Forest Climate Change in Maine

Spruce-Fir

Penobscot Experimental Forest

FIELD TOUR

October 29, 2021

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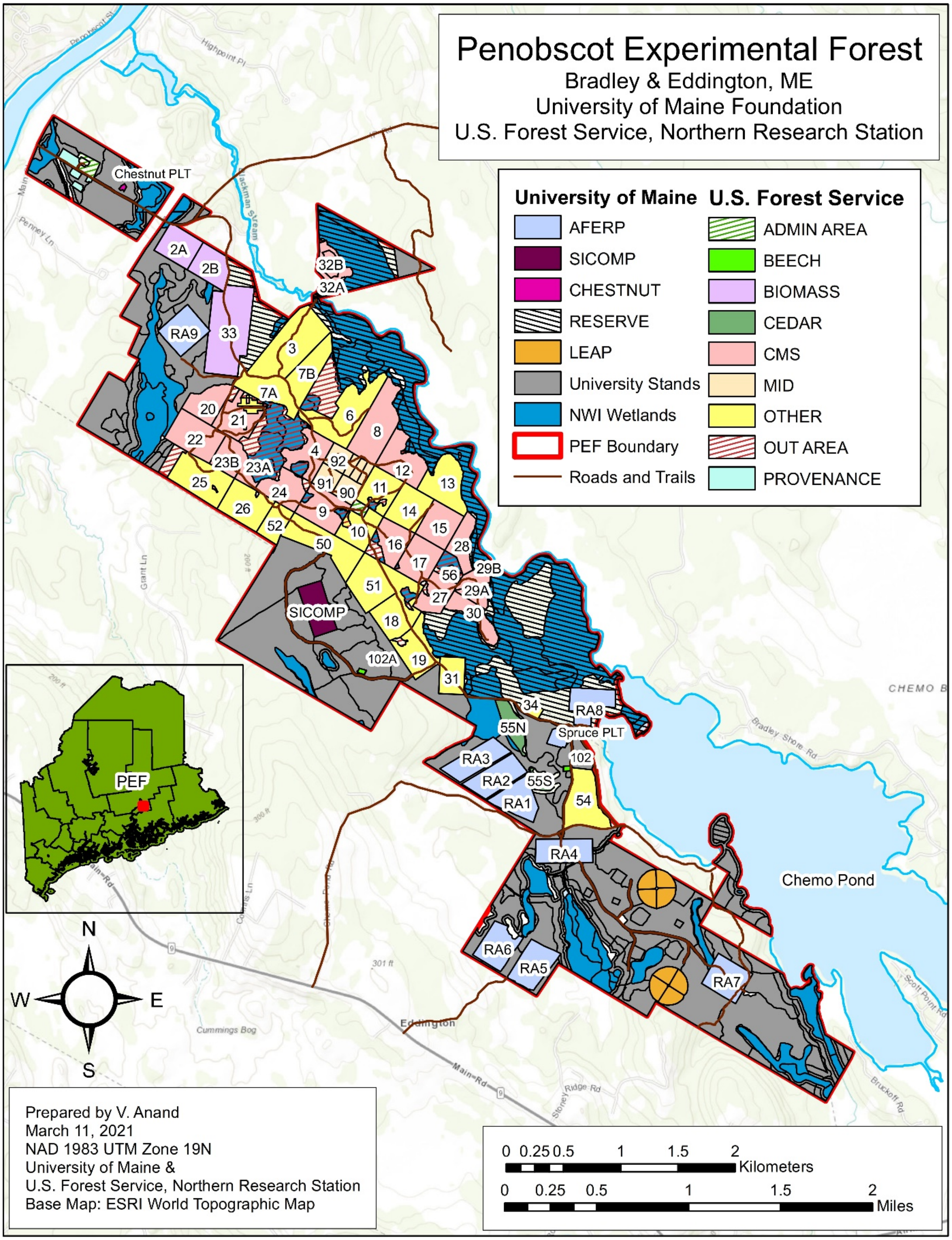

Penobscot Experimental Forest
Bradley & Eddington, ME
University of Maine Foundation
U.S. Forest Service, Northern Research Station
University of Maine
AFERP
SICOMP
CHESTNUT
RESERVE
LEAP
University Stands
NWI Wetlands
PEF Boundary
Roads and Trails
U.S. Forest Service
ADMIN AREA
BEECH
BIOMASS
CEDAR
CMS
MID
OTHER
OUT AREA
PROVENANCE
Chestnut PLT
Spruce PLT
SICOMP
Chemo Pond
PEF
N
W
E
S
Prepared by V. Anand
March 11, 2021
NAD 1983 UTM Zone 19N
University of Maine &
U.S. Forest Service, Northern Research Station
Base Map: ESRI World Topographic Map
0 0.25 0.5 1 1.5 2 Kilometers
0 0.25 0.5 1 1.5 2 Miles

INTRODUCTION TO THE PEF

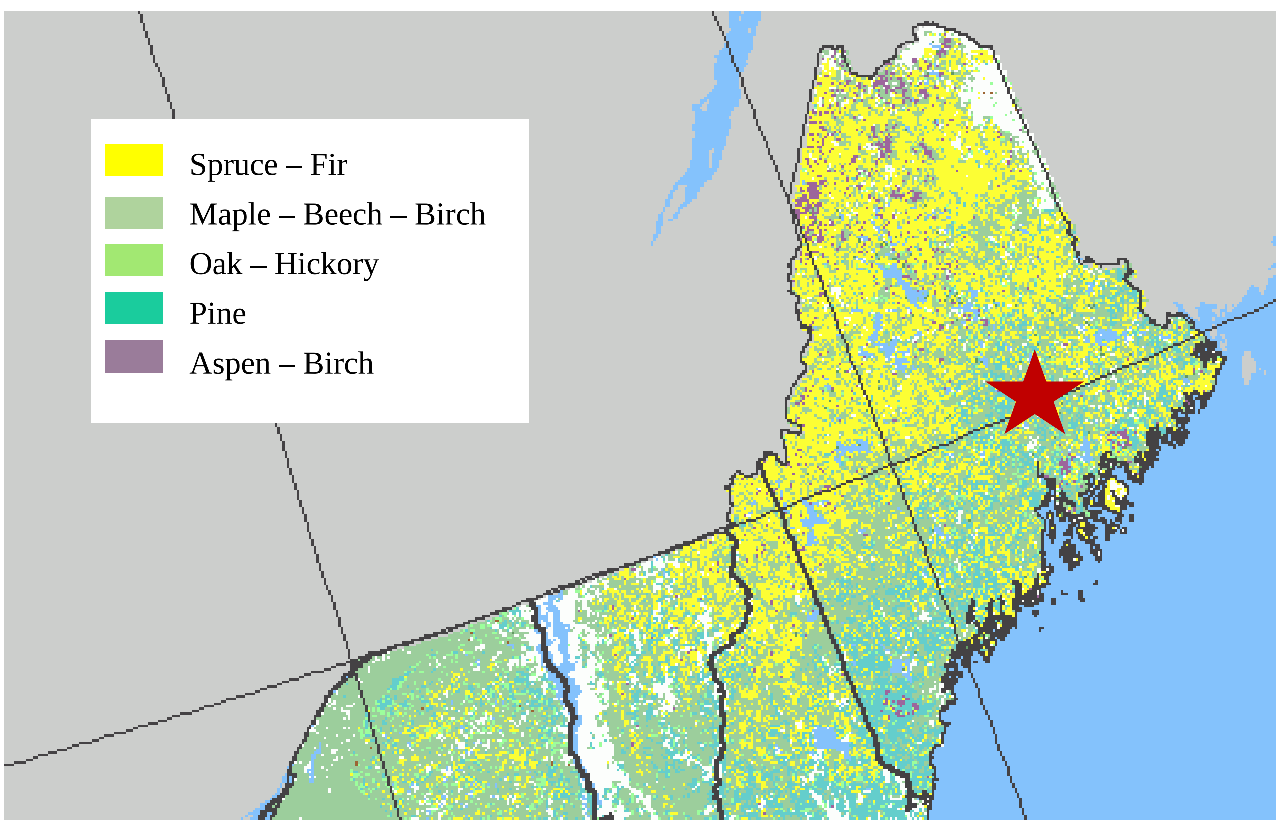
Background

Though most people know the U.S. Forest Service for its management of national forests, the agency also has a Research and Development (R&D) branch. One of R&D's most valuable assets is its network of more than 80 experimental forests and ranges nationwide. These are places designated by the Chief of the Forest Service for long-term ecology and management research in different forest types. Though most are on national forests, the Penobscot Experimental Forest in Maine is on private land.

Land for the Penobscot Experimental Forest (PEF) was purchased in 1950 by nine pulp and paper and land-holding companies and leased to the Forest Service for spruce-fir research. In 1994, the owners donated the land to the University of Maine Foundation. The University and Forest Service jointly manage the PEF, with the Forest Service retaining control of 1,000 acres of long-term studies.

When the PEF was donated to the University of Maine Foundation, the industrial owners stated

> "The mission of the PEF is to afford a setting for long-term research conducted cooperatively among USDA Forest Service scientists, university researchers and professional forest managers in Maine; to enhance forestry education of students and the public; and to demonstrate how the timber needs of society are met from a working forest."



Forest Characteristics

The PEF is in the Acadian Forest, 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 infrequent, but insect epidemics (e.g., spruce budworm) and windstorms cause sporadic mortality.

The climate is cool and humid. Soils are complex and variable because of glacial influences and composed of till, lacustrine, and marine sediments. Drainage varies from well- to very poorly drained stony, sandy, silt, and silty clay loams.

The Acadian Forest is compositionally diverse. The canopy is dominated by conifers, including spruce (mostly red but some white and black), fir, hemlock, 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, with yellow birch, American beech, sugar maple, and northern red oak on better sites.

Climate Change

Predicted change in suitable habitat in year 2100 for common PEF tree species in the Penobscot HUC6 Watershed under two scenarios: RCP4.5 (low emissions) and RCP8.5 (high emissions).

	Climate Change Tree Atlas Penobscot HUC6 Watershed		
	RCP4.5	RCP8.5	Species Adaptability
Balsam fir	4	4	Low
Red spruce	4	4	Low
White spruce	2	2	Medium
Eastern hemlock	2	3	Low
Northern white-cedar	4	4	Medium
White pine	2	2	Low
Red maple	2	2	High
Sugar maple	2	2	High
Paper birch	3	3	Medium
Yellow birch	4	4	Medium
American beech	3	3	Medium
Bigtooth aspen	1	1	Medium
Quaking aspen	1	1	Medium
Northern red oak	1	1	High

Suitable Habitat Change

1	Large Increase
2	Small Increase
3	No Change
4	Small decrease
5	Large decrease

Adaptability Rating:

Adaptability is derived from disturbance and biological factors.

Adpatability

1	Low
2	Medium
3	High

Compiled by Varun Anand from Peters, M.P., Prasad, A.M., Matthews, S.N., & Iverson, L.R. 2020. Climate change tree atlas, Version 4. U.S. Forest Service, Northern Research Station and Northern Institute of Applied Climate Science, Delaware, OH. https://www.nrs.fs.fed.us/atlas

LONG-TERM RESEARCH

Silvicultural Effects on Composition, Structure and Growth, 1952-present

The largest study on the PEF is called the Compartment Management Study. It includes two replicates each of 10 treatments applied to stands (management units, MUs) averaging 20 acres in size.

Even-aged:

- Commercial Clearcut (CC)
- Uniform 2-Stage Shelterwood (SW2)
    - with commercial thinning
- Uniform 3-Stage Shelterwood
    - with precommercial thinning ($SW3_P$)
    - without precommercial thinning (SW3)
        - with commercial thinning
        - without commercial thinning

Uneven-aged:

- Selection, 5-year cutting cycle (S05)
- Selection, 10-year cutting cycle (S10)
- Selection, 20-year cutting cycle (S20)

Diameter-limit cutting:

- Fixed Diameter Limit (FDL)
- Modified Diameter Limit (MDL, also called Guiding Diameter Limit)

Reference:

- No management (REF)

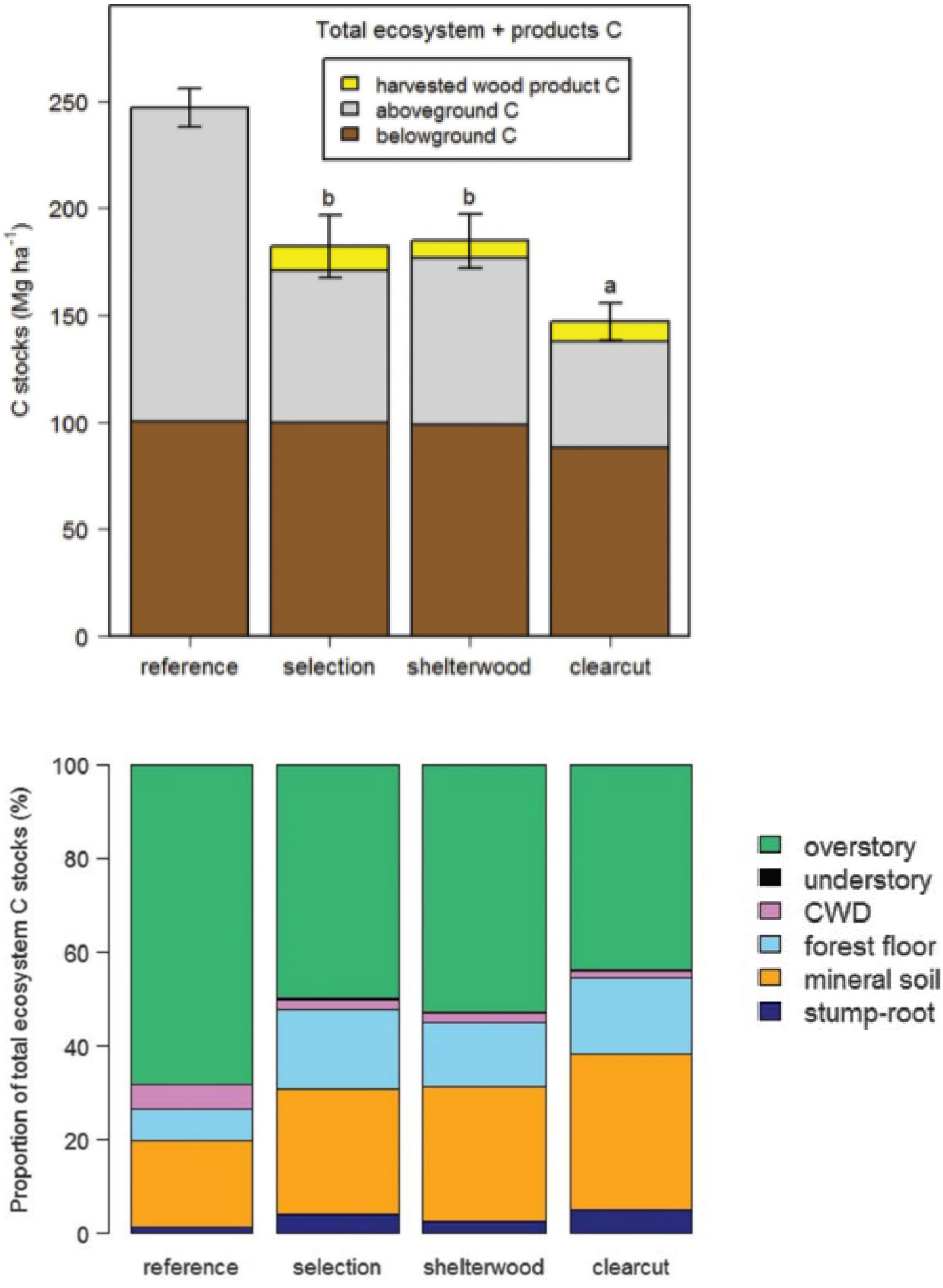
Other important Forest Service studies on the PEF include:

- Cutting Practice Level Study, 1950-present
- Biomass Harvesting and Prescribed Burning, 1964-present
- Precommercial and Commercial Thinning, 1976-present
- Beech Bark Disease Monitoring, 1979-present
- Rehabilitation of Cutover Stands, 2007-present
- Lowland White-Cedar Management, 2016-present

The Forest Service also maintains a Smart Forest (streaming meteorological data station) at the PEF.

For more information, see https://www.nrs.fs.fed.us/ef/locations/me/penobscot/

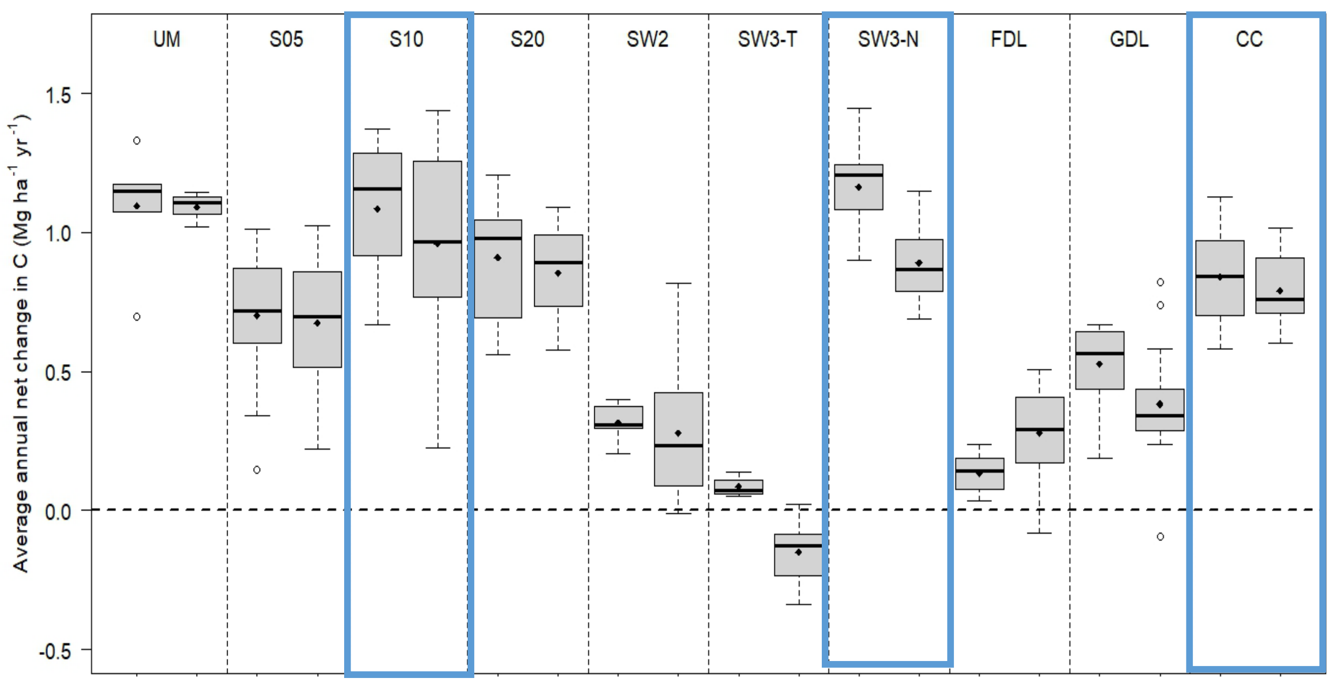
CARBON OUTCOMES: STOCKS



Puhlick et al. (2016) [*https://www.fs.usda.gov/treesearch/pubs/54052*](https://www.fs.usda.gov/treesearch/pubs/54052)

CARBON OUTCOMES: SEQUESTRATION

100 YEARS



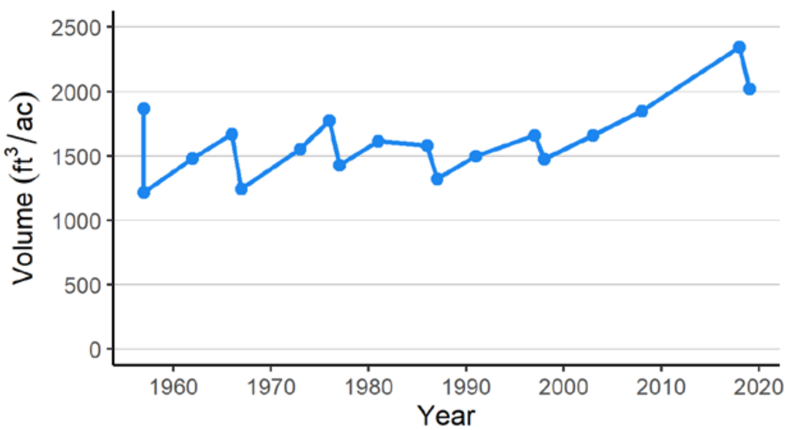
Puhlick et al. (2020) *https://www.fs.usda.gov/treesearch/pubs/62735*

Tour Stop 1
Management Unit 20
Selection Cutting, 10-Year Cycle

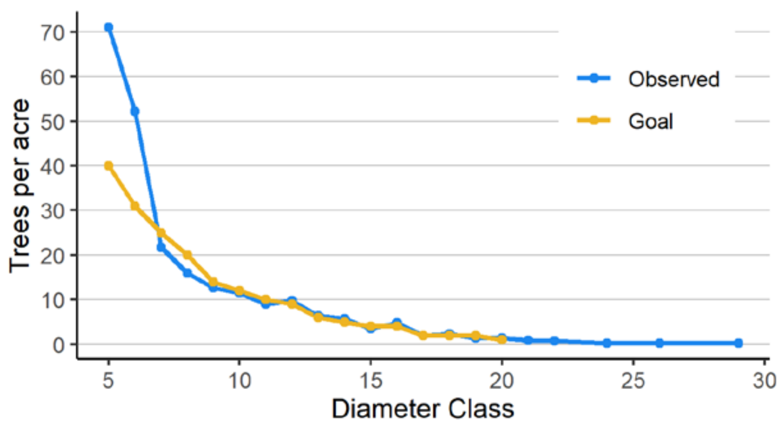
Acres: 21.8 (Hectares: 8.8)
Permanent Sample Plots: 21

Treatment: Single-tree selection system on a 10-year cutting cycle. Residual stand composition and structure are based on species and BD*q* (residual BA, maximum DBH, and *q*-factor) goals. The 6th treatment was skipped; the 7th treatment was in the winter of 2018/19.

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



Trees per acre (2019) as compared to goal in Study Plan



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

Basal Area (2019)
Sapling BA, DBH < 4.5 inches:
35.1 ft^2/ acre (8.1 m^2/ha)

Overstory BA, DBH ≥4.5 inches:
99.8 ft^2/ acre (22.9 m^2/ha)

Total Net Volume Growth (From 1957-2019)
38.3 ft^3/acre/year (2.7 m^3/ha/year)
0.5 cds/acre/year

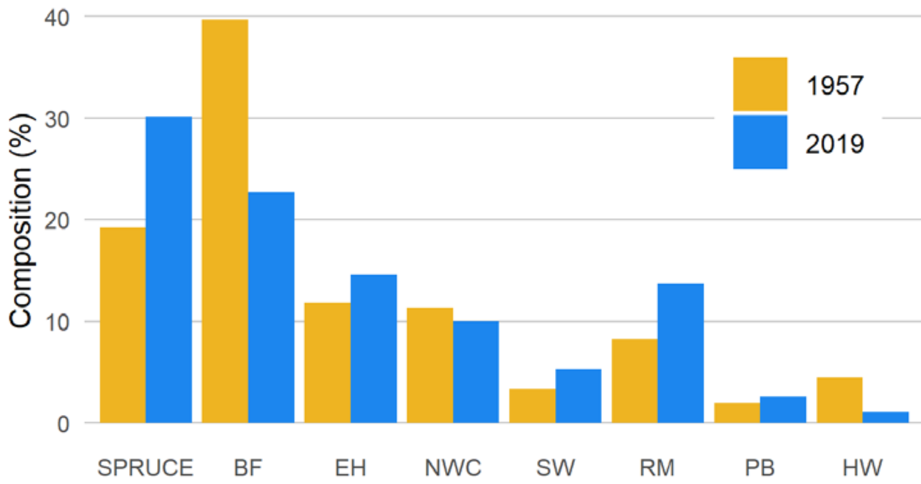
Average Removal (Total Harvest/ Number of Harvests)
317.1 ft^3/acre (22.2 m^3/ha)
3.7 cds/acre

Percent Cull by Volume
1957: 6.4% (± 1.0 SE)
2019: 0.4% (± 0.3% SE)

Trees per Acre (2019)
Sapling total**,** DBH < 4.5 inches: 1666
Overstory total, DBH ≥4.5 inches: 234

MU20 (continued)

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



Regeneration Stocking and Density (2019)

	Spruce	BF	EH	NWC	OSW	RM	PB	OHW
Density (per acre)	198	421	16	32	0	270	24	0
Stocking	9%	23%	2%	3%	0%	5%	2%	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 (2019)

	Woody Shrubs	Herbaceous Vegetation	Grasses, Sedges, Rushes	Ferns	Mosses & Lichens
Percent Cover (%)	0.2	3.7	0.6	0.6	25.0

Tour Stop 1 (continued)

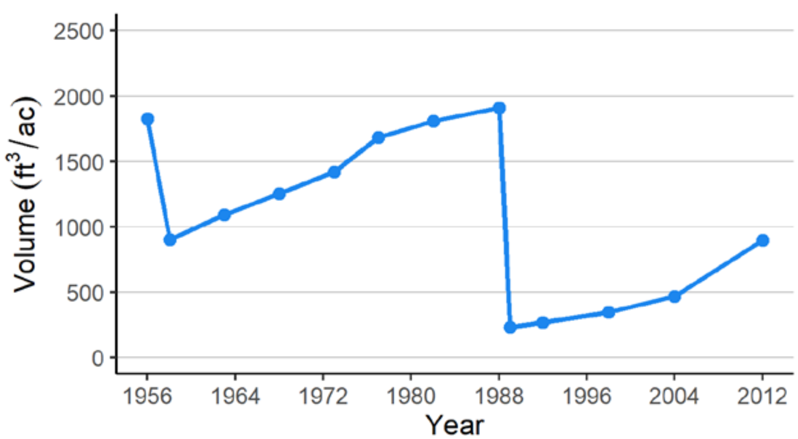
Management Unit 22
Commercial Clearcut

Acres: 33.5 Hectares: 13.6

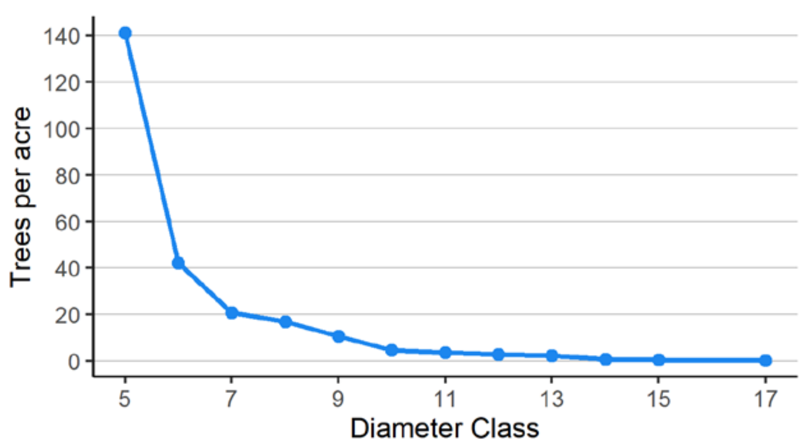
Permanent Sample Plots: 16

Treatment: Commercial clearcut, previously called unregulated harvest or logger's choice. The first harvest was in 1957 and the second was in 1988. A commercial clearcut removes all merchantable stems, without tending or attention to regeneration. It is not a silvicultural clearcut.

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



Trees per acre (2014)



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

Basal Area (2014)

Sapling BA, DBH < 4.5 inches:
77.3 ft^2/acre (17.7 m^2/ha)

Overstory BA, DBH ≥4.5 inches:
55.5 ft^2/acre (12.7 m^2/ha)

Net Volume Growth
From 1956-2013

29.9 ft^3/acre/year (2.1 m^3/ha/year)
0.4 cds/acre/year

Average Removal
(Total Harvest/Number of Harvests)

1303.1 ft^3/acre (91.1 m^3/ha)
15.3 cds/acre

Percent Cull by Volume

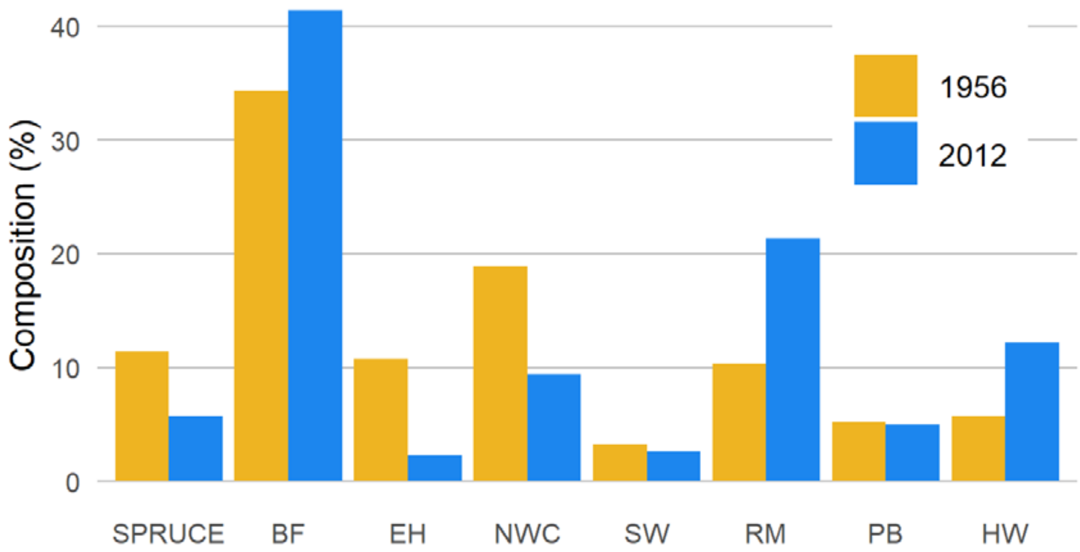
1956: 9.2% (±1.6 SE)
2013: 2.9% (±1.2 SE)

Trees per Acre (2014)

Sapling total, DBH < 4.5 inches: 2904
Overstory total, DBH ≥4.5 inches: 247

MU22 (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)	63	2771	42	125	0	369	63	563
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

MU22 (continued)

Rehabilitation Silviculture

Treatments (2008)

<u>Moderate rehabilitation</u>

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

<u>Intensive rehabilitation</u>

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

Results

Percent cull

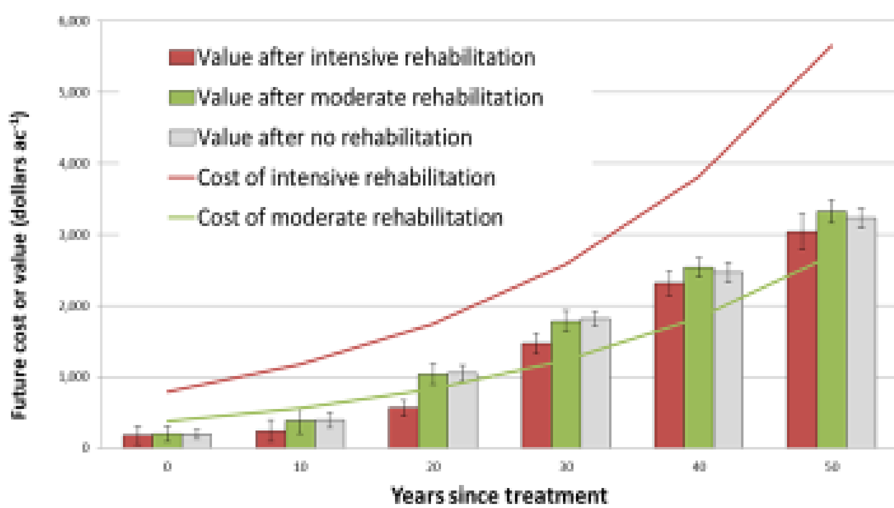
- Pre-treatment stand average 20%
- Post-treatment
  - Moderate: 1%
  - Intensive: 0%

Planting

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

Cost of labor:

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



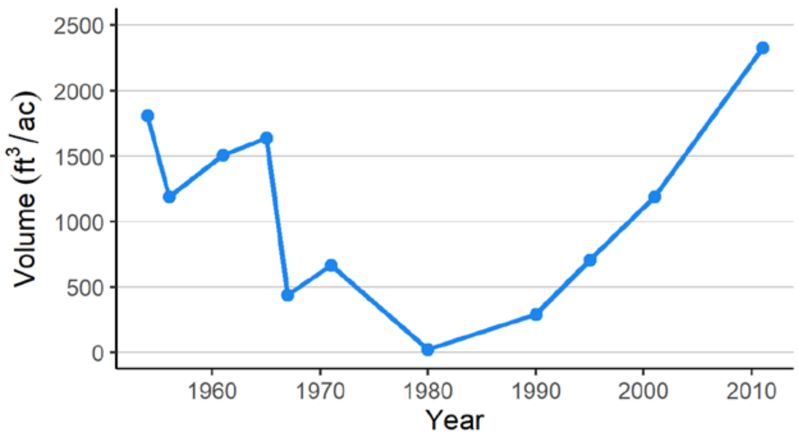
Kenefic, Laura S.; Bataineh, Mohammad; Wilson, Jeremy S.; Brissette, John C.; Nyland, Ralph D. 2014. Silvicultural rehabilitation of cutover mixedwood stands. Journal of Forestry. 112(3): 261-271.

Tour Stop 2
Management Unit 23B
Uniform Shelterwood System

Acres: 12.4 Hectares: 5.0
Permanent Sample Plots: 9

Treatment: Uniform shelterwood system with three-stage overstory removal. The final overstory removal occurred in 1971. All residuals trees >2 in dbh were removed. No intermediate treatments were conducted.

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

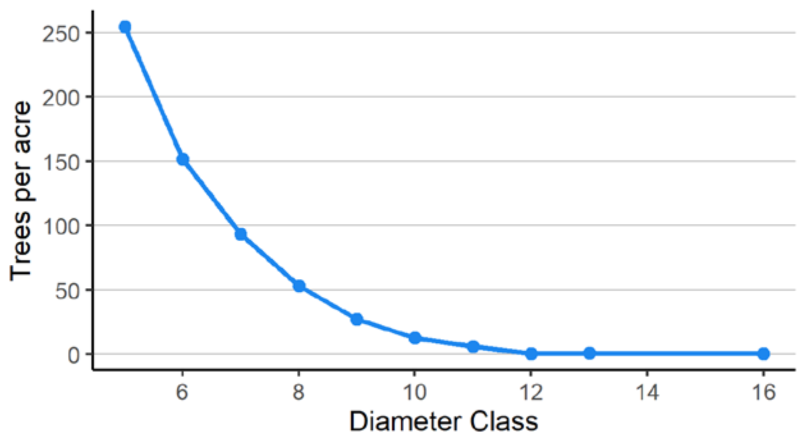


Basal Area (2011)
Sapling BA**,** DBH < 4.5 inches:
88.4 ft^2/acre (20.3 m^2/ha)

Overstory BA, DBH ≥ 4.5 inches:
133.3 ft^2/acre (30.6 m^2/ha)

Total Net Volume Growth (From 1954-2011)
52.2 ft^3/acre/year (3.7 m^3/ha/year)
0.6 cds/acre/year

Trees per acre (2011)



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

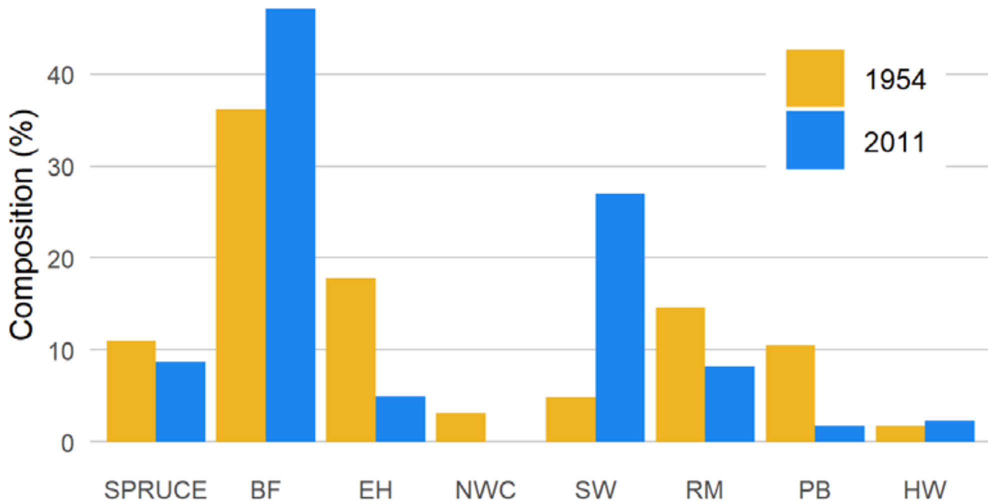
Average Removal (Total Harvest/Number of Harvests)
820.2 ft^3/acre (57.3 m^3/ha)
10 cds/acre

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

MU23B (continued)

Species Composition by % of Total Basal Area ≥ 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)

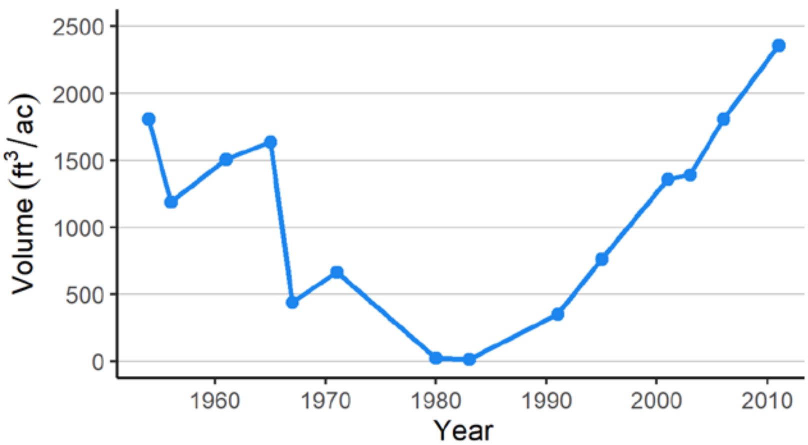
	Woody Shrubs	Herbaceous Vegetation	Grasses, Sedges, Rushes	Ferns	Mosses & Lichens
Percent Cover (%)	0	0.3	0	0	14.8

Tour Stop 2 (continued)
Management Unit 23A
Uniform Shelterwood System with Precommercial Thinning

Acres: 11.6 Hectares: 4.7
Permanent Sample Plots: 5

Treatment: Uniform shelterwood system with three-stage overstory removal. The final overstory removal occurred in 1971. All residuals trees >2 in dbh were removed. Manual PCT to a residual spacing of 2 x 3 m was applied in 1981; volunteer growth occurred between crop trees. In 2001 this MU was incorporated into the CFRU Commercial Thinning Research Network.

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

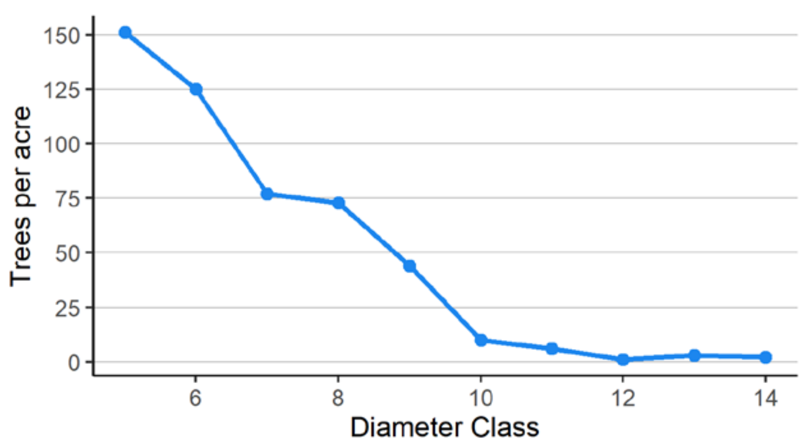


Basal Area (2011)
Sapling BA**,** DBH < 4.5 inches:
49.6 ft^2/acre (11.4 m^2/ha)

Overstory BA, DBH ≥ 4.5 inches:
125.7 ft^2/acre (28.9 m^2/ha)

Total Net Volume Growth (From 1954-2011)
53.0 ft^3/acre/year (3.7 m^3/ha/year)
0.6 cds/acre/year

Trees per acre (2011)



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

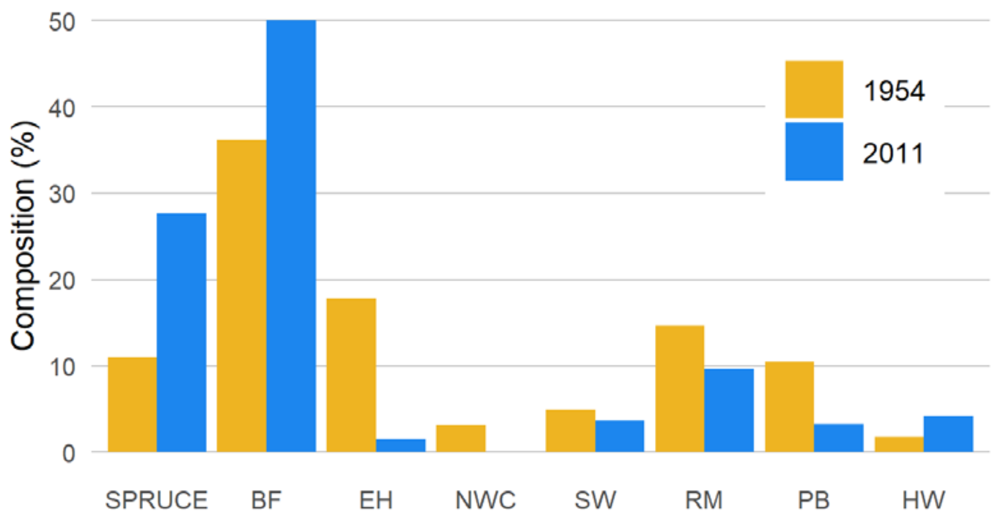
Average Removal (Total Harvest/Number of Harvests)
820.2 ft^3/acre (57.4 m^3/ha)
9.6 cds/acre

Percent Cull by Volume
1954: 4.7% (± 1.2 SE)
2011: 0%

Trees per Acre (2011)
Sapling total**,** DBH < 4.5 inches: 1958
Overstory total, DBH ≥4.5 inches: 492

MU23A (continued)

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



Regeneration Stocking and Density (2011)

	Spruce	BF	EH	NWC	OSW	RM	PB	OHW
Density (per acre)	67	1,700	167	0	0	400	0	0
Stocking	7%	27%	17%	0%	0%	10%	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 (%)	0.6	1.9	0.3	0.3	20.1

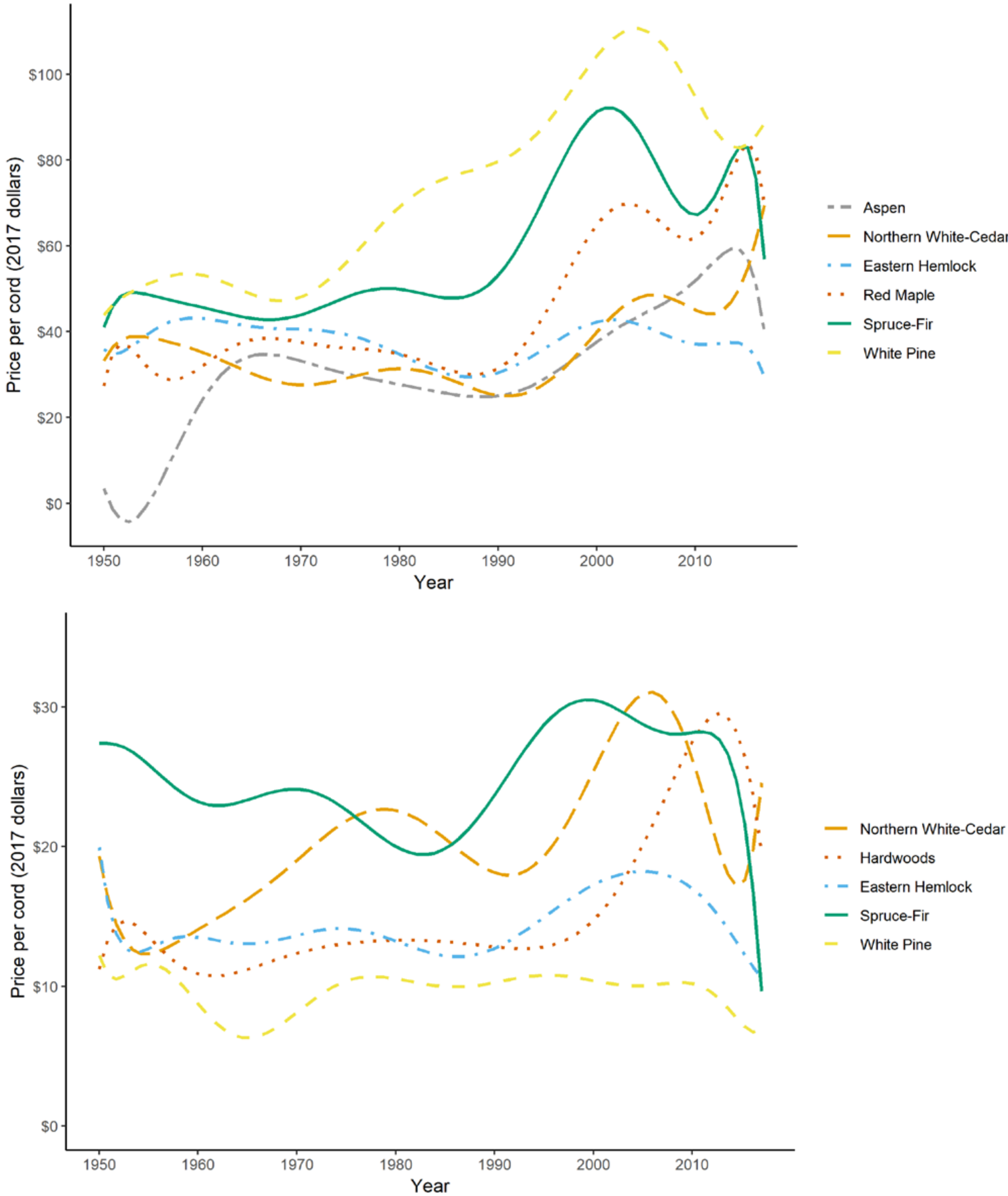
VALUES

Average value of all harvests and trees at most recent inventory (per acre in constant 2017 dollars, using stumpage prices from year in which harvest or inventory took place). Costs of marking and precommercial thinning were deducted.

Treatment	Value of harvested trees over 65 years ($/acre)	Value of standing trees after 65 years ($/acre)	Sum of harvested and standing tree values after 65 years ($/acre)
S05	$1,193	$1,296	$2,489
S10	$856	$1,182	$2,038
S20	$1,165	$743	$1,908
SW2	$1,213	$414	$1,627
SW3	$892	$673	$1,565
SW3p	$474	$768	$1,242
FDL	$1,155	$381	$1,536
CC	$810	$355	$1,165

Granstrom, M., Kenefic, L.S., Crandall, M., Stockwell, S., Giffen, A. In press. Managing your woodland: forestry research translated for landowners. General Technical Report. U.S. Forest Service, Northern Research Station. St. Paul, MN.

Stumpage prices for sawtimber (top) and pulpwood (bottom) from 1950 to 2017



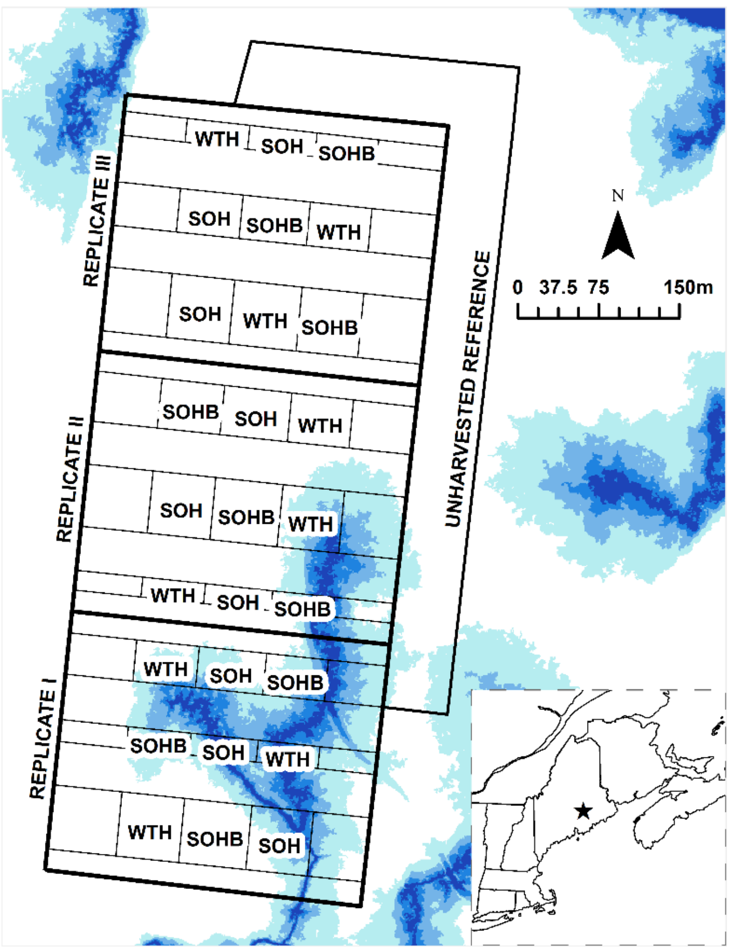
Records are from UNH extension (1950-1958) and Maine Forest Service (1959-2017)

Tour Stop 3
Management Unit 33
Strip Clearcut (1-, 2- and 3-chain)

Bethany Muñoz Delgado
Acres: 65.2 (Hectares: 26.4)

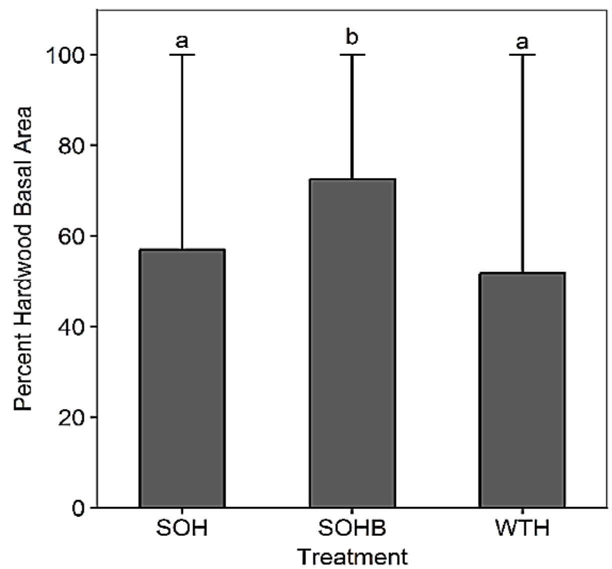
Treatment: Strip clearcut and prescribed burn conducted in 1964, and repeated in 2018. **Whole-tree Harvesting** (Slash Removed; WTH), **Stem-only Harvesting** (Slash Left; SOH), and **Stem-only Harvesting with Prescribed Burning** (Slash Burned; SOHB). In both harvests, all trees ≥ 4.5 ft in height were felled.

Operations:



Harvested in 1964 using a chain saw and John Deere Model 420 crawler-type tractor skidder

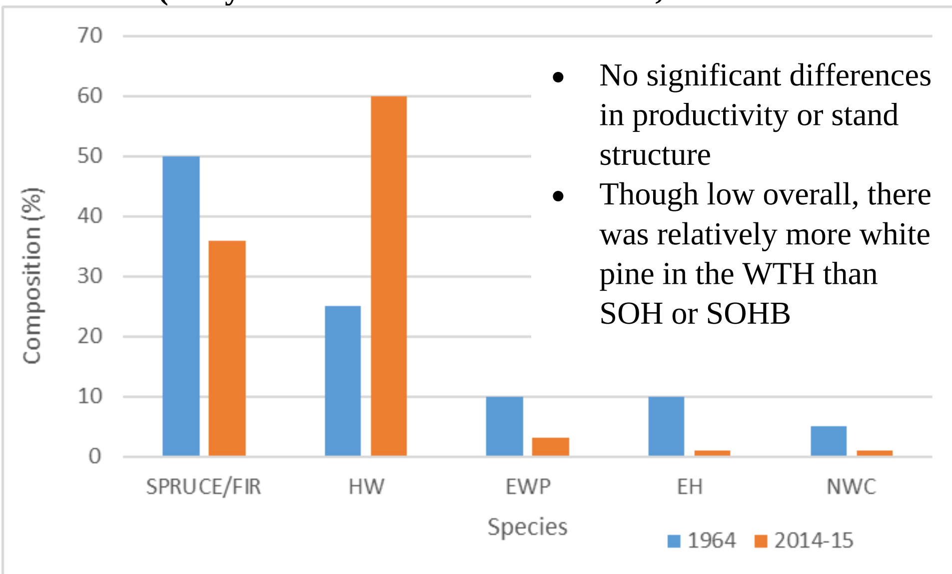
Harvested in 2018 using a feller-buncher, grapple skidder, and in-woods stroke de-limber



Percent Hardwood BA 50 years after the first harvest

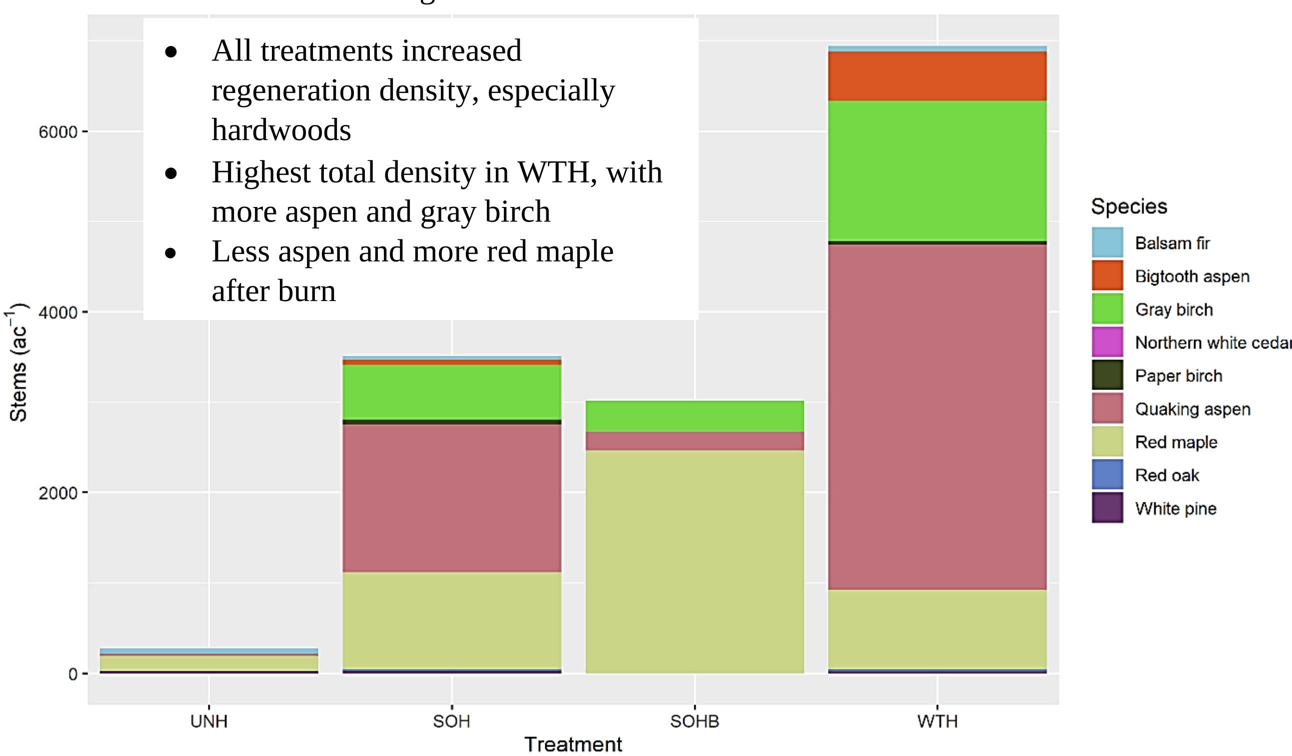
Management Unit 33 (continued)

Tree Species Composition (% Basal Area ≥ 0.5 inches DBH)
1964 and 2014 (~50 years after 1st harvest and burn, all treatments combined)



- No significant differences in productivity or stand structure
- Though low overall, there was relatively more white pine in the WTH than SOH or SOHB

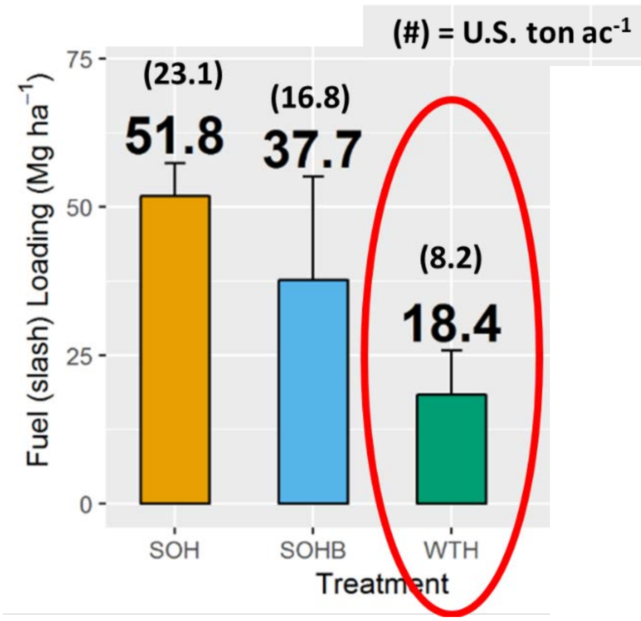
Regeneration Species Composition (Stem Density)
2019 (1-2 years after 2nd harvest and burn, by treatment)
Note: regeneration is 6 inches tall to 0.5 inches DBH



- All treatments increased regeneration density, especially hardwoods
- Highest total density in WTH, with more aspen and gray birch
- Less aspen and more red maple after burn

MU33 (continued)

Fuel Loading 2018 (after 2nd harvest and burn)



- Fuel biomass and height lowest in WTH
- Difference between SOH and SOHB was in small size classes
- Difference between SOHB and WTH was in large size classes

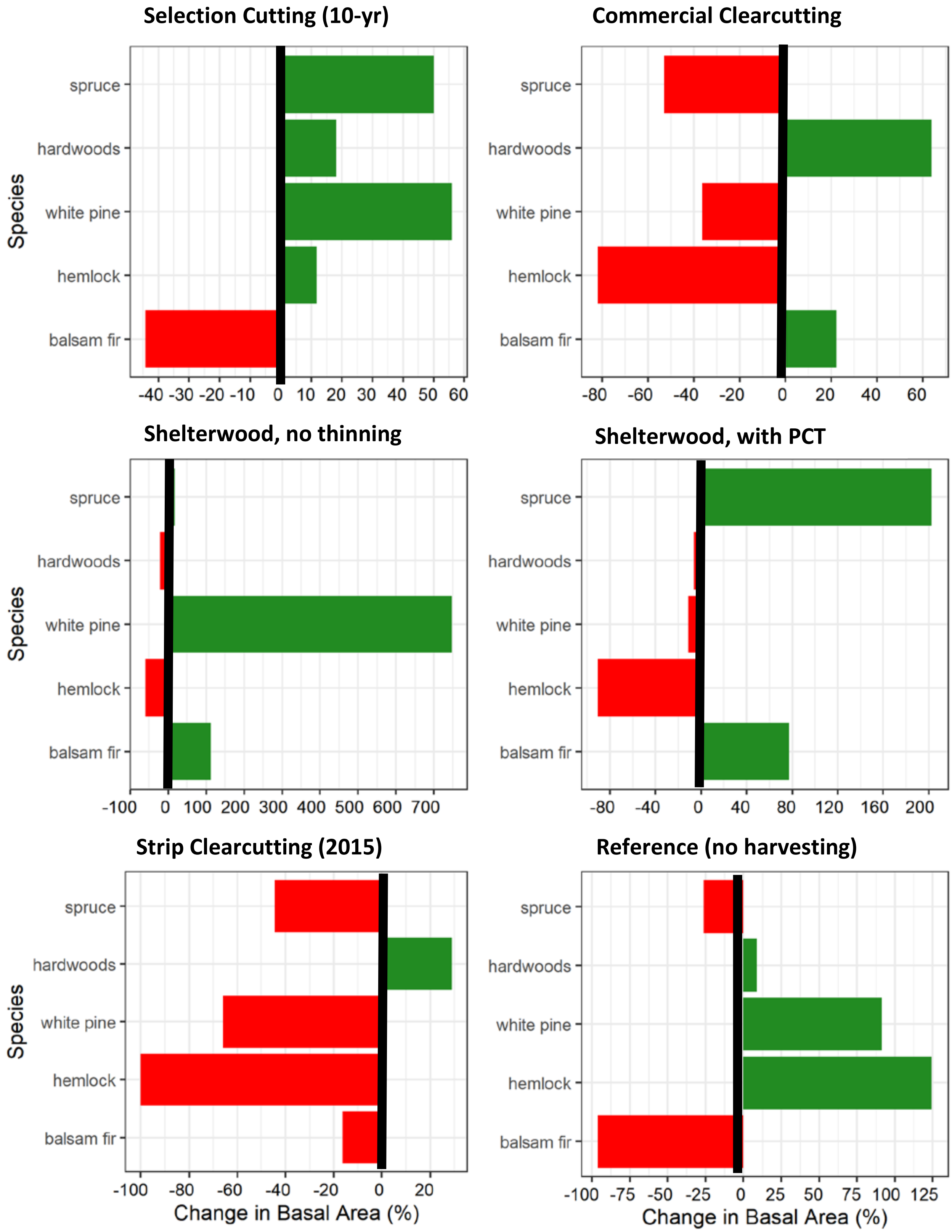
RELEVANCE

- Biomass harvesting
- Productivity impacts
- Fuels management
- Using old studies to answer new questions

ONGOING WORK

- Regeneration and browse
- UAV to monitor productivity
- Soil nutrition

Species Composition Changes by Treatment, 1950s to 2010s



For Your Reference

Literature Review by Jeanette Allogio

Silviculture for carbon storage (stocks) and uptake (sequestration) in spruce-fir; findings are from studies comparing two or more treatments (not all treatments are included in each). PEF research is highlighted. Ecosystem pools investigated are specified.

Greatest carbon storage across all ecosystem pools:

- No harvesting
  - Granstrom 2019, aboveground live biomass
  - Valipour et al. 2021, aboveground live biomass, woody debris, organic soil
- Single-tree selection
  - Granstrom 2019, aboveground live biomass
  - Puhlick et al. 2016 (a), O-horizon
  - Puhlick et al. 2016 (b), aboveground and belowground live and dead biomass, understory, coarse woody debris, forest floor, mineral soil, wood products
- Shifting from even to uneven-aged forest
  - Gunn and Buchholz 2018, aboveground and belowground live and dead biomass, wood products landfill, emissions, emission offsets
- Three-stage uniform shelterwood
  - Granstrom 2019, aboveground live biomass
  - Puhlick et al. 2016 (b), aboveground and belowground live and dead biomass, understory, coarse woody debris, forest floor, mineral soil, wood products
- Increasing rotation lengths
  - Valipour et al. 2021, aboveground live biomass, woody debris, organic soil
  - Nunery and Keeton 2010, aboveground live and dead biomass, downed log, wood products, landfill
  - Gunn and Buchholz 2018, aboveground and belowground live and dead biomass, wood products landfill, emissions, emission offsets
- Increasing basal area retention
  - Nunery and Keeton 2010, aboveground live and dead biomass, downed log, wood products, landfill
  - Gunn and Buchholz 2018, aboveground and belowground live and dead biomass, wood products landfill, emissions, emission offsets

Fastest rate of carbon uptake:

- No harvesting
  - Valipour et al. 2021, aboveground live biomass, woody debris, organic soil
  - Mika and Keeton 2015, aboveground live and dead biomass, coarse woody debris, wood products, emissions, fossil fuel offsets
  - Puhlick et al. 2020, aboveground live biomass, coarse woody debris, wood products
- Single-tree selection
  - Puhlick et al. 2020, aboveground live biomass, coarse woody debris, wood products

- Increasing rotation cycles
  Valipour et al. 2021, aboveground live biomass, woody debris, organic soil
  Mika and Keeton 2015, aboveground live and dead biomass, coarse woody debris, wood products, emissions, fossil fuel offsets
- Harvests not including bioenergy removals
  Mika and Keeton 2015, aboveground live and dead biomass, coarse woody debris, wood products, emissions, fossil fuel offsets
- Harvests including structural complexity enhancement
  Ford and Keeton 2017, aboveground live biomass, standing dead, downed log

Greatest resilience to climate change:

- Commercial clearcut shifted forests toward a more climate-adapted species composition
  Granstrom 2019, aboveground live biomass

Information gaps:

- Planting
- Few studies link future climate scenarios with different silvicultural treatments
- Few studies address natural disturbance in modeling projections

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