.41
22	2.61	2.64
23	0	1.44

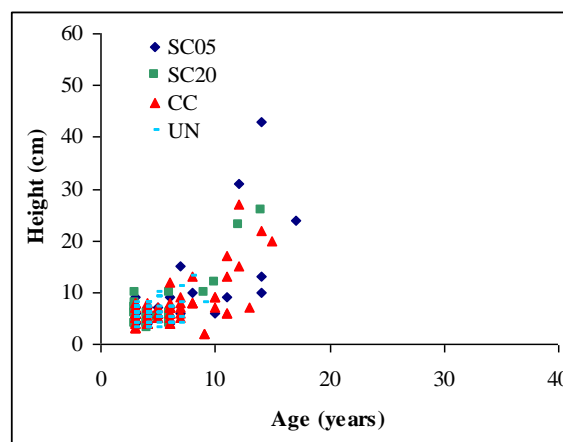
Regeneration Dynamics in Partially Cut Stands

Weaver (2007) aged $> 1,650$ red spruce, eastern hemlock, balsam fir and red maple seedlings ≤ 1.5 ft in height in 5- and 20-year selection, commercial clearcut and reference stands on the PEF. He found maximum ages of tolerant conifer seedlings in the unmanaged and selection treatments close to 40 years (< 1.5 ft tall).

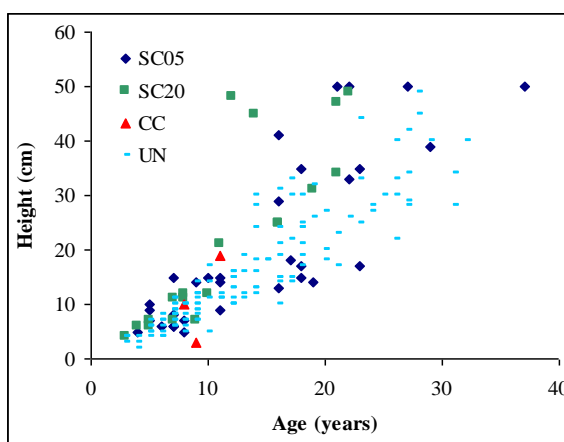
Note: metric units



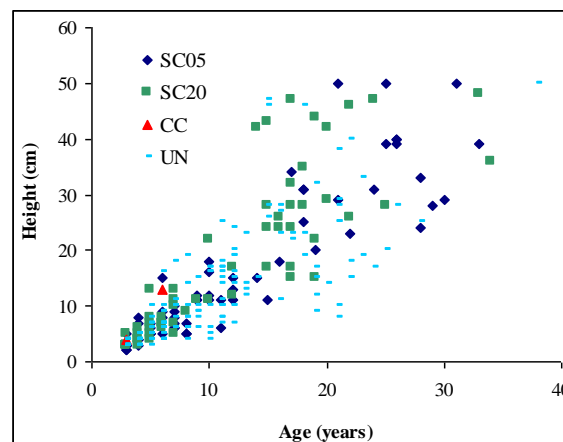
Balsam Fir



Red Maple



Red Spruce



Eastern Hemlock

Regeneration substrate

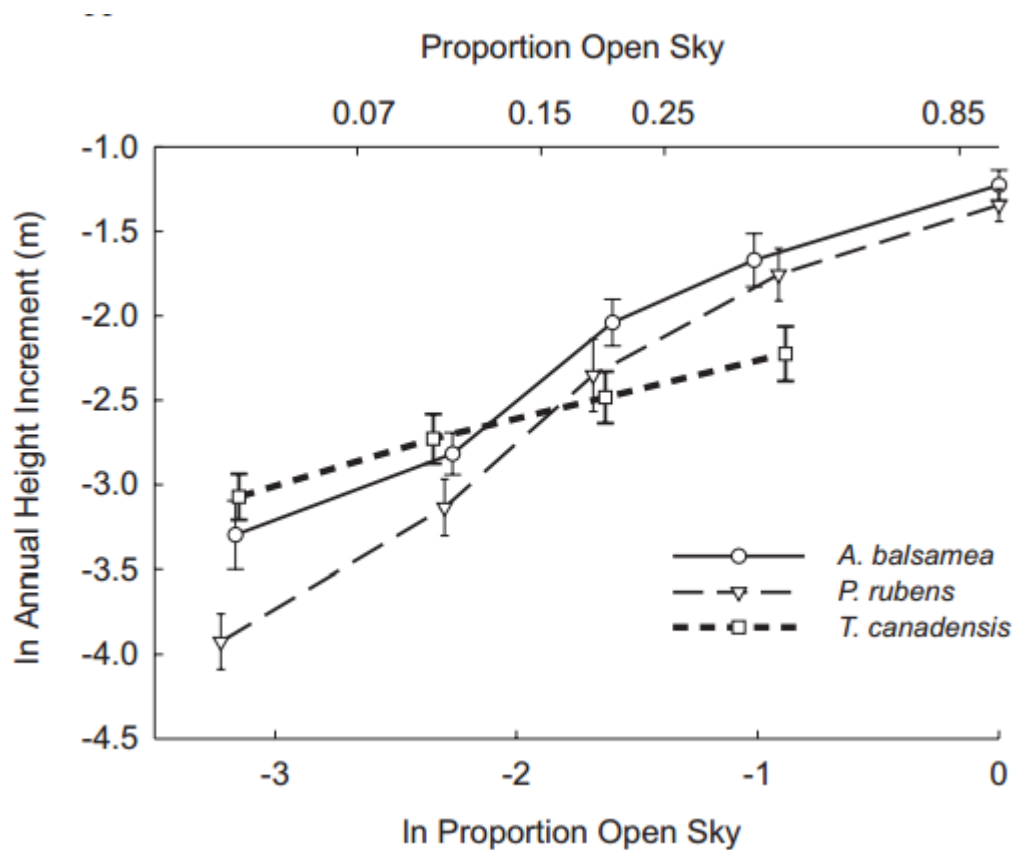
- Density of spruce and hemlock seedlings higher on decayed wood than adjacent forest floor
- Density of fir and red maple did not differ

Source: Weaver. 2007. Substrate availability and regeneration microsites of tolerant conifers in mixed-species stands in Maine. M.S. Thesis. University of Maine. 80 p.

Sapling Height Growth: Selection Stands

Moore et al. (2007) investigated the height growth rates of saplings 0.5 to 6.0 meters tall in the selection stands on the PEF. We found no level of canopy openness (overstory stocking) that conferred an advantage to spruce over its competitors.

Note: metric units



Source: Moore, A.R.; Seymour, R.S.; Kenefic, L.S. 2007. Height development of shade-tolerant conifer saplings in multiaged Acadian forest stands. *Canadian Journal of Forest Research*. 37(12): 2715-2723.



Seedling Herbivory

Browsing of seedlings < 0.5 in. DBH in the long-term U.S. Forest Service Compartment Study on the PEF, 2010

Species	Browsed		N	
	No	Yes		
Balsam Fir	1827	89	1916	4.6%
Eastern Hemlock	773	61	834	7.3%
E White Pine	41	5	46	10.9%
N White Cedar	142	46	188	24.5%
Red Spruce	243	145	388	37.4%
Black Ash	53	17	70	24.3%
Paper Birch	18	9	27	33.3%
Red Maple	2032	136	2168	6.3%
White Ash	5	20	25	80.0%
Yellow Birch	6	25	31	80.6%

Results shown for species with n > 20 seedlings.

Spruce are browsed by hare and rodents; white-cedar are browsed by deer; hemlock are browsed by deer.

Note: Maine IF&W data suggest that there are 15 to 20 deer per square mile in the region where the Penobscot Experimental Forest is located.

Source: Berven, K. 2011. U.S. Forest Service Northern Conifer Experimental Forests: Historical Review and Examples of Silvicultural Research Applications. University of Maine, School of Forest Resources. 115 p. M.S. Thesis.

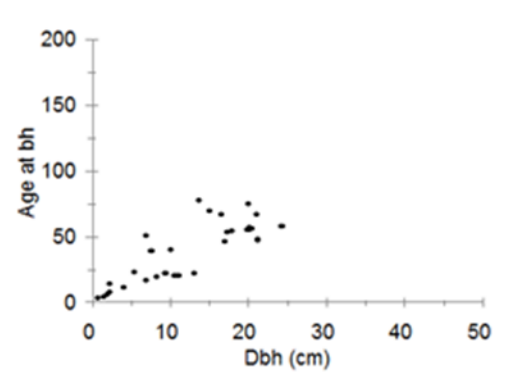
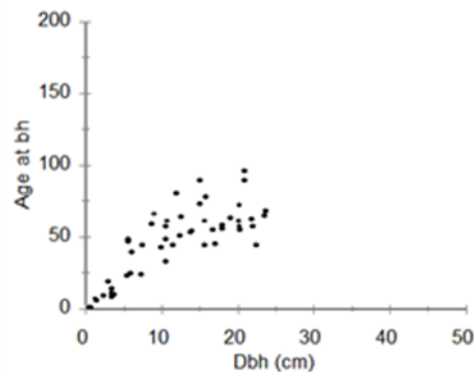


Relationships between tree size and age at breast height in the PEF selection treatments

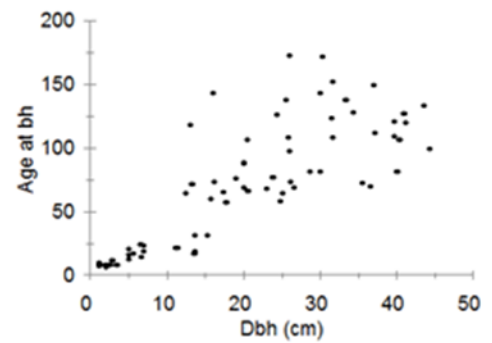
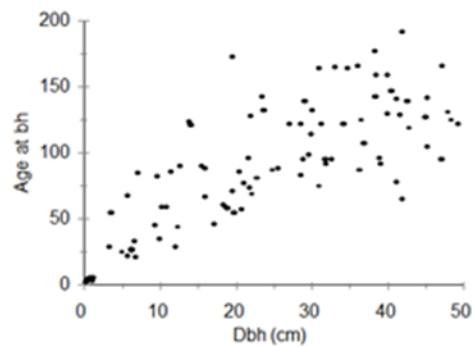
a. 5-year cutting cycle

b. 20-year cutting cycle

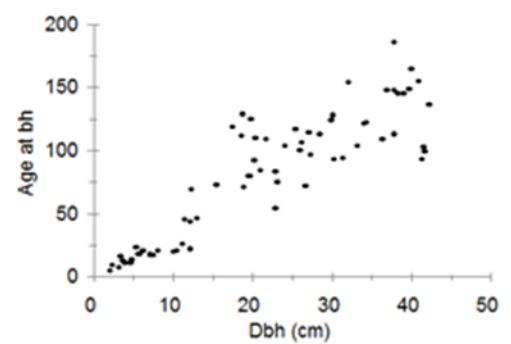
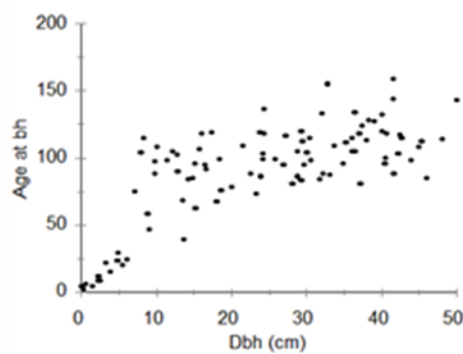
Balsam fir



Eastern hemlock



Red spruce





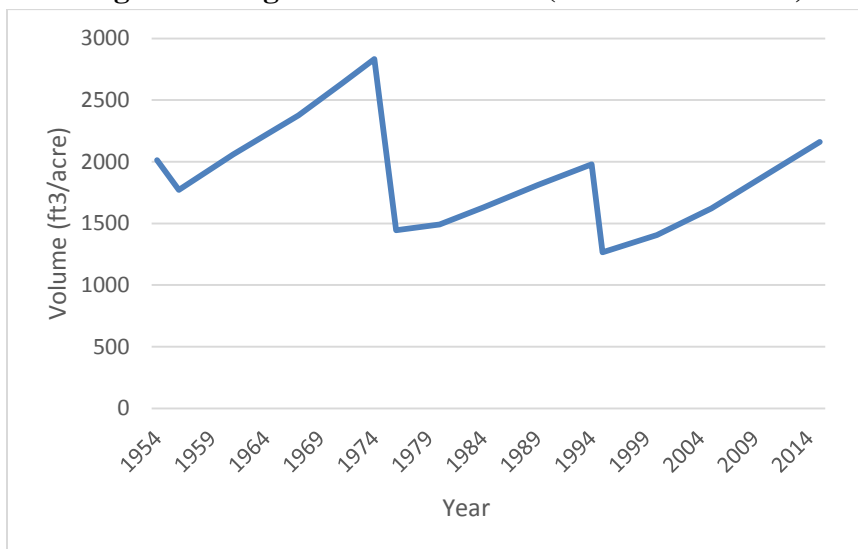
Management Unit 17 Selection Cutting, 20-Year Cycle

Acres: 26.4 (Hectares: 10.7)

Permanent Sample Plots: 14

Treatment: Single-tree selection on a 20-year cutting cycle. Residual stand composition and structure are based on species-specific and BD_q (residual BA, maximum DBH, and *q*-factor) goals. The 3rd treatment was applied in 1994. The last inventory was conducted in 2016 in preparation for treatment in the 2016-2017 harvest season.

Change in average volume over time (DClass > 4 inches)



Basal Area (2015)

Sapling BA, DBH < 4.5 inches:
42.6 ft²/ acre (9.8 m²/ha)

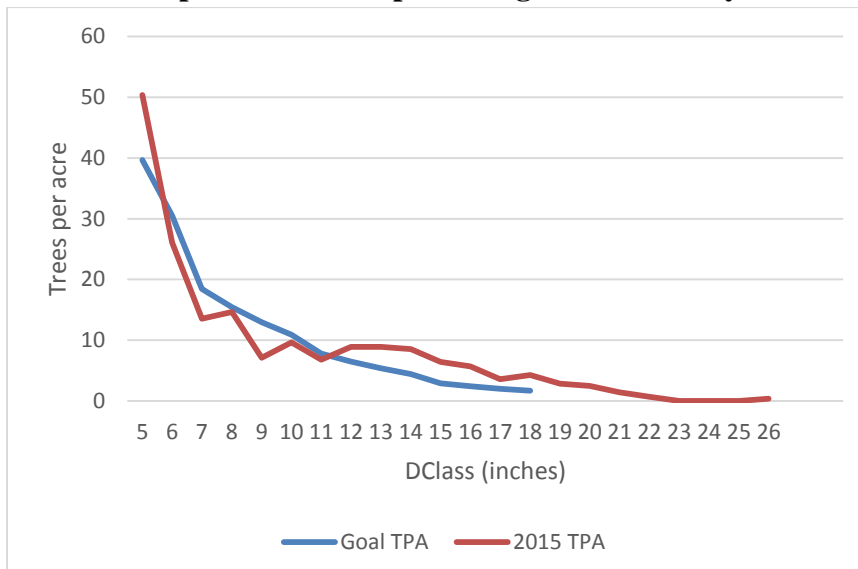
Overstory BA: (DBH ≥ 4.5 inches):
104.8 ft²/ acre (24.0 m²/ha)

Total Net Volume Growth (From 1954-2015)

40.9 ft³/acre (2.8 m³/ha)

**Average Removal
(Total Harvest/ Number of Harvests)**
781.8 ft³/acre (54.6 m³/ha)

Actual trees per acre as compared to goal set in Study Plan



Percent Cull by Volume

1954: 5.2% (± 1.0 SE)

2015: 0.14% (± 0.1% SE)

Trees per Acre (2015)

Sapling (DBH < 4.5 inches): 2358

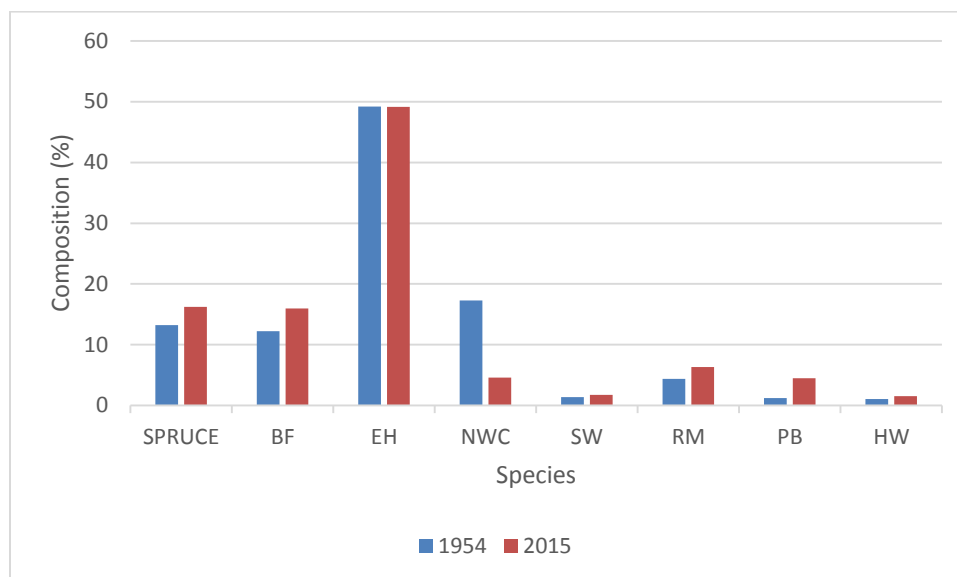
Overstory (DBH ≥ 4.5 inches): 182

Note: TPA × 0.404 = TPH; ft³/acre × 0.0699 = m³/ha.



Management Unit 17 (continued)

Species Composition by % of Total Basal Area ≥ 0.5 inches DBH



Regeneration Stocking and Density (2015)

	Spruce	BF	EH	NWC	OSW	RM	PB	OHW
Density (per acre)	357	1071	1928	262	24	167	48	214
Stocking	14%	45%	57%	7%	2%	10%	2%	5%

Note: Spruce refers to all spruce species, BF=balsam fir, EH=Eastern hemlock, NWC=Northern white cedar, RM=red maple, PB=paper birch, OHW=all other hardwoods not specified, and OSW=all other softwoods not specified.

Understory Vegetation Cover (2015)

	Woody Shrubs	Herbaceous Vegetation	Grasses, Sedges, Rushes	Ferns	Mosses & Lichens
Percent Cover (%)	<1	4.5	<1	2.2	37.5

Author: Rachel A. Knapp



Penobscot Experimental Forest – Over 60 Years of Silvicultural Research

Marking Guidelines C17, 20-year selection cutting

June 15, 2016

This treatment is prescribed per instructions in the Study Plan entitled “Silviculture Effects on Composition and Structure of Northern Conifers in the Acadian Forest Region: Revision of the Compartment Management Study on the Penobscot Experimental Forest” by J.C. Brisette and L.S. Kenefic (2008).

Section A: Basal Area, Trees ≥ 4.5 in. DBH

5. Target BA (trees ≥ 4.5 in. DBH)	70 ft ² /ac
6. Observed BA	104.8 ft ² /ac
7. Prescribed BA removal	34.8 ft ² /ac
8. Estimated Volume removal ³	6.9 cd-eq/ac

Section B: Species Composition (percent of BA ≥ 4.5 in. DBH; asterisks denote excess)

Species	Target	Observed
Spruce	40	21
B. fir	5	9*
E. hemlock	30	51**
N. white-cedar	5	6
E. white pine	5	2
Hardwoods	15	10

Given that spruce is well below the target for species composition it will not be marked for cutting unless cull, high-risk or other UGS.

Section C: Maximum DBH (in.)

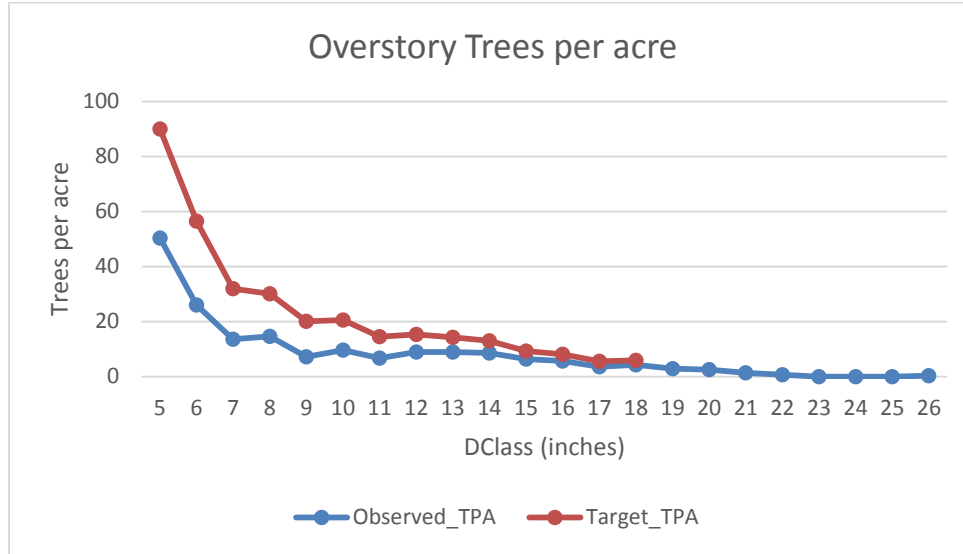
Species	Target	Observed
Spruce	18	22*
B. fir	6	12**
E. hemlock	18	22*
N. white-cedar	10	16
E. white pine	22	26*
Hardwoods	14	14

In light of a low rate of white-cedar recruitment across the PEF and our desire to retain seed trees, white-cedar will not be cut unless cull, high-risk, or other UGS.

³ BA (ft²/acre) is divided by 5 to estimate cord-equivalents.



Section D: Diameter Distributions (all species combined)



See: Section G for table of TPA by diameter class and species groups.

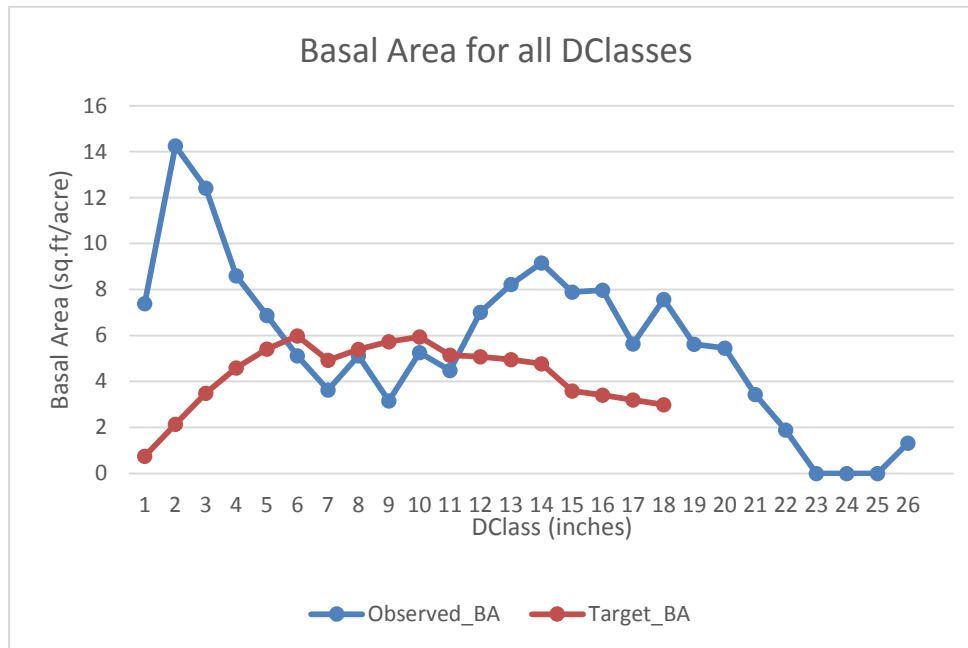
Trees per acre

Larger deficits in small poletimber (5-6 inches DBH).

Smaller deficits in larger poletimber and small sawtimber (7-11 inches DBH).

Close to target in medium to large sawtimber classes (>12 inches DBH).

Excess trees above maximum DBH.



See: Section H for table of basal area by diameter class.

Basal Area

Excess basal area in the saplings (<5 inches DBH) and medium to large sawtimber (>12 inches DBH).

Minor deficiencies in 7" DBH poletimber and 9" DBH sawtimber.

On target in 6" and 8" DBH poletimber and 10" DBH small sawtimber..

The fact that we are close to, but not yet above, our goal in the poletimber classes and that there is a surplus of saplings suggests that the target diameter distribution will be attainable in the future. Note that the preponderance of hemlock in the excess classes (See Section E next page) indicates that species composition is out of alignment with the goal.



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Section E; Species Composition (Trees per acre⁴, 0.5 – 4.5 in. DBH; asterisks denote excess)

Species	Target	Observed	
Spruce	80	137**	Eastern hemlock, spruce, balsam fir, and hardwood saplings are overstocked.
B. fir	140	634**	
E. hemlock	60	1267**	
N. white-cedar	10	6	
E. white pine	n/a	21	
Hardwoods	40	293**	

Section F: Instructions for marking:

Harvest: 34.8 ft²/ac (this is 33% of current total BA \geq 4.5 in DBH).

Priorities:

- Remove cull trees (without at least one sound 6-foot log), except northern white-cedar (retain cedar for seed and biodiversity unless competing with a crop tree). Note: < 2% of current stand BA is cull.
- Remove high-risk trees (expected to die within next 20 years) and unacceptable growing stock (UGS: trees without potential for volume and value increase).
- Control structure and composition by reducing proportion of hemlock in medium and large sawtimber classes.
- Remove trees greater than the species-specific MaxD, especially fir > 6 inches and hemlock > 18 inches.
- Release or thin potential crop trees in saplings, poles, and small sawtimber, especially spruce.

Notes:

- 1 – 2 trees > maximum diameter may be retained per management unit if of exceptional size and quality for their species.
- Dead trees (snags) and trees with active cavities or nests (wildlife trees) will not be harvested.
- When selecting trees to mark based on structure, composition, and quality goals, trees that release sapling and pole-sized spruce should be selected if other considerations are equal.
- Each field worker may leave two trees per management unit that would otherwise be marked, based on perceived non-commodity value (i.e. aesthetics, other).

Summary: Mark 34.8 ft²/ac. After cull (which should be rare), high-risk trees and UGS, priorities are to remove about half the hemlock trees 12-18 inches DBH, all hemlock trees >18 inches DBH, and all fir trees >6 inches DBH.

⁴ Rounded to the nearest 5 stems per acre, unless < 5.



Penobscot Experimental Forest – Over 60 Years of Silvicultural Research

Post-Harvest Precommercial Treatment

Per the 2008 Study Plan, mechanical (brushsaw) release of sapling crop trees (0.5 to 4.4 inches dbh) will be conducted 1-2 years post-harvest. While the study plan suggests release of spruce and hemlock, due to the overabundance of hemlock in this stand, only spruce and rare/understocked desirable species such as white-cedar, pine, and oak will be released. A minimum of 25 well-distributed spruce trees should be released per acre.

A handwritten signature in cursive script that reads "Rachel A. Knapp".

Rachel Knapp, Data Manager

A handwritten signature in cursive script that reads "Laura Kenefic".

Laura Kenefic, Research Forester

Penobscot Experimental Forest – Over 60 Years of Silvicultural Research



		EH		Spruce		BF		NWC		Hwoods		All Species (no pine)						
DBH in	Target	Observed		Target	Observed	Target	Observed	Target	Observed	Target	Observed	Target	Observed					
	1	16.07	853.57		21.43	71.43	83.69	300.00	3.56	0.00	12.70	117.86	137.45	1342.86				
	2	13.39	289.29		17.86	50.00	52.97	203.57	3.24	3.57	10.41	103.57	97.87	650.00				
	3	11.16	100.00		14.88	15.71	33.53	90.00	2.94	0.00	8.53	42.86	71.04	248.57				
	4	9.30	24.29		12.40	0.00	21.22	40.00	2.68	2.86	6.99	28.57	52.59	95.71				
	5	7.75	8.21		10.33	1.43	13.43	16.43	2.43	3.93	5.73	20.00	39.68	50.00				
	6	6.46	3.93		8.61	1.43	8.50	9.64	2.21	3.21	4.70	7.50	30.48	25.71				
	7	5.38	3.57		7.18	0.71		4.64	2.01	0.00	3.85	4.29	18.42	13.21				
	8	4.49	3.57		5.98	1.43		3.93	1.83	1.43	3.16	3.21	15.45	13.57				
	9	3.74	2.86		4.98	1.43		2.14	1.66	0.00	2.59	0.71	12.97	7.14				
	10	3.11	3.21		4.15	2.14		0.71	1.51	1.79	2.12	1.79	10.90	9.64				
	11	2.60	3.21		3.46	1.07		0.71		0.36	1.74	1.43	7.79	6.79				
	12	2.16	4.29		2.88	2.14		0.36		1.79	1.42	0.00	6.47	8.57				
	13	1.80	3.93		2.40	3.21				1.43	1.17	0.36	5.37	8.93				
	14	1.50	4.29		2.00	3.21				0.36	0.96	0.71	4.45	8.57				
	15	1.25	4.64		1.67	1.79				0.00			2.92	6.43				
	16	1.04	2.14		1.39	3.21				0.36			2.43	5.71				
	17	0.87	3.21		1.16	0.36							2.03	3.57				
	18	0.72	3.57		0.97	0.71							1.69	4.29				
	19		2.86			0.00								2.86				
	20		2.50			0.00								2.50				
	21		1.43			0.00								1.43				
	22		0.36			0.36								0.71				
		EXCESS				EXCESS		EXCESS				EXCESS				EXCESS		
Over_TOT	42.87	61.79	19	57.16	24.64	-33	21.93	38.57	17	11.65	14.64	3	27.44	40.00	13	161.05	179.64	19
Sap_TOT	49.92	1267.14	1217	66.57	137.14	71	191.41	633.57	442	12.42	6.43	-6	38.63	292.86	254	358.95	2337.14	1978

*Cells highlighted GREEN indicate excess.

**Cells outlined in RED indicate greater than MaxD.



Section H: Basal Area per acre by DClass

DClass	Target_BA	Observed_BA	
1	0.75	7.38	
2	2.14	14.26	
3	3.49	12.41	
4	4.59	8.60	
5	5.41	6.87	
6	5.98	5.12	
7	4.92	3.63	
8	5.39	5.11	
9	5.73	3.16	
10	5.94	5.26	
11	5.14	4.48	
12	5.08	7.01	
13	4.95	8.23	
14	4.77	9.16	
15	3.58	7.89	
16	3.40	7.98	
17	3.20	5.63	
18	2.99	7.57	
19		5.63	
20		5.45	
21		3.44	
22		1.89	
23		0.00	
24		0.00	
25		0.00	
26		1.32	
			EXCESS
Over_TOT	66.48	104.81	38
Sap_TOT	10.97	42.65	32

**Cells highlighted green indicate excess.



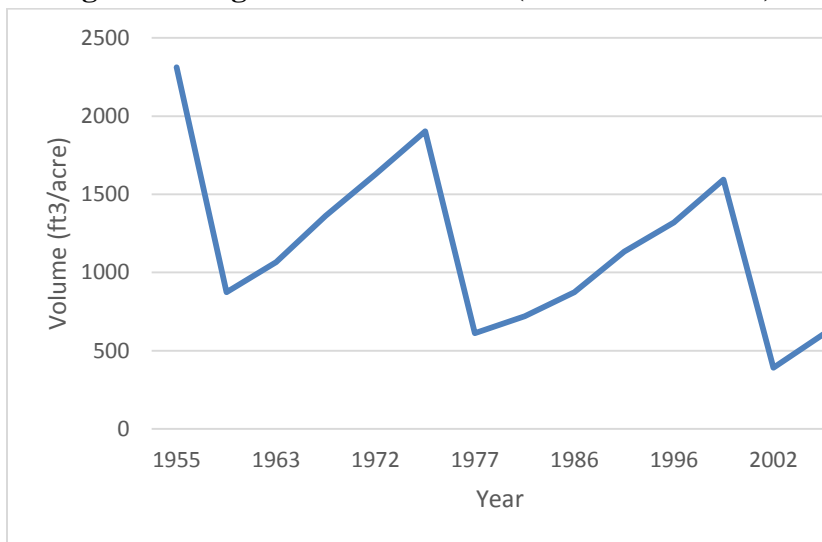
Management Unit 15 Fixed Diameter-Limit

Acres: 25.5 (Hectares: 10.3)

Permanent Sample Plots: 20

Treatment: Fixed diameter-limit cutting. All merchantable trees above species-specific limits are removed without tending. The treatment has been applied every 20 years. Diameter limits are specified for white pine (11 in. dbh), spruce and hemlock (9 in.), paper birch and white-cedar (8 in.); all merchantable trees of other species are removed. The 3rd harvest was in 2001.

Change in average volume over time (DClass > 4 inches)



Basal Area (2007)

Sapling BA, DBH < 4.5 inches:
40.2 ft²/ acre (9.2 m²/ha)

Overstory Tree BA: (DBH ≥ 4.5 inches):
37.5 ft²/ acre (8.6 m²/ha)

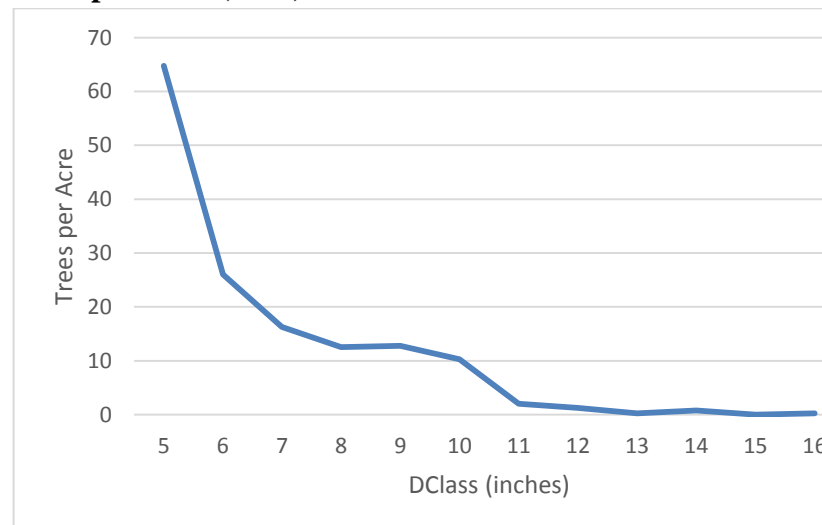
Net Volume Growth (From 1955-2007)

42.8 ft³/acre/year (3.0 m³/ha/year)

Average Removal

(Total Harvest/ Number of Harvests)
1311.4 ft³/acre (91.7 m³/ha)

Trees per Acre (2007)



Percent Cull by Volume

1955: 7.08% (± 1.6 SE)

2007: 6.90 % (± 3.4 SE)

Trees per Acre (2007)

Sapling (DBH < 4.5 inches): 2358

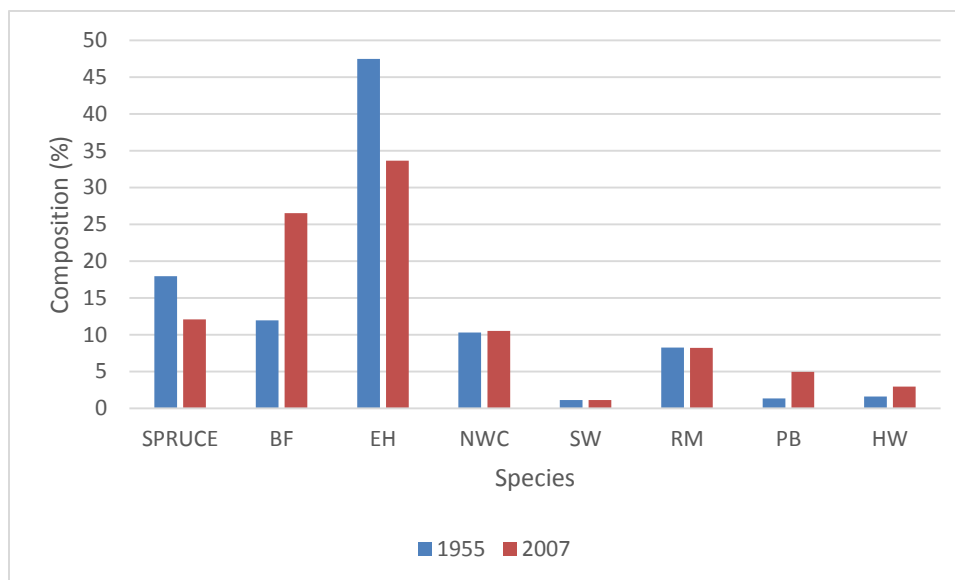
Overstory (DBH ≥ 4.5 inches): 182

Note: TPA × 0.404 = TPH; ft³/acre × 0.0699 = m³/ha.



Management Unit 15 (continued)

Species Composition by % of Total Basal Area ≥ 0.5 inches DBH



Regeneration Stocking and Density (2007)

	Spruce	BF	EH	NWC	OSW	RM	PB	OHW
Density (per acre)	100	1317	800	33	42	1100	608	633
Stocking	10%	52%	45%	3%	4%	52%	26%	23%

Note: Spruce refers to all spruce species, BF=balsam fir, EH=Eastern hemlock, NWC=Northern white cedar, RM=red maple, PB=paper birch, OHW=all other hardwoods not specified, and OSW=all other softwoods not specified.

Understory Vegetation Cover (2007)

	Woody Shrubs	Herbaceous Vegetation	Grasses, Sedges, Rushes	Ferns	Mosses & Lichens
Percent Cover (%)	19.8	29.7	6.8	10.0	32.9

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COMPARISON OF FIXED DIAMETER-LIMIT AND SELECTION TREATMENTS

Fixed diameter-limit and selection cutting were both applied at 20-year intervals, facilitating long-term comparison (Kenefic et al. 2005). There were no differences in volume, density, structure, composition or quality prior to treatment ($\alpha = 0.10$). Harvest volume and mortality were not differentiated by treatment over 40 years. Significant differences were found after three treatments in harvest value, residual value, structure, growth, and quality.

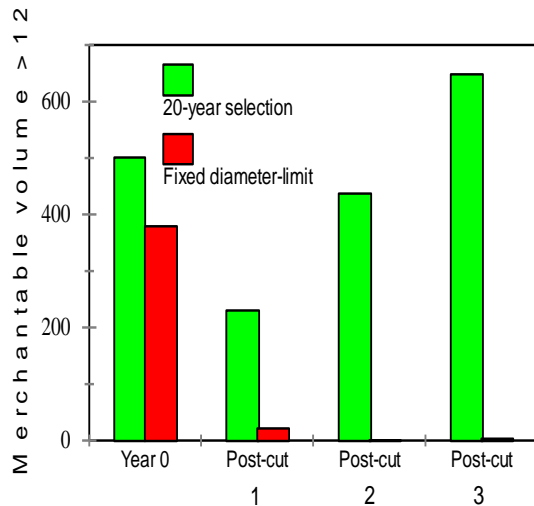


Figure 1. Merchantable medium – large sawtimber volume in the selection and fixed diameter-limit after three treatments ($p < 0.01$).

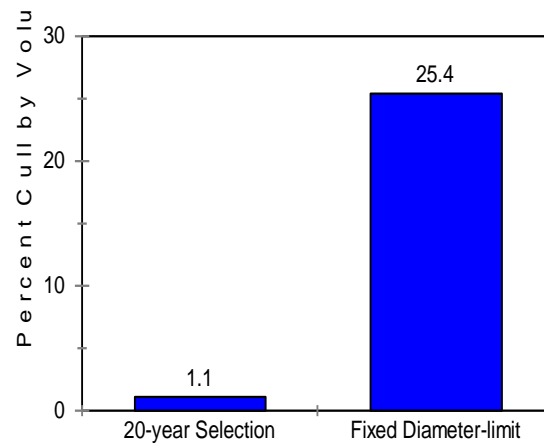


Figure 2. Percentage of unmerchantable timber in the selection and fixed diameter-limit after three treatments ($p < 0.01$).



Growth and Financial Analysis from the Cutting Practice Level Study

Standing merchantable volume (ft³/ac) and volume growth, mortality, and harvest (ft³/ac/year) by treatment for selection cutting and diameter-limit on a 15-year interval, 1950 to 2010.

Treatment	Volume	Volume	Gross	Net growth	Mortality	Harvest
	1950	2010	growth			
	(ft ³ /ac)	...	(ft ³ /ac/year)
SC15	1,825	2,022	72.4	63.9	8.6	60.6
FDL	1,994	473	60.0	48.4	11.6	73.9

Real value and harvest revenue by treatment expressed in constant dollars (2011=100).

Treatment	Stand value	Stand value	Harvest	Cumulative value	Discounted
	year 0	year 60	revenue	(harvest+ year 60)	cumulative
	(\$/ac)	value (2%)
SC15	1,008	648	2,024	2,672	1,389
FDL	1,769	65	2,272	2,336	1,714

Rogers, N.S. *et al.* In press. Sixty Years of Silviculture in a Northern Conifer Forest in Maine, USA. For. Sci.