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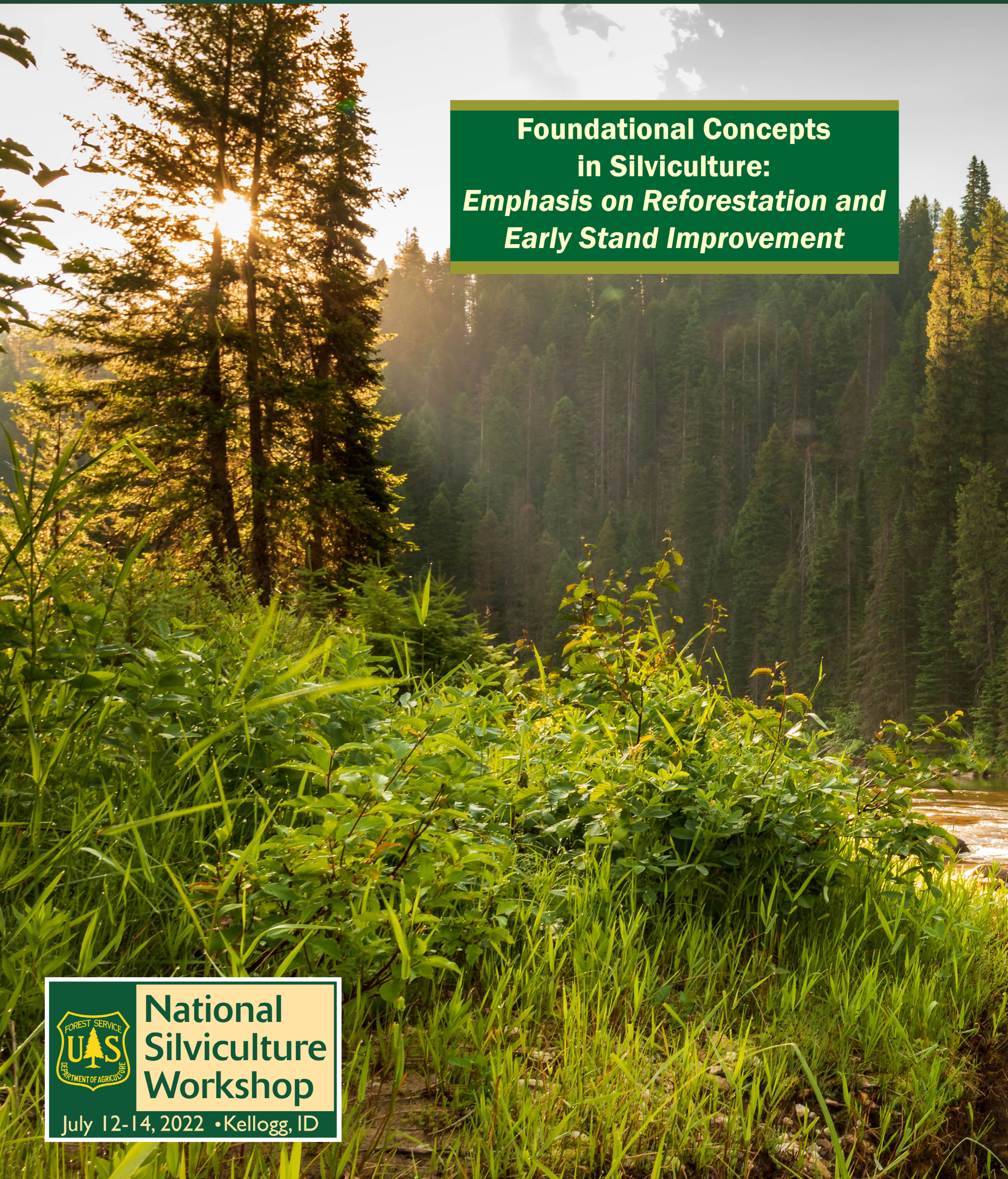

Foundational Concepts in Silviculture: *Emphasis on Reforestation and Early Stand Improvement*

National Silviculture Workshop
July 12-14, 2022 •Kellogg, ID

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Abstract

Beginning in 1973, the National Silviculture Workshop (NSW) purposely brought together USDA Forest Service scientists from Research and Development and forest managers from the National Forest System to meet face-to-face to build a science and management partnership in silviculture. Recently, scientists from universities and other partners have joined this annual gathering. The 2022 NSW theme is "Foundational Concepts in Silviculture: Emphasis on Reforestation and Early Stand Improvement." In 2022, the workshop is scheduled to take place in Kellogg, Idaho and is being jointly hosted by the National Forest System (NFS) and Research and Development (R&D) and sponsored by the Forest Management, Rangeland Management and Vegetation Ecology (NFS) and Sustainable Forest Management Research (R&D) staff areas. In addition, regional hosts will be the Forest Service Northern Region and the Rocky Mountain Research Station. Unique to this workshop was the occurrence of COVID-19, which resulted in the postponement of the workshop scheduled for 2021 when the workshop participants could meet in person. The intent of the workshop is to provide face-to-face interactions among the attendees to build a community of scientists and managers in the field of silviculture to better manage our national forests. Critical to this effort are field tours where scientists and managers can see firsthand how treatments have been implemented and share different perspectives where everyone can be heard. Each paper in this proceedings follows a designed template that includes an overview, summary, silvicultural concepts, and management applications, or in some cases, highlighted management opportunities.

Keywords: *silviculture, stand improvement, artificial and natural regeneration, forest thinning, forest management, restoration, stand tending reforestation*

Cover: Sunrise in northern Idaho. Licensed photo by Olya Lutz/Shutterstock.

Acknowledgments

This workshop's success is dependent upon a community of people who are willing to not only speak or submit their forest management story, but to the extended commitment of individuals who will make the workshop unique. Although it is not yet certain that the workshop will be held in person, Tom and I want to express our gratitude to this community. We want to thank our speakers who will welcome participants to the workshop: Leanne Marten, Regional Forester, Northern Region; Keith Lannom, Deputy Regional Forester, Northern Region; Monica Lear, Director, Rocky Mountain Research Station; Alison Hill, Forest and Woodland Ecosystems Program Manager, Rocky Mountain Research Station; and Karl Petrick, Forest Supervisor, Idaho Panhandle National Forests.

We also want to thank Toral Patel-Weynand, Director of Sustainable Forest Management Research, USDA Forest Service and David Lytle, Director of Forest and Rangeland Management and Vegetation Ecology, USDA Forest Service, for supporting the workshop. We are also grateful to Dr. Richard Hallett for accepting our invitation as the evening banquet speaker; we look forward to your presentation "Silviculture in the City: Urban and Climate Adapted Management Strategies for Forested Natural Areas in the Northeastern U.S."

The proceedings would have not been feasible without the support from Alison Hill, Patricia Cohn, Rocky Mountain Research Station Publishing Services Group Leader; Lane Eskew, who edited the proceedings; and Frances Smith, Visual Information Specialist, who developed the template for the papers and prepared the proceedings for publication.

Thomas and I would also like to thank the planning and program committee for setting aside the hours to plan the workshop, even with the uncertainty of COVID-19 and we are both indebted to the session moderators who we hope will keep everyone on time and successfully manage the audience engagement sessions. We also want to acknowledge the numerous individuals who supported the workshop behind the scenes. Richard Zabel, Executive Director, Western Forestry and Conservation Association, who was responsible for the minute details associated with workshop preparation and the numerous individuals who contributed their time during the meeting from overseeing the video technology to handling the field trip details.

Foundational Concepts in Silviculture: Emphasis on Reforestation and Early Stand Improvement

Proceedings of a workshop held at Silver Mountain Resort, Kellogg, Idaho

July 12-14, 2022

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Sponsored by:

USDA Forest Service, Washington Office Forest Management, Rangelands Management, and Vegetation Ecology

USDA Forest Service, Washington Office Sustainable Forest Management Research

USDA Forest Service, Northern Region

USDA Forest Service, Rocky Mountain Research Station

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Nichole Balloffet, USDA Forest Service, National Forest Systems, Washington Office, Washington, DC (Organized Special Reforestation Session)

2022 National Silviculture Workshop Agenda

Times are Pacific Standard Time

July 12, Day 1: Focus on Reforestation

0800-0915 Welcome/Introduction/Scope of Workshop

Monica Lear - Rocky Mountain Research Station

Leanne Marten - Northern Region

Carl Petrick - Idaho Panhandle National Forest

Theresa Jain - Rocky Mountain Research Station

0915-1000 National Reforestation Outlook and Opportunities

Reforestation on National Forest System Lands: Laws, Policies, and Opportunities

The National Reforestation Strategy and the REPLANT Act: Growing and Nurturing Resilient Forests

1000-1020 Break

1020-1120 Critical Infrastructure for Successful Reforestation

Nurseries Have a Critical Role in Meeting Forest Restoration Goals

The USDA Forest Service National Seed Laboratory: Supporting Reforestation and Restoration Efforts on National Forests.

RNGR: A National Resource for Forest Seedling Production and Outplanting Programs

1120-1245 Lunch - Special Session on REPLANT Act

1300-1400 Growing a Better Seedling

Driving Seedling Morpho-Physiology Towards Drought Tolerance With Drought Conditions in the Nursery

Testing the Potential of Biochar to Improve Bareroot Nursery Efficiencies

Effects of Biochar on Drought Tolerance of *Pinus banksiana* Seedlings

Using Disease Resistance Breeding and Silviculture to Ensure a Diverse, Healthy Forest for the Future (poster)

1400-1420 Break

1425-1530 Partnerships Are Crucial

Postfire Reforestation in Northern Sierra Nevada Forests: Testing Silvicultural and Genetic Approaches in a Changing Climate

A Long-Term Research-Practice Partnership Leads to Successful Reforestation in Northern California

Adaptive Silviculture in an Urban Environment: Initial Survival and Design Set-Up

2022 National Silviculture Workshop Agenda

1530-1630 **Genetic Resource Management Across the United States: Climate Change and Reforestation**

Guidelines for Assisted Migration and Seed Movement in the Eastern United States

Developing an Assisted Migration Plan for the Superior National Forest

A Proposed Protocol for Prioritizing National Forest Seedlots for Reforestation and Restoration Given Concerns of Climate Change

1630-1645 **Fireside Chat: Summary of the day and teaser for the field trip.**

1700 **Poster Session**

Using Disease Resistance Breeding and Silviculture to Ensure a Diverse, Healthy Forest for the Future

Short-term Effects From Late-season Freeze on White Oak (*Quercus alba* L.) Acorn Production in the Southeastern Coastal Plain

Evaluating the Role of Plant Species as Indicators of Climate Change, Disclimax, and Ecotones

Forest Canopy Opening Influence on Seedling Establishment and Growth

Intensity Frequency and Seasonality of Prescribed Burning to Control Survival and Growth of Competing Understory Red Maple During Regeneration

Crop Tree Release in Western White Pine Plantations

Transitioning From Even-aged to Multi-aged Forest Structure in Second-growth Ponderosa Pine

500 years? Who has Time for That? Accelerating Forest Succession with Reforestation and the Role of Port-Orford-cedar on the Rogue River-Siskiyou National Forest

Short- and Long-Term Growth Responses of Northern Rocky Mountain Conifers to Varying Thinning Intensities

2022 National Silviculture Workshop Agenda

Times are Pacific Standard Time

July 13, Day 2: Field Trip - Be prepared to walk in the woods

0630	**Load buses and leave Kellogg**
0800-1030	**Stop 1: Challenges in managing historical white pine forests**
1100-1245	**Stop 2: Lunch, Deception Creek Experimental Forest - Evolution of free selection and tending young forest plantations**
1300-1400	**Stop 3: Uneven-aged management - Implementing free selection**
1430-1530	**Stop 4: Dry mixed-conifer forest tending: Challenges with disease and tree stress**
1630-1700	**Return to Kellogg**
1730	**Banquet and award ceremony; Dr. Richard Hallett: Silviculture in the City: Urban and Climate Adapted Management Strategies for Forested Natural Areas in the Northeastern U.S.**

2022 National Silviculture Workshop Agenda

Times are Pacific Standard Time

July 14, Day 3: Foundational Silviculture

0800-0930 **Environmental Indicators in Reforestation and Growth**

The Influence of Hydroclimate and Harvest Method on Rates of Forest Regrowth Across the Western U.S.

REGEN Mapper: A Web-Based Tool for Predicting Post-Fire Conifer Regeneration and Prioritizing Reforestation Efforts in the Western United States

Regeneration of ʻIliahi: Hemiparasitic Relationships in Hawaiian Tropical Dry Forests

Short-term Effects From Late-season Freeze on White Oak (*Quercus alba* L.) Acorn Production in the Southeastern Coastal Plain (poster)

Evaluating the Role of Plant Species as Indicators of Climate Change, Disclimax, and Ecotones (poster)

Forest Canopy Opening Influence on Seedling Establishment and Growth (poster)

0930-1000 **Break**

1000-1115 **Stand Tending: National Forest Mandate, Disturbance as a Tending Option**

Trends in Stand Improvement Needs and Treatments on National Forest System Lands

Effects of Flooding on Survival and Performance of Potential Replacement Species in Black Ash Swamp Hardwood Forests

Sprout-Origin Hardwood Reproduction Dominates After Multiple Prescribed Fires on the William B. Bankhead National Forest, Alabama

Smoke, Goats, and Oaks: Effects of Goat Browsing and Prescribed Fire on Woodland Structure and Floristic Composition in Ozark Hardwoods

1115-1215 **Tackling Competitive Vegetation**

Effects of Logging-Debris Removal, Vegetation Control, and Site Quality on Stand Characteristics of Coast Douglas-fir

Seven-year Response of Planted Northern Red Oak (*Quercus rubra*) Seedlings to Regeneration Harvesting, Burning, and Herbicide Treatments in Western North Carolina

Developing Advance Reproduction of Intermediate Light-Tolerant Species such as White Oak – A Focus on Midstory Removal

Intensity Frequency and Seasonality of Prescribed Burning to Control Survival and Growth of Competing Understory Red Maple During Regeneration (poster)

1215-1315 **Lunch**

1315-1500 **Climate Resilience, Introducing Diversity Through Tending**

- Stand Tending Dilemmas – A Decision Tree for Climate Resilience and Adaptation
- Adapting Gingrich Stocking Guides for Managing Oak Woodlands and Savannas
- Early Stand Improvement for Multiple Ecosystem Services Using Adaptive Complexity Thinning
- Effect of Pruning in Sitka Spruce-Western Hemlock Forests in the Pacific Temperate Rainforest
- Regenerating and Tending Under the Vision for Resilience and Function in the Free Selection System
- How a “Fuzzy” Approach to Old-Growth Can Provide Silvicultural Clarity
- Crop Tree Release in Western White Pine Plantations (poster)
- Transitioning From Even-aged to Multi-aged Forest Structure in Second-growth Ponderosa Pine (poster)
- 500 years? Who Has Time for That? Accelerating Forest Succession with Reforestation and the Role of Port-Orford-cedar on the Rogue River-Siskiyou National Forest (poster)

1500-1530 **Break**

1530-1615 **Long-term Thinning Research**

- Evaluating Long-Term Ponderosa Pine Seedling Growth Across Densities Using Nelder Plots and FVS in the Black Hills, South Dakota, USA
- History of Stand Improvement Practices at the Fort Valley Experimental Forest
- Short- and Long-Term Growth Responses of Northern Rocky Mountain Conifers to Varying Thinning Intensities (poster)

1615-1645 **Closing remarks**

1645-1700 **Closeout**

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Introduction

Subject: Foundational Concepts in Silviculture With Emphasis on Reforestation and Early Stand Improvement--2022 National Silviculture Workshop

Dear Readers:

The National Silviculture Workshop (NSW) started in 1973 to provide a purposeful venue for scientists and managers to meet face-to-face and discuss contemporary topics and address management challenges (see table 1). The NSW has been held in different locations throughout the United States enabling each place to illustrate the ecology and management of the local forest ecosystem. For example, in 1973, the first NSW focused on Hardwood Management and was in Marquette, MI, and in 1977, the workshop was in Flagstaff, AZ, where participants discussed silvicultural implications of the newly adopted National Forest Management Act. Throughout the history of the NSW, topics have included the economics of silviculture (1983), silviculture for all resources (1987), and forest health through silviculture (1995); most recently, the theme was highlighting forest management and research partnerships (2019). Each workshop has been jointly hosted by a Forest Service Region and Research Station and was located within a national forest.

This most recent NSW was to be held in 2021, but COVID-19 prevented us from coming together. As we prepare the proceedings for 2022, we are still unsure if we will have the opportunity to gather in July 2022. One critical component of the NSW is that it takes place in person, rather than occurring as a virtual meeting. A primary goal and unique aspect – and why the National Silviculture Workshop was started – was to provide the opportunity for attendees to meet new people, engage with colleagues, hear about new forest management challenges and potential solutions, and learn from each other. To accomplish this, the workshop is a 3-day event with two days of indoor presentations, panel discussions, poster session, and audience interactions, along with a full-day field trip. The field trip portion of the workshop provides an opportunity for people to see different forest ecosystems and evaluate local management techniques and related research and explore new strategies that attendees may adapt and apply in their own forest ecosystem. The idea is to build a community of scientists and managers who work together to ensure that we successfully manage our Nation's forests. The workshop also provides an opportunity to recognize people who have made a difference in forest management and research. Each workshop has recognized individual managers and scientists who received the "Excellence in National Silviculture" award. These awards are particularly special because the honorees are nominated by their peers.

The theme for the 2022 National Silviculture Workshop is Foundational Concepts in Silviculture: Emphasis on Reforestation and Early Stand Improvement, scheduled for July 12–14, 2022, in Kellogg, Idaho. The workshop is again jointly hosted by the National Forest System (NFS) and Research and Development (R&D) and sponsored by the Forest Management, Rangeland Management, and Vegetation Ecology (NFS) and Sustainable Forest Management Research (R&D) staff areas. The workshop is also hosted by the Northern Region and the Rocky Mountain Research Station. The meeting's field trip will highlight mixed-conifer forests on the Idaho Panhandle National Forests and on Deception Creek Experimental Forest. Specific objectives are to enhance awareness of the importance of reforestation and early stand improvement to improve forest conditions, exchange information on successes and challenges of implementing reforestation and stand improvement projects, communicate science and technology advances in reforestation and stand improvement, and enhance and highlight forest management and research interactions within the Agency to address reforestation and early stand improvement needs.

There will be several different elements associated with this workshop. First, the proceedings will be published prior to the workshop so that attendees will have the proceedings in hand. Second, the proceeding papers are short vignettes that could be read in 5 minutes. Each paper follows a designed template that includes an overview, summary, silvicultural concepts, and management applications, or in some cases highlighted management opportunities with a 1,500-word limit. The short vignettes are to provide an opportunity to gain useful knowledge in a very short time. Second, the workshop presentations are organized within the context of a foundational silviculture concept. For example, one such foundational concept is the need to have "critical infrastructure." One may ask why is this a foundational aspect of silviculture? It is foundational because as a silviculturist, one must be informed on nurseries, seedling programs, and National Seed Laboratories. In this workshop, foundational elements associated with reforestation include methods to grow better seedlings, the value of partnerships between science, management, and other stakeholders, and climate change influences in reforestation. Foundational concepts for stand tending, include the application of alternative disturbances outside of mechanical treatments such as prescribed fire or targeted grazing that can influence distribution of tree species and related spacing. Like reforestation, climate change can also influence decisions associated with thinning or other intermediate treatments. One recent advent in stand tending is methods associated with introducing diversity in vegetation composition and tree spacing. The workshop will also highlight the unique component associated with Forest Service Research and Development, which is the advantage of long-term studies located on experimental forests. Third, a special luncheon session to discuss the REPLANT Act and how it may affect reforestation and tending efforts will be led by Nichole Balloffet, National Reforestation and Nurseries Program Manager. Fourth, Don Bragg (Southern Research Station) and Janet Hinchee (Retired Regional Silviculturist) are providing closing remarks; this is an element that has occurred in some of the workshops in the past.

Finally, Wednesday July 13th, is the field trip which will provide attendees an opportunity to see northern Idaho mixed-conifer forests. The field trip will have four stops. The first stop will have attendees walk through the woods and be introduced to the forests, including forest dynamics and the role of disturbance. They will be shown how disturbance such as root disease, when coupled with vulnerable species, can diminish the potential productivity. The second stop will be Montford Creek Natural Area on Deception Creek Experimental Forest, where lunch will be served in an old hemlock forest followed by Theresa telling the story on the evolution of uneven-aged management. Also, organizers will illustrate two different methods of crop tree release (individual tree release and group release) and discuss the benefits and trade-offs of each method. The third stop is to illustrate the free-selection silviculture system illustrating the original research followed by the application of this approach on National Forest System lands. The fourth and final stop for the day will be to show people what mesic-mixed conifer forests look like and to discuss tending options and how to proceed with creating disturbance resilient young forests.

We look forward to your presence and participation during the 2022 National Silviculture workshop.

Sincerely

Theresa B. Jain and Thomas M. Schuler

Previous National Silviculture Workshops

Table 1—The themes and locations of all previous National Silviculture Workshops.

Year	Theme	Location	Citation
1973	Forestry to Meet Special Objectives: A Look at Uneven-Aged Management	Marquette, MI	Barton et al. 1973
1974	Tree Improvement and Fertilization	Sacramento, CA	Nelson et al. 1974
1976	Density of Stocking Control	Eugene, OR	Usher et al. 1976
1977	Silvicultural Implications of Section 4, NFMA 1976	Flagstaff, AZ	Cargill et al 1977
1978	Silviculture Examination, Prescription, and Related Activities	Missoula, MT	Gould et al. 1978
1979	The Shelterwood Regeneration Method	Charleston, NC	Cramsey et al. 1979
1981	Hardwood Management	Roanoke, VA	Gillespie et al. 1981
1983	Economics of Silvicultural Investments	Eugene, OR	Row et al. 1983
1985	Successes in Silviculture	Rapid City, SD	McCoy et al. 1985
1987	Silviculture for All Resources	Sacramento, CA	Woolever et al. 1987
1989	Silvicultural Challenges and Opportunities in the 1990s	Petersburg, AK	Sesco et al. 1989
1990	Genetics/Silviculture	Wenatchee, WA	Miller and Murphy 1999
1991	Getting to the Future Through Silviculture	Cedar City, UT	Murphy 1992
1993	From the Cradle of Forestry to Ecosystem Management	Henderson, NC	Foley 1994
1995	Forest Health Through Silviculture	Mescalaro, NM	Eskew 1995
1997	Communicating the Role of Silviculture in Managing the National Forests	Warren, PA	Northeastern Experiment Station 1997
1999	The Past, Present, and Desired Future of Silviculture’s Role and Practice	Kalispell, MT	Barras 2001
2001	Silvicultural Odyssey to Sustaining Terrestrial and Aquatic Ecosystems?	Hood River, OR	Parker and Hummel 2002
2003	Silviculture in Special Places	Grandby, CO	Shepperd and Eskew 2004
2005	Restoring Fire-Adapted Ecosystems	Lake Tahoe, CA	Powers 2007
2007	Integrated Restoration of Forested Ecosystems to Achieve Multisource Benefits	Ketchikan, AK	Deal 2008
2009	Integrated Management of Carbon Sequestration and Biomass Utilization Opportunities in a Changing Climate	Boise, ID	Jain et al. 2010
2013	Silviculture Matters	Charleston, NC	Guldin and Buford 2014

Year	Theme	Location	Citation
2015	Silviculture and Changing Climate Strategies, Tactics, and Practical Prescriptions	Baton Rouge	Guldin and Buford 2017
2017	Restoration, Resilience, and Climate Adaptation	Flagstaff, AZ	Jain 2019
2019	A Focus on Forest Management-Research Partnerships	Bemidji, MN	Pile et al. 2019
2022	Foundational Concepts in Silviculture: Emphasis on Reforestation and Early Stand Improvement	Kellogg, ID	Jain and Schuler 2022

Barras, Stanley J., ed. 2001. Proceedings: National Silvicultural Workshop. Proc. RMRS-P-19. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p.

Barton, Michael A.; Verme, Louis J.; Radtke, Robert E.; Reed, Berwyn O.; Plass, William T.; Boyce, Stephen G., eds. 1973. National Silviculture Meeting: Forestry to Meet Special Objectives (A Look at Uneven-aged Management); Marquette, Michigan; September 10-14, 1973. Milwaukee, WI: U.S. Department of Agriculture, Forest Service, Eastern Region. 201 p.

Cargill, Gary; Gillespie, Robert; Mann, Wayne; Blomquist, Bob; Todd. Jack; Strode, Don; Schneegas, Edward R.; Sundstrom, Charles; Corliss, John F.; Pint, Bill; Zeedyk, William D.; Pfister, Robert D.; Shearer, Raymond C.; Leven, Andrew A.; Alexander, Robert R.; Sandquist, Roger E.; Stevens, Robert E.; Row, Clark; Sabin, Jim; Engle, LaMont; Greathouse, Tom, eds. 1977. Proceedings of the National Silviculture Workshop: Silvicultural Implications of Section 4, NFMA 1976; Flagstaff, Arizona; September 26-30, 1977. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management. 120 p.

Cramsey, Dan; Puuri, Carl; Miller, Dick; Page, Billy E.; Smith, David; Marquis, David; Usher, Jack; Naumann, Bob; Beaufait, William; Loomis, Robert; Smith, Edward; Loftis, David; Langdon, Gordon; Croker, Thomas; Boyer, William; Edgren, Jim; Roy, Douglas; Hughes, John; Boldt, Charles; Jacobson, Glenn; Godman, Dick; Tubbs, Carl; Sander, Ivan; Blomquist, Bob, eds. 1979. Proceedings of the National Silviculture Workshop: The Shelterwood Regeneration Method; Charleston, South Carolina September 17-21, 1979. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management. 288 p.

Deal, Robert L., tech. ed. 2008. Integrated Restoration of Forested Ecosystems to Achieve Multiresource Benefits: Proceedings of the 2007 National Silviculture Workshop. Gen. Tech. Rep. PNW-GTR-733. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 306 p.

Eskew, Lane G., compiler. 1995. Forest Health Through Silviculture: Proceedings of the 1995 National Silviculture Workshop; Mescalero, New Mexico; May 8-11, 1995. Gen. Tech. Rep. RM-GTR-267. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 246 p.

Foley, L.H., comp. 1994. Silviculture: From the Cradle of Forestry to Ecosystem Management. Asheville, NC: USDA Forest Service Gen. Tech. Rep. SE-88, Southeastern Forest Experiment Station. 258 p.

Gillespie, Robert; Cramsey, Dan; Miller, Dick; Hamel, Dennis; Puuri, Carl; Clark, F. Bryan; Erickson, John; Loftus, Nelson; Casey, Lloyd; Smith, H. Clay; Marquis, Bob; Dale, Martin; McGee, Charles E.; Williams, Robert D.; Erdmann, Gayne G.; Godman, R. M.; Boyce, Stephen G.; Schrauder, Paul A.; Beck, DonaId E.; Marquis, David A.; McConnell, James L.; Debald, Paul S.; Houston, David R.; Knapp, Walter; Turpin, Tom; Bacon, Warren; Schulz, Arnold, eds. 1981. Proceedings of the National Silviculture Workshop: Hardwood Management; Roanoke, Virginia; June 1-5, 1981. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management. 316 p.

Gould, Norman E.; Potter, Don; Johnston, Ray; Loton, Jim; Pierce, Donald; Hamilton, Ronald C.; Gruell, George E.; DeKalb, Victor; Wright, Dav; Beaufait, Bill; Schroeder, Dan; Blomquist, Bob; Tappeiner, John C., II; Puuri, Carl; Terry, Dav; Stewart, R. E.; Knapp, Walter H. 1978. Proceedings of the National Silviculture Workshop: Silvicultural Examination, Prescription, and Related Activities; Missoula, Montana; September 26-28, 1978. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management. 162 p.

Guldin, James M.; Buford, Marilyn A. 2014. A special issue of the Journal of Forestry—Proceedings of the 2013 National Silviculture Workshop. Journal of Forestry. 112(5): 393-394.

Guldin, James M.; Buford, Marilyn A. 2017. A Special Issue of the Journal of Forestry—Proceedings of the 2015 National Silviculture Workshop. J. For. 115(3):157–243.

Jain, Theresa B.; Graham, Russell T.; Sandquist, Jonathan, tech. eds. 2010. Integrated Management of Carbon Sequestration and Biomass Utilization Opportunities in a Changing Climate: Proceedings of the 2009 National Silviculture Workshop; 2009 June 15-18; Boise, ID. Proc. RMRS-P-61. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 351 p.

Jain, T.B. 2019. Introduction: 2017 National Silviculture Workshop: Forest Management Policy, Forest Restoration, Disturbance Resilience, Climate Adaptation. For. Sci. 65(4):492-495.

Jain. T.B.; T. Schuler. 2022 National Silviculture Workshop: Foundational Concepts in Silviculture: Emphasis on Reforestation and Early Stand Improvement; July 12-14, 2022. Proc. RMRS-P-80. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. XX p.

Nelson, Thomas C.; Libby, William J.; Krugman, Stanley; Miller, Richard G.; Bell, David M.; Powers, Robert F.; Davey, C. B.; Durrow, George. 1974. Service-wide Silviculture Work Conference Proceedings; Sacramento, California; October 21-25, 1974. Washington, DC: U.S. Department of Agriculture, Forest Service, Division of Timber Management. 201 p.

Northeastern Forest Experiment Station 1997. Communicating the Role of Silviculture in Managing the National Forests: Proceedings of the National Silviculture Workshop. Gen. Tech. Rep. NE-238. Radnor, PA: U. S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 205p.

McCoy, Gary L.; Gross, Larry; Lachowski, Henry; Chew, Jim; Joy, John W.; Henderson, Jerry; Murphy, Mike; Loftus, Nelson S.; Jacobsen, Glenn; Kracht, Richard L.; Musser, Lloyd A.; Avery, Brian H.; Thomas, David F.; Williamson, Max; Znerold, Mike; Belanger, Roger; Nesbitt, John; Beckman, Tom; Baker, James B.; Amundson, John B.; Fiddler, Gary O.; Laacke, Robert J.; Rauscher, Mike; Saha, Hrishi; Robert, Pierre; Winn, David; Richards, Darwin L.; Burke, Marianne; Kitchens, Bobby; Murphy, John; Kang, Hyun-Chung. 1985. Proceedings of the National Silviculture Workshop: Successes in Silviculture; Rapid City, South Dakota; May 13-16, 1985. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management. 295 p.

Miller, Richard G.; Murphy, Dennis D., compis. 1990. Genetics/Silviculture Workshop Proceedings; Wenatchee, WA; August 27-31, 1990. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management Staff. 263 p.

Murphy, Dennis, compiler. 1992. Getting to the Future Through Silviculture - Workshop Proceedings; 1991 May 6-9; Cedar City, UT. Gen. Tech. Rep. INT-GTR-291. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 97 p.

Parker, Sharon; Hummel, Susan Stevens. 2002. Beyond 2001: A Silvicultural Odyssey to Sustaining Terrestrial and Aquatic Ecosystems? Proceedings of the 2001 National Silviculture Workshop, May 6-10, Hood River, Oregon. Gen. Tech. Rep. PNW-GTR-546. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 114 p.

Pile, Lauren S.; Deal, Robert L.; Dey, Daniel C.; Gwaze, David; Kabrick, John M.; Palik, Brian J.; Schuler, Thomas M., comps. 2020. Forest Management – Research Partnerships: Proceedings of the 2019 National Silviculture Workshop; 2019 May 21-23; Bemidji, MN. Gen. Tech. Rep. NRS-P-193. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 226 p. https://doi.org/10.2737/NRS-GTR-P-193.

Powers, Robert F., tech. editor. 2007. Restoring Fire-Adapted Ecosystems: Proceedings of the 2005 National Silviculture Workshop. Gen. Tech. Rep. PSW-GTR-203, Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture. 306 p.

Row, Clark; Palmer, Charles; Randall, Robert M.; Ortman, Tom; Merzenich, James P.; Manning, Gary; Howe, George; McDivitt, Jim; Hansen, Chris; Fey, Willard R.; Robinson, Vernon L.; Sleavin, K. E.; Johnson, K. N.; Fight, Roger D.; Stanger, L. O. (Pete); Medema, Lee; Risbrudt, Christopher D.; Guldin, Richard W.; Greenhalgh, Richard; Skinner, Mike; Fiske, John; Mills, Thomas J.; Beuter, John H. 1983. Proceedings of the National Silviculture Workshop: Economics of Silvicultural Investments; Eugene, OR; May 16-20, 1983. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management. 246 p.

Sesco, Jerry; Naumann, John R.; Schmidt, Wyman C.; Kain, Peggy; DeBell, Dean S.; Lanasa, Mike; Marquis, David A.; Kitchens, Robert N.; Baker, James B.; Diggle, Paul K.; Graham, Russell T.; Jacobsen, Glenn; Knapp, Walter H.; Howe, George E.; Holland, David G.; Gordon, Christi; Powers, Robert F.; Ellen, Dave; Zasada, John; Owston, Peyton W.; Murphy, Dennis D.; Wood, William R.; Harry, Lee; Cawrse, Dave; Loftis, David L.; Wickman, Boyd E.; Thomas, David F.; Shepperd, Wayne D.; Hann, W. J.; Crow, Thomas R.; Miller, Richard G.; Conkle, M. Thompson; Friedman, Sharon T.; Basford, Douglas D.; Holland, Carol J. 1989. Proceedings of the National Silviculture Workshop: Silvicultural Challenges and Opportunities in the 1990s; Petersburg, Alaska; July 10-13, 1989. Washington, DC: U.S. Dept. of Agriculture, Forest Service, Timber Management. 216 p.

Shepperd, Wayne D.; Eskew, Lane G. 2004. Silviculture in Special Places: Proceedings of the 2003 National Silviculture Workshop. Proc. RMRS-P-34. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 255 p.

Usher, Jack H.; Jones, Daniel B.; Stage, A. R.; Roach, Benjamin A.; Schubert, Gilbert B.; Crawford, Darrell W.; Schubert, Gilbert H.; Fox, Walter; Smith, Edward A.; Sofes, Richard E. Lowrey; Watt, Richard F. 1976. Proceedings of the National Silviculture Workshop: Density of Stocking Control; Eugene, Oregon; October 13-15, 1976. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management. 203 p.

Woolever, Melanie Malespin; Smith, Mike; McGraw, Elizabeth; Lanasa, Mike; Zack, Arthur C.; Reichert, Chris; MacWhorter, Robert; Lennartz, Michael R.; Lancia, Richard A.; Rounsaville, Marc G.; Sedell, James R.; Everest, Fred H.; Gibbons, David R.; Shifley, Stephen R.; Moeur, Melinda; Marquis, David A.; Fitzgerald, Richard O.; Loftus, Nelson; Turpin, Thomas C.; Terrill, William R.; Crouch, Glenn L.; Shepperd, Wayne D.; Petrick, Edith W.; Petrick, John J.; Dennington, Roger W.; Ashton, Allan W.; Mittmann, Hubertus J.; Thompson, Gary; Sonksen, Ken; Stark, David A.; Ware, Michael A.; West, Allan J.; Jackson, Patrick D.; Bassett, Richard L.; Chew, Jimmie D.; White, William B.; Morse, Bruce W.; Znerold, Mike; Graham, Russell T.; Owston, Peyton W.; Miller, Richard G.; Nesbitt, John R.; Porterie, Gaston; Del Rio, Ernest. 1987. Proceedings of the National Silviculture Workshop: Silviculture for All Resources; Sacramento, CA; May 11-14, 1987. Washington, DC: U.S. Department of Agriculture, Forest Service, Timber Management. 322 p.

National Reforestation Outlook and Opportunities

Reforestation on National Forest System Lands: Laws, Policies, and Opportunities

David Gwaze

Overview:

- Reforestation following harvest, and/or natural disasters, is critical to sustaining healthy forests. Recent increases in frequency, scale, and severity in wildfires in the West combined with ongoing turnover in personnel make the National Silviculture Workshop an ideal venue to review the laws and policies that direct reforestation on National Forest System Lands.
- The U.S. Department of Agriculture, Forest Service reforestation program has five major goals. (1) Maintain appropriate forest cover on all forest lands within the National Forest System (NFS). (2) Restore forested conditions to provide ecosystem services. (3) Improve the quality and yield of the timber resource. (4) Accelerate the attainment of desired species composition and stocking objectives in a cost-efficient manner. (5) Develop and demonstrate successful reforestation methods and techniques and encourage their use by other landowners.
- The United States has laws and the Forest Service has policies that direct reforestation on NFS lands; however, reforestation needs continue to grow because of lack of funding and capacity. Some laws are outdated and updating them could eliminate the accumulated and future reforestation needs. Decreases in timber sales have resulted in declining Knutson-Vandenberg funding. Threats to natural resources—and our diminishing expertise in addressing reforestation needs—have increased.
- Fortunately, the Repairing Existing Public Land by Adding Necessary Trees Act (REPLANT Act) will increase Reforestation Trust Funds plus global support on reforestation, like the One Trillion Tree Initiative, which gives an opportunity for the Forest Service to increase funding for reforestation from nongovernmental organizations and the public. Finally, the Reforestation Strategy developed by the Forest Service provides a plan to address the agency's accumulated and future reforestation needs.

Summary:

Table 1 provides a summary of how each law and policy addresses reforestation on NFS lands, but here I want to focus on the National Forest Management Act (NFMA) of 1976. NFMA directs the Forest Service to reforest by restoring lands to an appropriate forest cover that maximizes benefits of multiple use sustained yield management. Reforestation work is also embedded in the law because the law requires that timber harvest only occur on NFS lands and harvested lands need to be adequately restocked within 5 years after a regeneration harvest. The act goes further to ensure that the reforestation is monitored (first and third growing season) and be certified as fully stocked. Any lands not certified need to be promptly treated so they can be certified.

In addition, NFMA requires the following information be compiled and submitted annually to Congress:

(1) The amount, by Forest, State, and productivity class, of all lands where objectives of land management plans indicate the need for reforestation.
(2) The amount, by Forest, State, and productivity class, of all forest lands not growing at the growth rate needed to meet the goals of the land management plan.
(3) The status of newly deforested lands.
(4) The status of precommercial thinning, release, pruning, and fertilization needs.
(5) The amounts of treated land that have been certified as having achieved satisfactory stocking or growth rate as the result of the treatment after the first and third growing seasons.
(6) The budgetary resources we need to prevent the development of a reforestation backlog.

Silvicultural Concepts:

Forest policies provide specific requirements for implementing the laws.

- FSM2470 provides policy direction for silvicultural practices on NFS lands (table 1).
  - Section 2472 provides (1) standard definitions for reforestation terms, (2) reforestation objectives, (3) reforestation plans and reports, (4) reforestation process, (5) certification of restocking and treatment, and (6) regeneration examinations.
  - Sections 2473, 2474, 2475 provide guidance and encourage the Forest Service to provide and use high quality, genetically appropriate seed to meet reforestation needs.
- FSM2470 clarifies the NFMA 5-year restocking requirement.
  - Section 2472.03 states, "Before scheduling stands for regeneration harvest, ensure, based on literature, research, or local experience, that stands to be managed using **even-aged management methods** can be adequately restocked within five years of final harvest (clearcutting, final overstory removal in shelter woodcutting, and seed tree removal cut in seed tree cutting). When using

uneven-aged management methods, they must be adequately restocked within five years after every regeneration harvest."
    - Section 2471.41 states, "Salvage and sanitation cuts are considered an intermediate harvest where intermediate cutting is required. However, if salvage or sanitation cutting is heavy enough to require regeneration, it is considered a regeneration harvest, and steps should be taken to adequately restock the stand within five years of final harvest."
    - Section 2475 provides greater clarity to the use of assisted migration (AM). It allows use of AM when science-based analysis indicates that current seed zones may lead to maladapted forests due to changes in climate and advocates using assisted population migration and assisted range expansion.
    - Section 2475 provides new policy on genetically modified (GM) trees. It allows GM trees to be considered after regulatory review, and evaluation of risks vs. benefits. It requires the planting of GM trees be approved by a Regional Forester.
- FSM 2490 provides direction on data collection and reporting and review procedures associated with data collection and reporting procedures that quantify reforestation needs.
- FSM 2070 authorizes use of native plants on NFS lands.

Management Applications:

- Reforestation has now become a global priority—for example, the Trillion Trees Initiative (1t.org) launched by the World Economic Forum aimed at conserving, growing, and restoring 1 trillion trees globally by 2030. To date, dozens of companies, governments, and nongovernmental organizations have pledged to plant and conserve over 1 billion trees throughout the United States, and some of these pledges have included nursery production and investment.
- Executive Order 13955 (13 October 2020) established the One Trillion Trees Interagency Council in the United States, which will be responsible for coordinating the Federal government's support of the global One Trillion Trees Initiative. Other global initiatives are in the broad area of restoration (including reforestation).
- Executive Order 14008 (27 January 2021), Tackling the Climate Crisis at Home and Abroad, utilizes reforestation to protect natural resources, increase resilience, and develop a diverse, well-supported conservation workforce.

Table 1—Laws and policies that provide Forest Service direction on achieving reforestation goals.

	Legislative laws and statutes
National Forest Management Act (NFMA) of 1976 (16 U.S.C. 1600 et seq.)	Section 3(d)(1) requires cutover or otherwise denuded lands to be restored to "appropriate forest cover" with "the species of trees, degree of stocking, rate of growth, and stand condition designed to secure maximum benefits of multiple use sustained yield management in accordance with management plans." Section 6(g)(3)(E) requires that timber harvest will only occur on National Forest System lands where "there is assurance that such lands can be adequately restocked within five years after harvest." Moreover, treated lands "shall be examined after the first and third growing seasons and certified…as to stocking rate…Any lands not certified as satisfactory shall be…scheduled for prompt treatment" (16 U.S.C. 1601 Sec. 4 (d)(1)). Forest plans provide guidance about adequate restocking to meet the management objectives for a specific area.
The Forest Service Organic Administration Act of 1897, as amended (16 USC 473-478, 479–482 and 551)	Identifies the purposes for establishing and administering National Forests, which are to improve and protect the forest, to secure favorable conditions of water flows, and to furnish a continuous supply of timber for the use and necessities of citizens of the United States and, in so doing, provide for reforestation work in support of these aims.
The Transfer Act of 1905 (33 Stat. 628)	Moved Forest Service and National Forests from the U.S. Department of Interior to the U.S. Department of Agriculture, and further justified reforestation by requiring a permanence of forest resources.
The Weeks Law of 1911 (16 USC 528–531)	Directed the acquisition of forested, cutover, or denuded lands to regulate the flow of navigable streams or to produce timber and gave direction for reforestation to conserve forests and water supplies.
The Knutson-Vandenberg (K-V) Act of 1930 (16 U.S.C. 576–576b)	Establishment of forest tree nurseries and authorized timber sale purchasers to make deposits to cover the cost of reforestation and related work within timber sale boundaries. The K-V Act was amended in 1976 to broaden its purpose to include other renewable resources, such as wildlife habitat improvement. This Act ensures our reforestation treatment needs are met within timber sale areas.
Repairing Existing Public Land by Adding Necessary Trees Act (REPLANT Act) The REPLANT Act	Amends Title III of the Recreational Boating Safety and Facilities Improvement Act of 1980 removing the $30 million per year cap on Reforestation Trust Fund. It mandates the Forest Service, and gives additional funds, to tackle the backlog of reforestation needs in 10 years.
	Forest Service policies
Forest Service Manual 2470 (FSM 2470)	Provides policy direction for silvicultural practices on National Forest System lands.
Forest Service Manual 2490 (FSM 2490)	Provides direction on data collection and reporting and review procedures associated with data collection and reporting procedures that quantify reforestation needs.

The National Reforestation Strategy and the REPLANT Act: Growing and Nurturing Resilient Forests

Nicole Balloffet and R. Kasten Dumroese

Overview:

- The National Forest Management Act of 1976 (NFMA) mandates prompt reforestation.
- Passage of the 2021 Infrastructure Investment and Jobs Act (IIJA) included the Repairing Existing Public Land by Adding Necessary Trees Act (REPLANT Act), which removes the cap on the Reforestation Trust Fund, indefinitely increasing annual funding for reforestation from $30 million to $140 million or more.
- REPLANT mandates removing our current reforestation backlog during the next decade.
- We have a 3- to 5-million-acre backlog of reforestation needs that grows each year because of fire. Charting a way forward to address the current backlog plus our new reforestation needs requires a coordinated effort and realization of what limits our ability to meet those challenges.
- Our most limiting factor is professional capacity: we need new, additional on-the-ground professionals and specialized supporting staff. The long-term nature of the Reforestation Trust Fund should allow us to increase capacity.
- Meeting the huge Congressional mandates of the REPLANT Act presents “unsolved opportunities” for the Forest Service, especially the integration of reforestation, post-fire restoration, fuel management, and early stand-tending policies. What are our values, management approaches, and trade-offs?

Summary:

Management Problem: During the past two decades: (1) harvest activities, which formerly funded most Forest Service reforestation work, continued their sharp decline; (2) the non-fire portion of the Forest Service workforce decreased by 40%, which has negatively affected monitoring and FACTS reporting; and (3) the amount of wildfire increased substantially. The result is that the Forest Service is currently not in compliance with NFMA and a significant amount of reforestation backlog has developed. Our partners are supporting reforestation efforts, but our lack of human capacity is throttling our ability to fully leverage their potential commitments. With passage of the REPLANT Act, Congress has mandated the Forest Service to

alleviate the current backlog of acres requiring reforestation per National Forest Management Plans.

Management Need: Given the ever-increasing demands on current staff, a critical need is to increase the number of nonfire professionals within the Forest Service substantially dedicated to reforestation and early stand tending. In addition to hiring on-the-ground professionals in the field and in the nurseries, we also require additional, specialized supporting staff (e.g., HR, budget, engineering, contracting). Paramount to required Congressional mandates within the REPLANT Act is better data collection and entry to ensure timely and necessary interpretation, prioritization, and implementation of reforestation activities.

Proposed Solution: In addition to the National Reforestation Strategy that provides a broad framework for Forest Service reforestation work, passage of the REPLANT Act within the 2021 IIJA removes the annual $30 million cap on the Reforestation Trust Fund. This increases the annual flow of available funds for reforestation to $140 million or more. Given the long-term status of the Trust Fund, it provides opportunity to increase staffing to support reforestation. This additional capacity, along with a coordinated effort across the Regions and the WO, will lead to successful restoration of our 3- to 5-million-acre reforestation backlog as well as meet our annual new reforestation needs.

Silvicultural Concepts:

- Reforestation has always been an important function of the Forest Service and is now required by NFMA and the REPLANT Act.
- Reforestation is part of the holistic approach to forest management that helps us manage our national forest assets for multiple uses, including carbon sequestration and climate change mitigation.
- The REPLANT Act presents the Forest Service with a bold opportunity to integrate new approaches to reforestation in response to today's challenges that include changes in fire intensity and frequency, climate change, invasive species, and loss of biodiversity.

Management Applications:

None provided.

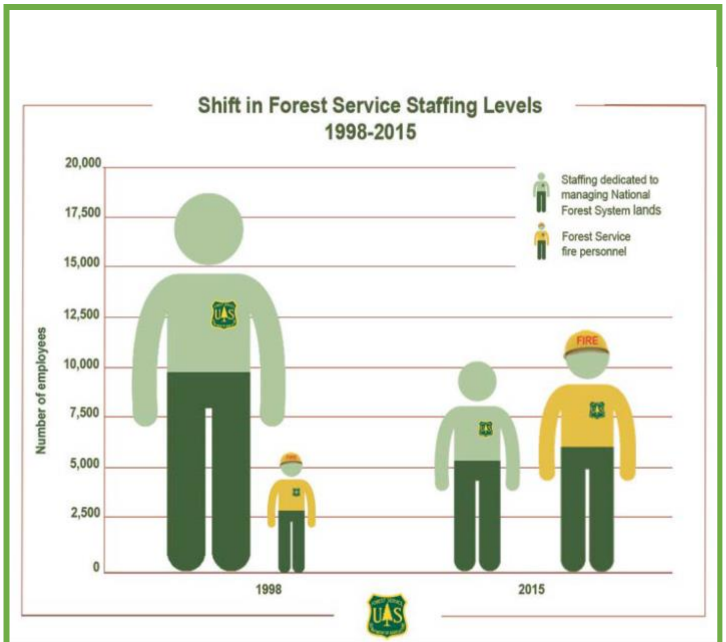


Figure 1—The number of nonfire personal has declined 40% since 1995, contributing to the Forest Service's noncompliance with the National Forest Management Act of 1976. (USDA Forest Service 2015.)

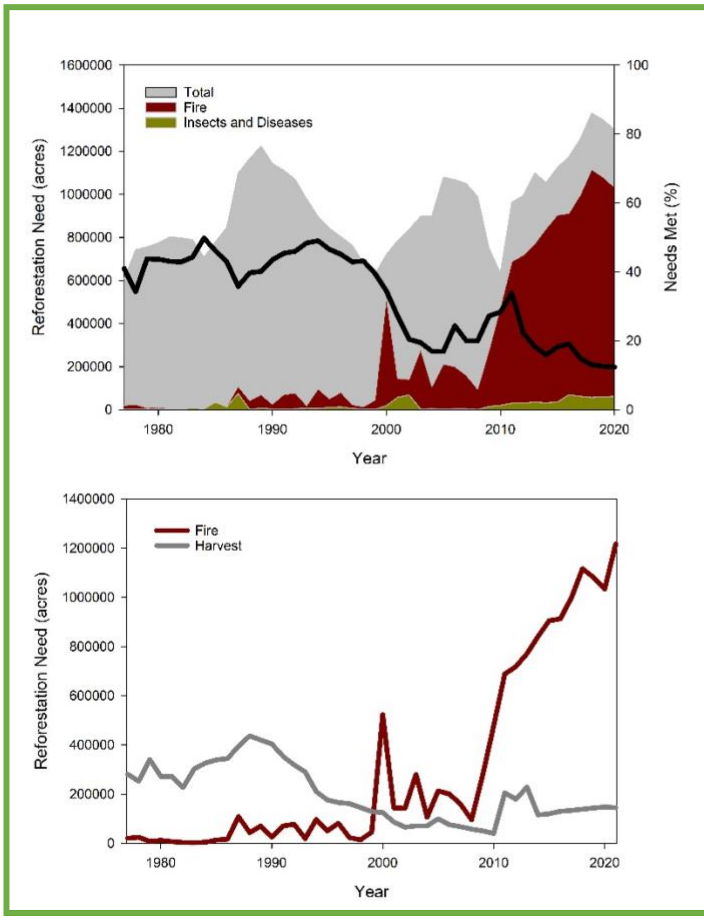


Figure 2—Since the late 1970s, reforestation need caused by harvest activities has declined, whereas needs due to wildfire have increased exponentially since 2010. (Based on FACTS data; modified from Dumroese et al. 2019.)

References

Dumroese, R.K; Balloffet, N.; Crockett, J.W.; Stanturf, J.A.; Nave, L.E. 2019. A national approach to leverage the benefits of tree planting on public lands. New Forests. 50: 1−9.

U.S. Department of Agriculture Forest Service. 2015. The rising cost of wildfire operations: effects on the Forest Service's nonfire work. August 4, 2015. Washington, DC: 16 p.

U.S. Department of Agriculture Forest Service. 2022. Growing and nurturing resilient forests: a reforestation strategy for the National Forest System. Washington, DC: in press.

Critical Infrastructure for Successful Reforestation

Nurseries Have a Critical Role in Meeting Forest Restoration Goals

Diane L. Haase

Overview:

- Meeting forest restoration goals requires establishment and growth of seedlings that can thrive for many decades. Often, this requires use of nursery-grown plants. Despite their obvious role, however, nurseries can be considered a low priority and/or overlooked during the planning process.
- During the past 20 years, staffing and resources have declined for state and federal nurseries, resulting in decreased capacity. At the same time, forest disturbances from wildfires, pests, pathogens, and invasive species have increased. Thus, a renewed focus on nursery capacity and resources is needed.
- Meeting forest restoration goals in a timely and effective manner requires a keen understanding of nursery practices and target seedling characteristics as they relate to outplanting performance along with close communication and collaboration with nursery personnel.

Summary:

Quality, nursery-grown seedlings matched to the outplanting site are necessary to meet national forest restoration goals. Seedling needs have increased during the past decade as a result of forest disturbances and expanding restoration goals. Additionally, new legislation is aimed toward addressing current reforestation backlogs as well as future planting needs. Thus, nursery production capacity is expected (and necessary) to increase seedling supplies.

The role of forest nurseries is to provide sufficient quantities of high-quality seedlings in a timely manner. Nurseries also help to ensure appropriate species and genetic sources are available for various geographic zones and serve as sources of plant and environmental expertise. Many nurseries also maintain seed banks and/or seed orchards. To operate a nursery efficiently and effectively, nursery personnel must have in-depth expertise on many factors including: biology, genetics, and growth patterns of each species from seed to seedling; culturing practices (e.g., irrigation and fertilization) for establishment, active growth, and hardening growth stages designed to meet morphological specifications and delivery dates for a multitude of seed sources, stocktypes, and customers; soil/growing media properties;

environmental influences; prevention and management of insects and diseases; equipment operations; and much more.

Recognition and understanding of the critical role of nurseries is imperative to coordinate the necessary resources and efforts for scaling up tree planting to meet current and future forest restoration goals. Overlooking this critical aspect of the reforestation pipeline can have long-term economic and environmental consequences.

Silvicultural Concepts:

- Successful forest restoration with nursery-grown seedlings depends on selection of target seedlings that have the best potential to perform well after outplanting. Thus, the forest manager/silviculturist must have a good understanding of nursery production processes and target seedling specifications as they relate to post-planting survival and growth.
- Applying the Target Plant Concept (fig. 1) ensures the right plants are planted on the right site at the right time. This process includes communication between the land manager and the nursery manager to determine the best seedling species, stocktype, genetic source, and other characteristics that are matched to the designated outplanting site.

Management Applications:

- While natural regeneration and direct seeding can meet a portion of reforestation goals, the use of nursery-grown seedlings is necessary in many areas to ensure adequate stocking density and distribution. Thus, nursery production practices and capacity must be considered in the planning process.
- Foresters involved in reforestation activities need to understand the nursery production cycle so they can make informed and timely decisions regarding stock for their sites. A basic understanding of nursery propagation activities as related to plant physiology, morphology, phenology, genetics, and ecotype is vital for working effectively with nursery staff, setting target specifications, and troubleshooting variations in field performance.
- Frequent and clear communication with nursery personnel and visits to the nursery to observe the growing stock can facilitate production and delivery of seedlings best suited for the outplanting site (fig. 2). This communication can also serve to identify bottlenecks, quality issues, timing concerns, or other factors that can be adjusted to improve future crops.

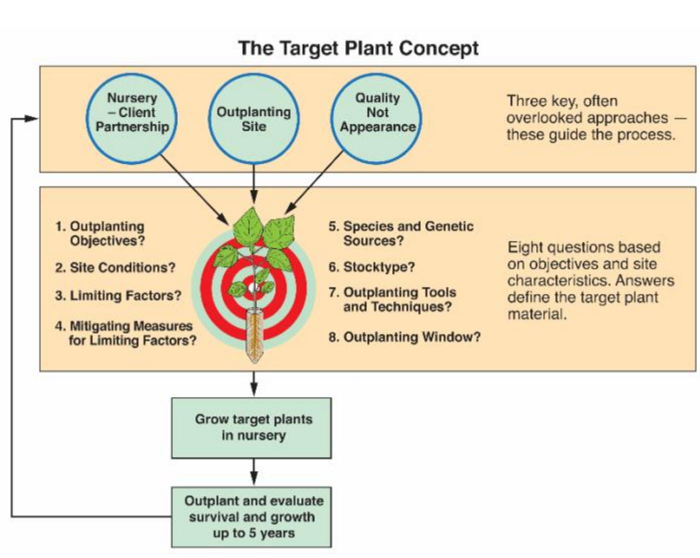


Figure 1—The Target Plant Concept guides nursery and land managers on decisions regarding the best plant materials for a given outplanting site.

Figure 2—On-site visits to examine stock quality, discuss production schedules, and improve understanding of nursery processes are invaluable to foresters.

References

Dumroese, R.K.; Landis, T.D.; Pinto, J.R.; Haase, D.L.; Wilkinson, K.M.; Davis, A.S. 2016. Meeting forest restoration challenges: Using the target plant concept. Reforesta. 1(1): 37–52.

Fargione, J.; Haase, D.L.; Burney, O.T.; Kildisheva, O.A.; Edge, G.; Cook-Patton, S.C.; Chapman, T.; Rempel, A.; Hurteau, M.D.; Davis, K.T.; Dobrowski, S.; Enebak, S.; De La Torre, R.; Bhuta, A.A.R.; Cubbage, F.; Kittler, B.; Zhang, D.; Guldin, R.W. 2021. Challenges to the reforestation pipeline in the United States. Frontiers in Forests and Global Change. 4:629198.

Haase, D.L.; Davis, A.S. 2017. Developing and supporting quality nursery facilities and staff are necessary to meet global forest and landscape restoration needs. Reforesta. 4: 69–93.

The USDA Forest Service National Seed Laboratory: Supporting Reforestation and Restoration Efforts on National Forests

Victor Vankus

Overview:

- On the USDA Forest Service National Forest System, reforestation and restoration plans often require tree seedlings and native plant seed to expedite achieving a desired future condition following timber harvests, wildfires, and outbreaks of disease and insect pests. The seed and seedlings used by the agency for these purposes are produced by its Genetic Resource Program and its Nursery System, State forestry offices and other public agencies, and the commercial forest nursery and native seed industries. The Forest Service National Seed Laboratory (NSL) was established in 1954 to support these producers by providing seed testing services and technical assistance to ensure the production of high-quality seed and seedlings. Seed tests determine seed quality and the results are used by forest nurseries to efficiently manage the annual production of more than one billion seedlings, by seed processing plants to evaluate the quality of seed produced, and by seed companies and agencies as the basis for seed price determination. From 2012 to 2019 the NSL conducted more than 45,000 seed tests for more than 200 clients and provided technical assistance to partners by providing expertise and information on seed collection, processing, storage, germination, and production in support of a wide range of research and management objectives. The NSL is a national program funded cooperatively by State and Private Forestry, the National Forest System, and Research and Development. It is also a part of the National Center for Reforestation, Nurseries, and Genetic Resources (RNGR) program. This presentation will review the NSL program with an emphasis on service delivery.

Summary:

None provided.

Silvicultural Applications:

- None provided.

Management Opportunities:

- None provided.

RNGR: A National Resource for Forest Seedling Production and Outplanting Programs

Diane L. Haase

Overview:

- The USDA Forest Service's Reforestation, Nurseries, and Genetic Resources (RNGR) Team is a unique and innovative collaboration across all three Deputy Chief Areas.
- The RNGR Team develops and delivers science-based technology used by the Agency and Federal, State, Tribal, and private partners to produce high-quality, genetically appropriate seedlings critical for meeting reforestation, conservation, and restoration goals nationally and internationally.

Summary:

The U.S. Department of Agriculture, Forest Service's National Reforestation, Nursery, and Genetics Resources (RNGR) Program is conducted by a team of specialists (referred to as the "RiNGeR Team") that provides regional and national technical assistance to nursery, reforestation, restoration, and seed professionals. The Forest Service National Seed Laboratory (NSL), a Tribal nursery emphasis, and research projects are also key components of the RNGR Program. RNGR Team members are geographically dispersed (fig. 1) and attuned to both regional and national needs.

Through on-site visits, workshops, regional meetings, publications, web resources, and partnerships, the RNGR Team provides technical expertise and resources to solve problems, improve efficiency, and increase quality and diversity of nursery-grown plants. Many of RNGR's technical publications often serve as the authoritative standard (fig. 2). The RNGR website (https://rngr.net) is used extensively by nursery, forestry, and restoration professionals around the world. The site contains a repository of more than 12,000 articles, a national nursery directory, a database of more than 3,000 propagation protocols, a calendar of events, and many other resources.

Given the rising demand for nursery production and outplanting to restore forests affected by wildfire, pests, insects, and other disturbances, RNGR's coordination, development, and dissemination of science-based technology will continue to be an integral resource for nursery and land managers engaged in ecosystem restoration.

Silvicultural Concepts:

- The success of reforestation and restoration outplanting projects necessitates the use of quality plant materials from genetically and ecologically appropriate seed sources.
- Each tree species has its own requirements for seed germination, propagation, storage, and handling.
- The agency's RNGR team provides technological support regarding all aspects of seedling production, handling, planting, and quality.

Management Applications:

- The current rise in attention and legislation for expanding forest restoration and seedling production necessitates expert technical support on all aspects of seedling production from seed to outplanting.
- The RNGR Team provides current, relevant technical assistance to help managers respond to an ever-increasing demand for ecologically appropriate plant materials critical for addressing forest restoration, climate change, invasive species and pests, habitat loss, wildfire, and other factors.

Figure 1—The eight-member Reforestation, Nurseries, and Genetics Resources (RNGR) Team is geographically dispersed to provide expert support both regionally and nationally.

Figure 2—Technical manuals and publications generated by RNGR often serve as the industry standard.

References

Fargione, J.; Haase, D.L.; Burney, O.T.; Kildisheva, O.A.; Edge, G.; Cook-Patton, S.C.; Chapman, T.; Rempel, A.; Hurteau, M.D.; Davis, K.T.; Dobrowski, S.; Enebak, S.; De La Torre, R.; Bhuta, A.A.R.; Cubbage, F.; Kittler, B.; Zhang, D.; Guldin, R.W. 2021. Challenges to the reforestation pipeline in the United States. Frontiers in Forests and Global Change. 4:629198.

Haase, D.L.; Pinto, J.R.; Dumroese, R.K.; Hernández, G.; Karrfalt, B.; Overton, R. 2011. RNGR: A national resource for reforestation, restoration, and nursery professionals. Tree Planters' Notes. 54(1): 28–34.

Haase, D.L.; Pike, C.; Enebak, S.; Mackey, L.; Ma, Z.; Silva, C.; Warren, J. 2021. Forest nursery seedling production in the United States—fiscal year 2020. Tree Planters' Notes. 64(2): 108–114.

Growing a Better Seedling

Growing a Better Seedling

Driving Seedling Morpho-Physiology Towards Drought Tolerance With Drought Conditioning in the Nursery

Jessie M. Godfrey, Andrew Nelson, Jeremiah Pinto

Overview:

- Experiment 1: A late season drought of 10 weeks was applied to potted ponderosa pine and western redcedar seedlings, then followed by 1 month of recovery. Measurements of growth, photosynthesis, water status, wood anatomy, and biochemistry in droughted seedlings were compared to a well-watered control.
    - For ponderosa pine, living parenchyma cells occupied a smaller fraction of wood in droughted seedlings than in control seedlings, which may indicate a drought acclimation available to ponderosa pine. Incoming carbon is often limited by drought, but if less sugar (less carbon) is distributed over equivalently lower cell volume, the osmotic strength required for water retention (and so cell turgor) may be maintained.
    - Droughted western redcedar seedlings demonstrated less variability (no significant differences) in the wood fraction occupied by living parenchyma cells relative to control seedlings. Comparatively, these cells occupied significantly lower fractions of wood relative to ponderosa pine regardless of treatment. This may help to explain western redcedar's consistently low stem vulnerability to embolism (high stem resistance to drought).
- Experiment 2: Greenhouse irrigation treatments were used to drought condition ponderosa pine and western redcedar seedlings prior to outplanting.
    - For ponderosa pine, a nursery culturing treatment that reduced irrigation starting 10 weeks after radical emergence, then returned to well-watered conditions at around budset, led to no significant difference from consistently well-watered control seedlings in new root tip counts prior to outplanting; however, the same treatment had significantly deeper tap roots and 0% mortality after the first outplanting season (relative to 4.2% for the control).
- Western redcedar seedlings responded poorly to any drought-conditioning in terms of root growth and performed no better than the control or worse at outplanting.

Summary:

Hot, dry climates are a menace to seedling establishment in naturally and artificially regenerated forests alike. These tough outplanting conditions are problematic because a seedling's limited mass dictates reserves of energy (sugars or starch), water, and nutrients. Furthermore, in order to establish itself, risky investments in growth must precede any leap in a seedling's ability to acquire new resources (i.e., increases in light interception for photosynthesis or soil exploration for water and nutrient uptake). With new climate normals indicating hotter and dryer growing seasons combined with more frequent stand replacing (and seedbank-incinerating) fires, as well as initiatives from governments across the world to plant more trees, it is critical to advance our understanding of how nursery interventions may prepare seedlings for dry environments. In two studies, we examine some of the ways that seedling morphophysiological characteristics may be modified by nursery culture to increase seedling survival under dry outplanting conditions.

Silvicultural Concepts:

- This research aligns with the target plant concept in tailoring seedling fitness for purpose. Targets for conventionally grown seedlings, set to maximize productivity at high productivity sites, may lead to traits that decrease fitness (survival and subsequent growth) at sites subject to tough outplanting conditions or low productivity. Just as treatments like thinning, prescribed burning, or vegetation control can be used to manage growth and composition in a standing forest, cultural controls in the nursery such as irrigation, fertilization, temperature, or light may be used to enhance a seedling's fitness for purpose—in this case, at dry outplanting sites.

Management Applications:

- Our preliminary findings indicate that stems (living cells in the wood) and roots (early season tap root length) of ponderosa pine seedlings may vary significantly with the moisture conditions imposed at outplanting and/or with the moisture conditions imposed in the nursery. These observations may make ponderosa pine an ideal model plant for additional drought conditioning research in conifers, and the traits observed may be candidates for wide scale nursery conditioning for drought tolerance in similar species.

- The root morphology and stem anatomy of western redcedar appear relatively unresponsive to moisture conditions. This species does not form a taproot and its stems are relatively resistant to embolism even under well-watered conditions (50% loss of conductivity occurs in western redcedar at around -5 MPa relative to -3 MPa in ponderosa pine). It may be that because the stem anatomy of this species is always comparatively primed for drought tolerance with lower parenchyma fractions as well as narrower tracheids, it has less morphological leeway for adjustment.

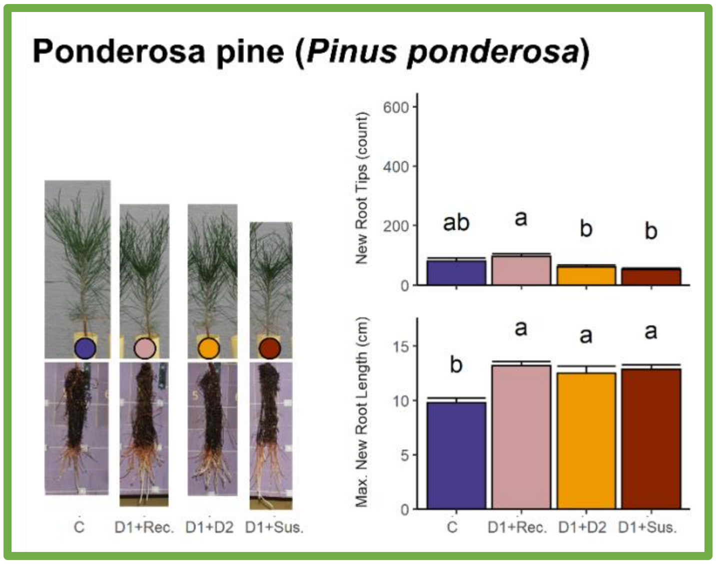


Figure 1—Ponderosa pine seedling characteristics after the greenhouse-imposed drought culture treatments in Experiment 2. Treatments were a well-watered control (C, blue) as well as three drought-conditioning treatments (D1+Recovery in pink, D1+D2 in orange, and D1+Sustained in red). See treatment details in the table description below. Data represent means and standard error; letters indicate significance groupings (Tukey's HSD, $P < 0.05$).

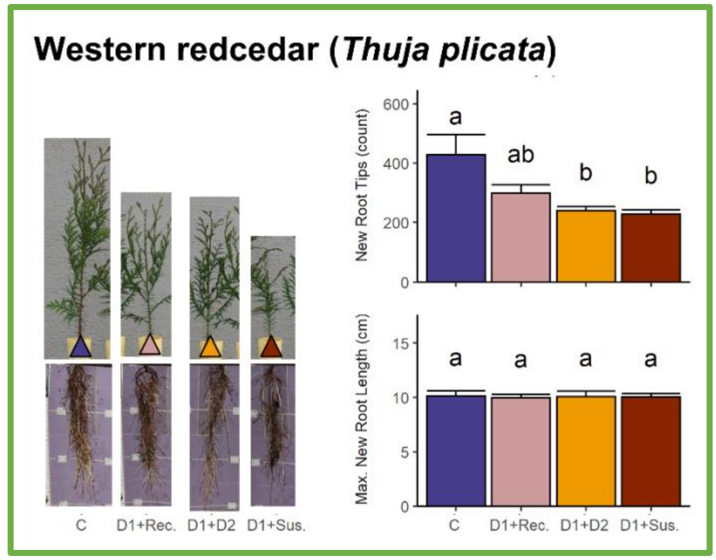


Figure 2—Western redcedar seedling characteristics after the greenhouse-imposed drought culture treatments in Experiment 2. Treatments were a well-watered control (C, blue) as well as three drought-conditioning treatments (D1+Recovery in pink, D1+D2 in orange, and D1+Sustained in red). See treatment details in the table description below. Data represent means and standard error; letters indicate significance groupings (Tukey's HSD, $P < 0.05$).

Table 1—Ponderosa pine and western redcedar seedling characteristics (averages ± standard error, n = 6) prior to outplanting for the greenhouse-imposed drought culture treatments in Experiment 2. These treatments included (1) a well-watered control (C); (2) an early season reduced irrigation period, followed by recovery to well-watered conditions (D1+Recovery); (3) an early season reduced irrigation period, followed by some recovery then a late season irrigation period and a final recovery (D1+D2); and (4) an early season reduced irrigation period, sustained to the end of the season and a final recovery (D1+Sustained). Letters in parentheses indicate significance groupings (Tukey's HSD, $P < 0.05$). Asterisk (*) in the Survival column indicates that no statistical analysis was performed.

Species	Treatment	Height (cm)	Diameter (mm)	Survival (%)*
Ponderosa pine	C	16.71 ± 0.60 (a)	4.02 ± 0.10 (a)	95.8 ± 4.17
	D1+Recovery	13.42 ± 0.49 (b)	3.74 ± 0.18 (bc)	100 ± 0.00
	D1+D2	12.78 ± 0.50 (b)	3.48 ± 0.14 (bc)	95.8 ± 4.17
	D1+Sustained	12.71 ± 0.54 (b)	3.13 ± 0.09 (c)	95.8 ± 4.17
Western redcedar	C	36.63 ± 1.63 (a)	3.55 ± 0.17 (a)	66.7 ± 10.54
	D1+Recovery	25.81 ± 1.16 (b)	2.93 ± 0.10 (ab)	66.7 ± 16.67
	D1+D2	22.53 ± 0.83 (b)	2.57 ± 0.07 (bc)	41.7 ± 15.37
	D1+Sustained	18.67 ± 0.31 (b)	2.13 ± 0.07 (c)	45.8 ± 15.02

Testing the Potential of Biochar to Improve Bareroot Nursery Efficiencies

D. Page-Dumroese, R.K. Dumroese,
J. Tirocke, R. Gilbert, S. Wilson

Overview:

- Excessive woody biomass from forest sites can be used to create biochar that can be used in forest nurseries.
- Biochar applications add carbon to soils, which increases nutrient and water retention.
- We applied biochar at a rate of 0.5 tons/acre to bareroot beds at Lucky Peak and Bessey nurseries.
- Early results indicate that biochar can increase the amount of nitrate and ammonium available to plants and decrease the amount lost to leaching.
- Biochar also increases available water in the root zone, which has the potential to reduce irrigation frequency.

Summary:

One way to increase conversion of woody residues often burned in slash piles into a value-added product is to expand markets for biochar. Biochar has been used to increase the growth of agricultural crops, grass, and urban trees and it has also been used as replacement for *Sphagnum* peat moss, perlite, or vermiculite in growing substrates for container seedlings (Dumroese et al. 2020). Using biochar in bareroot nursery beds is an opportunity for improving soil properties while also reducing nutrient and irrigation inputs. After 1 year, biochar reduced the amounts of NO_3^-- N (fig. 1) leaching downward through the soil profile and increased the amount of soil solution NH_4^+-N (fig. 2) at the 10 cm depth. This nitrogen data highlights the importance of adding a high-carbon substrate (biochar) to limit fertilizer losses. One benefit often described about biochar additions to soil, particularly coarse-textured soil, is the ability to increase plant available water (Page-Dumroese et al. 2017). At the Bessey Nursery, biochar increased plant available water at the 5 cm soil depth as compared to the control. Plant available water at 15 cm was, however, less after biochar application. This is likely because biochar may have retained more water in the upper soil profile rather than allowing it to move downward in the soil profile. Biochar has also been shown to reduce soil bulk density (Page-Dumroese et al. 2017), which can also improve root growth and prevent

root defects. In addition, biochar can reduce *Phytophthora* expansion in nursery beds (Zwart and Kim 2012). To date, no deleterious impacts of biochar to bareroot nursery soils have been observed.

Silvicultural Concepts:

- Many forests have excess woody biomass created during fuels reduction, thinning, or other harvest activities.
- Excess woody biomass can be converted to biochar rather than burned in slash piles using in-woods processing systems or creating slash piles to maximize biochar production.
- Conversion to biochar emits less emissions than burning slash piles.
- Distributing the biochar to local nurseries can improve bareroot nursery bed soil while also sequestering carbon.
- Biochar can improve soil health and produce healthy seedlings with fewer fertilizer and irrigation inputs.

Management Applications:

- Soil scientists, land managers, and nursery managers have an opportunity to convert excess woody biomass into a high-value, high-carbon product that can be used in bareroot nursery beds.
- Biochar increases soil organic matter content and can reduce nutrient leaching while increasing plant available water. Higher soil organic matter content has implications for pest control, especially fumigation.
- In addition, biochar is a tool to sequester carbon for many decades while reducing the risk of wildfire on public lands.

References

Dumroese, R.K.; Page-Dumroese, D.S.; Pinto, J.R. 2020. Biochar potential to enhance forest resilience, seedling quality, and nursery efficiency. Tree Planters' Notes. 62: 61–69.

Page-Dumroese, D.S.; Coleman, M.; Thomas, S.C. 2017. Opportunities and uses of biochar on forest sites in North America. In: Biochar: A regional supply chain approach in view of climate change mitigation. Chapter 15. Cambridge, UK: Cambridge University Press.

Zwart, D.C.; Kim, S.H. 2012. Biochar amendment increases resistance to stem lesions caused by *Phytophthora* spp. in tree seedlings. HortScience. 47: 1736–1740.

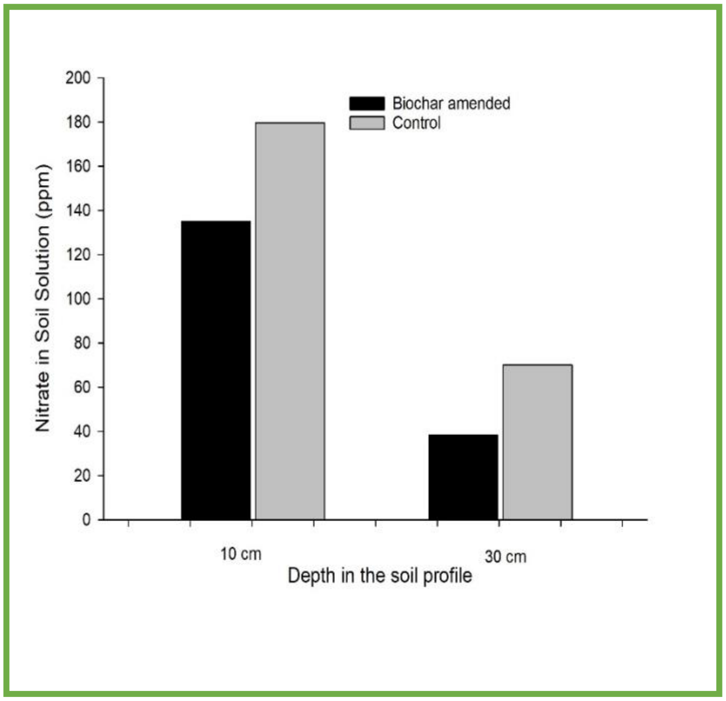


Figure 1—Nitrate in soil solution in plots with 0.5 tons/acre biochar and the control at the Bessey Nursery.

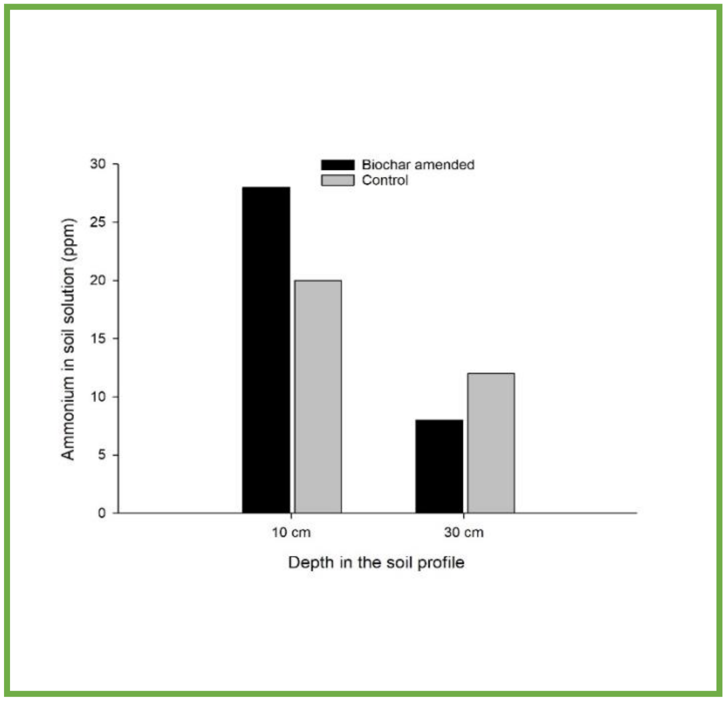


Figure 2—Ammonium in soil solution in plots with 0.5 tons/acre biochar and the control at Bessey Nursery.

Table 1—Soil bulk density and available water one year after applying 0.5 tons/acre biochar

Treatment	Soil depth (cm)	Bulk density (Mg m^{-3})	Available water (%)
Control	5	1.7	4.3
	15	1.6	5.7
Biochar	5	1.6	5.4
	15	1.7	3.6

Effects of Biochar on Drought Tolerance of *Pinus banksiana* Seedlings

Laura F. Reuling, Alan J. Z. Toczydlowski, Robert A. Slesak, Marcella A. Windmuller-Campione

Overview:

- With climate change, seedlings are likely to experience more prolonged and more extreme drought.
- Biochar has been proposed as a soil amendment that could increase water holding capacity in soils, reducing drought impact on planted seedlings.
- In a greenhouse experiment, we did not see any significant effect of biochar as a soil amendment on growth or survival of *Pinus banksiana* seedlings subjected to low water availability or increasing levels of drought duration.
- Field trials are needed to determine if biochar may be more effective when seedlings develop under ambient field conditions.

Summary:

In the upper Midwest, climate change is expected to result in longer periods of drought during the growing season and increased summer temperatures. These pose a particular threat to seedlings, both natural and artificial regeneration, which are more susceptible to drought than mature trees. Biochar, a product created through pyrolysis of organic material (including wood and wood waste), has been proposed as a soil amendment that can both increase the water-holding capacity of soil (and therefore increase the drought tolerance of seedlings in that soil) and increase carbon storage. In this experiment, we used a greenhouse setting to test whether the addition of biochar to sandy soil would increase the survival of jack pine *(Pinus banksiana)* seedlings under drought conditions. We tested three amounts of biochar (none, 3% biochar by weight, and 6% biochar by weight) in two separate experiments. The first experiment manipulated timing of drought onset; seedlings received a sufficient amount of water until week 3, 7, or 11 after planting and then no water after that. We evaluated effects of both biochar and drought timing on seedling survival. In the second experiment seedlings received water throughout the experiment, either in low (20 ml) or high (200 ml) amounts every other day. In this experiment, we assessed the effects of both biochar and water amount on seedling growth and on seedling physiological processes.

Silvicultural Concepts:

- Biochar was not found to have a significant effect on seedling survival or growth in either experiment.
- Timing of drought onset also did not have an effect on seedling survival (fig. 1). Seedlings experiencing a drought beginning in week 3 after planting survived approximately the same number of days of drought as seedlings experiencing a drought beginning in week 11. A longer establishment time did not give seedlings an advantage to survive the drought.
- In experiment 2, watering level (low vs. high) had a significant effect on both seedling height and seedling basal diameter (fig. 2). Seedlings receiving more water were both taller and had larger diameters, but the differences in diameter were much more pronounced than the height differences. Seedlings receiving a low amount of water seemed to allocate resources to height growth over diameter growth.

Management Applications:

- Our findings did not support the hypothesis that the addition of biochar to soil will help seedlings survive drought in sandy outwash soils.
- However, since we did not find any impact of biochar to seedling growth or survival (positive or negative), biochar may be able to be added to soil for other reasons (such as carbon storage) without having a negative impact on seedlings.
- Seedlings receiving little water allocated more resources to height growth than diameter growth, which may mean that seedlings experiencing drought conditions can meet height requirements for regeneration to be considered successful, but still have significant growth deficiencies in stem diameter.
- Additional field trials should be performed to determine if seedling development under field conditions is influenced by biochar addition.

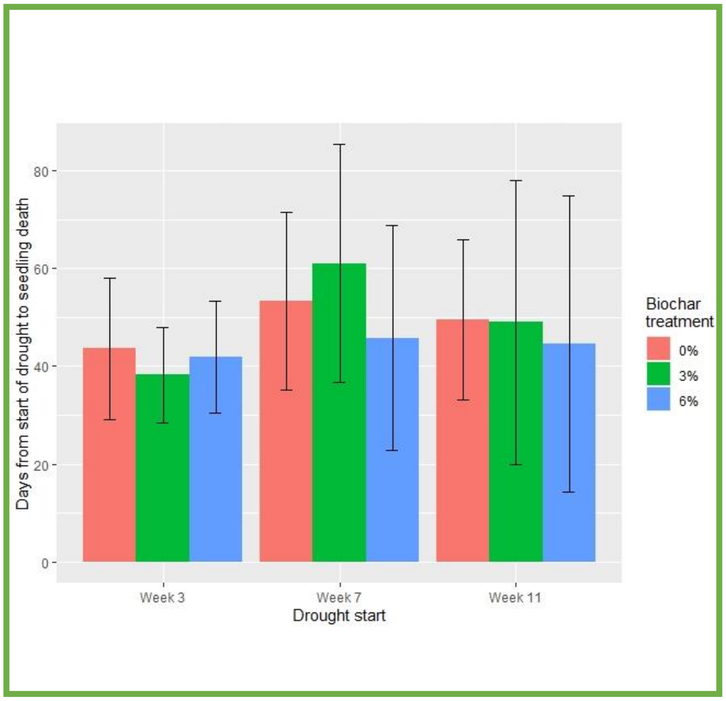


Figure 1—Experiment 1: Seedling survival after drought onset by biochar treatment and drought start week.

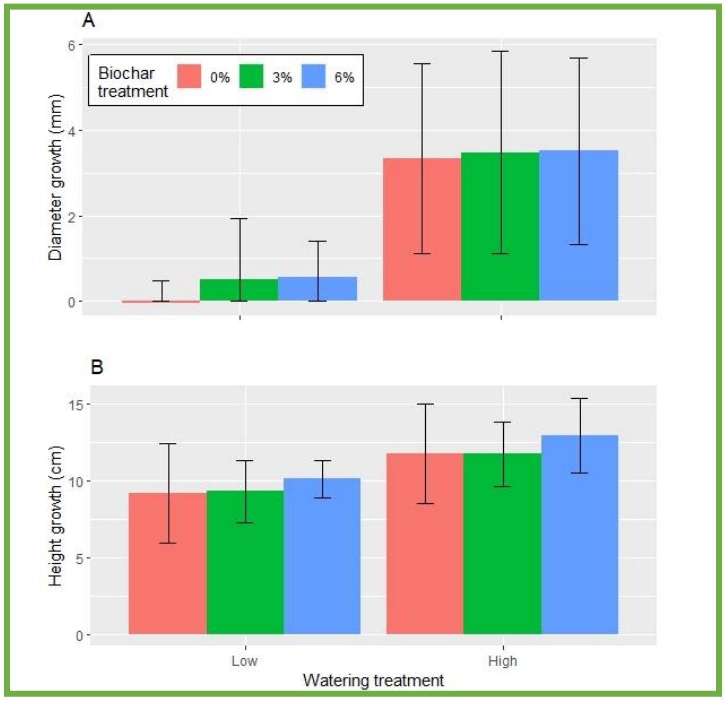


Figure 2—Experiment 2: Seedling (A) diameter and (B) height growth from time of planting to end of experiment by biochar treatment and watering level treatment. Error bars represent one standard deviation.

Using Disease Resistance Breeding and Silviculture to Ensure a Diverse, Healthy Forest for the Future

Richard A. Sniezko, Robyn Darbyshire

Overview:

- More and more of our Nation's tree species are under attack by nonnative, invasive diseases or pests. In many cases, there is high mortality and not much that prevents the functional loss of many of the affected species. In some cases, the mortality is high enough to that species may be considered endangered. Too often, investigations to determine levels of natural resistance are delayed while other avenues of containment or biocontrol are tried, often to no available. There are increasing number of success stories in the development of populations resistant to diseases and pests, and more focus is needed here. Once resistant populations are developed, silviculturists will be key to getting the species back on the landscape. We will provide examples of successful resistance programs and how the materials are being used.

Summary:

None provided.

Silvicultural Applications:

- None provided.

Management Opportunities:

- None provided.

Partnerships Are Critical

Postfire Reforestation in Northern Sierra Nevada Forests: Testing Silvicultural and Genetic Approaches in a Changing Climate

Christopher Looney, Jessica Wright, Clay Davis, Ryan Davy, Joseph Stewart, Jianwei Zhang

Overview:

- Scientist-manager partnerships are investigating novel silvicultural approaches for improving postfire reforestation success and fostering long-term climate-change adaptation in California's low-elevation, westside Sierra Nevada forests.
- A three-species assisted migration field trial of tree seedlings representing genotypes from a range of climates is being installed to (1) identify the most suitable species and seed sources for reforestation of low-elevation sites of varied quality and (2) validate the Climate Adapted Seed Tool developed from extensive provenance test data to inform seed transfer decisions.
- A parallel mixed-species planting study will assess whether species mixtures can aid short-term planting success by buffering against microclimate, site variation, and damaging agents.
- A greenhouse study will help identify key differences between seed sources driving the results of the genetics and mixed-species field experiments.
- On a separate site, a reforestation study will evaluate the effects of initial spacing and vegetation control on the performance of clustered plantings, a controversial and scientifically untested technique that some ecologists theorize could reduce fire risk and improve tree survival.

Summary:

Climate change is intensifying the scope and severity of California wildfires, causing widespread deforestation. Successfully reforesting burn areas is key to recouping lost carbon sequestration and storage, wood products, wildlife habitat, and aesthetics. However, rising aridity under climate change poses major challenges to reforestation success, depriving planted seedlings of moisture while elevating reburn risk, particularly on arid, low-elevation sites. In partnership with managers, we are establishing three experiments on recently

burned sites in the Plumas National Forest to identify attributes conducive to low-elevation reforestation success.

In the Concow Basin near Paradise, California, parallel genetics/silviculture field trials are being installed. To address genetics questions, we will plant ponderosa pine, incense cedar, and black oak seedlings from a range of current climates and evaluate their response to the novel environment. This trial will also validate the Climate Adapted Seed Tool developed using extensive provenance test data. The silvicultural study will plant the same species to assess growth and survival of mixed-species versus monoculture plantings and determine whether species mixtures boost planting success by buffering against microclimate, site variation, and damaging agents. A greenhouse component, using the same seed sources as the genetics trial, will help identify key physiological factors driving the results of the paired field experiments.

A separate initial spacing/vegetation control experiment will evaluate the effects on growth, drought-resistance and overall survival of clustered plantings, a technique that has gotten much attention recently. Some ecologists theorize that it may reduce fire risk and improve tree survival, but this hypothesis is untested.

Silvicultural Concepts:

- Tree species are expected to be locally adapted to the climate where they are found. By using information about current and modeled future climate at a planting site, it may be possible to select seed sources that are better adapted to the site than local seed. This idea is being tested by planting different seed sources of the same species in each planting area.
- Diverse plantings are anticipated to reduce the risk of reforestation project loss under drought, microsite variability, and future disturbance. The Concow Basin study will evaluate the initial performance of plantings ranging from monocultures to three-species polycultures.
- Mixed-species stands may enhance the rate and stability of stand growth, but biodiversity-productivity relationships frequently vary by site quality. The Concow Basin study will inform managers in selecting the most effective species combinations for the rapid, stable recovery of ecosystem services on challenging Nevada foothill sites.
- Two tactics to reduce the risk of reburn in young stands are (1) increasing initial spacing between trees, and (2) planting seedlings in clustered arrangements. Wider spaces between trees or clusters of trees are anticipated to increase the already critical importance of effective competing vegetation control. These techniques assure that trees grow quickly over the flame length and accumulate thicker bark that resists wildfires. Whereas the purpose of the cluster arrangement is to break up the stand

canopy, it may also increase the intensity of competition for soil water and nutrients, yielding slower stand growth.

Management Applications:

- Ryan Davy, Silviculturist, Feather River Ranger District, Plumas National Forest: “While recent research has provided a lot of foundational regeneration principles for the Central Sierras, large-scale fires have made it imperative to focus limited resources into successful reforestation efforts. This research will help refine multiple silviculture techniques and help guide us locally for tackling the challenges we have ahead.”
- Wolfgang Rougle, Forest Health Watershed Coordinator, Butte County Resource Conservation District: “Stand-replacing fires, while traumatic for a community, also furnish an opportunity to supplement local tree seeds with conspecific seeds from far-away locations. Seeds that are of a location’s native species, but come from hotter or drier parts of the native species’ range, could be well-adapted to the climate that will arrive in that location 5 or 10 years (or has already arrived). When it comes to this style of assisted migration, models exist to help land managers narrow down their guesses, but they have not been field-tested until now.”

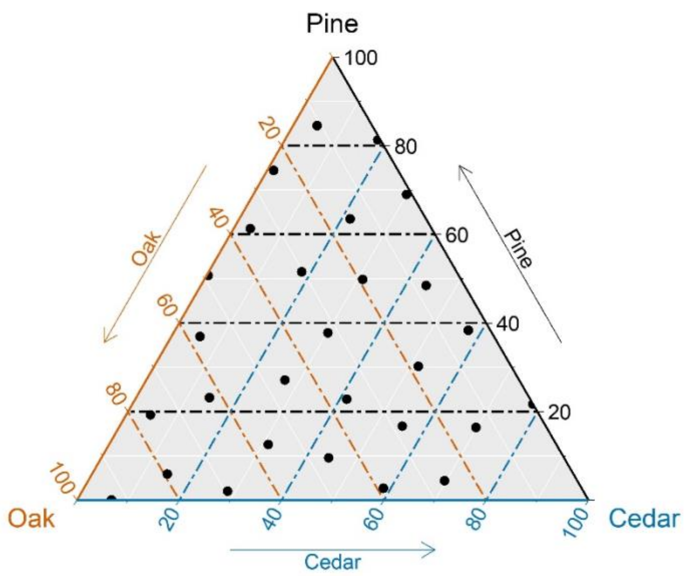


Figure 1—Ternary plot illustrating the space-filling design used to create three-way continuous mixtures of black oak, incense-cedar, and ponderosa pine.

Figure 2—Example plot of the Concow Basin study following site preparation and monumentation prior to planting.

A Long-Term Research-Practice Partnership Leads to Successful Reforestation in Northern California

Jianwei Zhang, Bob Rynearson, Mark Gray, Jeff Webster, Ed Fredrickson, Kaelyn Finley

Overview:

- A partnership between forest researchers and practitioners called Sierra Cascade Intensive Forest Management Research Coop has been established since 2000 to tackle reforestation problems in Northern California and Southern Oregon.
- Major obstacles were identified and techniques have been developed for various reforestation stages from seed, seedling culture and handling, site preparation, competing vegetation control, plantation pre-commercial thinning, and future density management.
- Although new problems appear and research continues to be proposed to address them, the developed techniques have assured an average of 36 million of seedlings to be successfully established on wildfire-burned ground in Northern California for the last several decades.

Summary:

Management problem: The successful reestablishment of native conifer tree stands is a key step in forest restoration. In recent years, high severity wildfires have burned tens of millions of acres of forests in the western United States. Many of these lands require artificial reforestation and subsequent management in order to be fully restored and resilient to future drought, wildfire, and widespread insect attacks. Even though some seed trees may remain in the burned landscapes, natural regeneration has not guaranteed a resilient forest that can withstand the next wildfire. Furthermore, following regeneration, young stands require appropriate density and fuels management to promote or enhance tree stands toward resilient forest.

Management need: To successfully restore forests on these massively burned landscapes, forest managers need all available techniques in their toolbox, from appropriate seed selection to quality seedling production, from site preparation to effectively controlling competing vegetation, and from precommercial thinning to later plantation density and fuel

management. All these techniques must be developed from the carefully designed studies on particular climate and soil.

Research purpose: During the last half century, a long-term collaboration between forest researchers and forest practitioners in national forests and privately owned forests has developed highly successful practices for young stand establishment and density and/or fuels management. This cooperative process involved endeavors and efforts to work with, learn from, and communicate the results among generations of scientists and field foresters. Success has been demonstrated by many large-scale postfire reforestation projects across Northern California.

Silvicultural Concepts:

- Successful reforestation must be done by breaking the project into ecological/operational units based on soils, aspect, elevation, vegetation type, access, slope, operability, and other attributes. A series of steps or techniques will vary with different conditions.
- Selecting appropriate seeds and seed sources enables managers to not only raise high quality seedlings, but also enhance seedling survival. In addition, managers can choose seed sources from the lower end of suitable seed zones to assist species migration in response to future climate warming.
- Conifer seedlings require a period of chilling to complete dormancy before they resume growth. Seedling handling times such as sowing, blacking out, lifting, and storing directly relate to seedling dormancy and cold hardiness; both are very important to the seedling field performance.
- Given the Mediterranean climate in California, soil water availability is the key limiting factor for tree survival and growth. Therefore, effectively controlling competing vegetation has made a significant contribution for the success of stand establishment. The most effective and efficient methods are applying herbicide; considerable studies on efficacy and conifer tolerance have developed some successful treatments.
- Before stand canopy closure, an appropriate precommercial thinning must be conducted for stand growth potential and for the planted forest to remain healthy and resilient as it grows.

Management Applications:

- The key to success of any reforestation project is proper planning that consists of a series of steps and requires paying much attention to detail. Failing on any one of these steps often spells failure for the whole effort. One common failure that people often see while travelling around Northern California is a lack of vegetation control (fig. 1). Forest managers have used the results from our research-practice partnership group to effectively control competing vegetation with herbicide application. The data were also used for the herbicide registration in the states of California and Oregon. As a result, any reforestation project with competing vegetation controlled by herbicide has produced better outcomes (more successful) than by manual grubbing, with the added benefit of being much cheaper.

- Successful plantation establishment is not possible without high-quality seedlings, which requires nursery managers not only to understand how to grow seedlings in nursery beds or containers, but also how to lift, pack, store, and deliver seedlings while maintaining quality. Our partnership research has focused on studying the effects of seedling culture and handling on field performance of containerized Douglas-fir seedlings and found that using an appropriate seedlot and seedling culture would significantly increase reforestation success. Regeneration foresters can use the results to obtain planting stocks matching the planting seasons and sites.
- As trees grow larger in either natural stands or plantations, competition develops among them. Competition weakens trees and weak trees are potentially more susceptible to bark beetles and climate change. Lowering stand density was found to enhance remaining tree growth, reduce mortality, and increase stand resiliency to disturbance and climate change. Since neither climate nor disturbances can be easily controlled, forest managers can manage stand density based on stand age and environmental conditions to potentially mitigate the threats from climate change and potential disturbances.

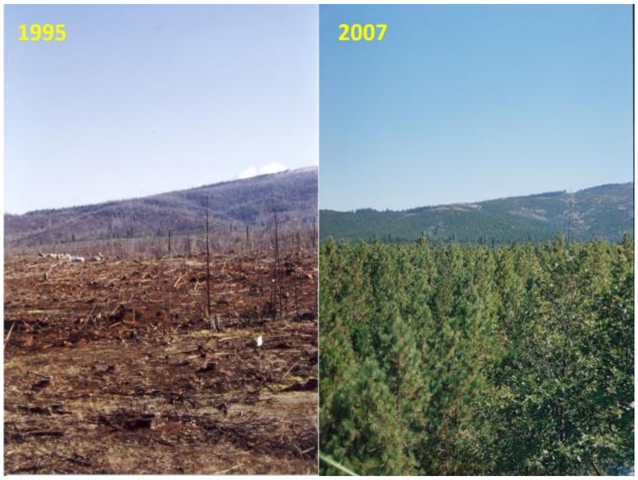


Figure 1—Successful post-fire reforestation on the 1992 Fountain Fire at Shasta County, California. The fire burned through 64,000 acres. Most industry-owned 40,000 acres were reforested within next 5 years.

Figure 2—Eleven-year-old ponderosa pine plantations at the same area within the 2007 Moonlight Fire with herbicide controlling competing vegetation applied at second and fourth years after planting at top one that was pre-commercially thinned 3–4 years earlier and with manual grubbing shrubs around each tree at the bottom one. Both photos were taken in 2019.

References

Stewart, W. [tech. ed.]. 2021. Reforestation practices for conifers in California. Berkeley, CA: University of California Press. 604 p.

Zhang, J.; Jopson, T; Gray, M. 2020. Effects of lift date and seed lot on field performance of containerized Douglas-fir seedlings. Tree Planters' Notes. 64(2): 4–15. https://rngr.net/publications/tpn/64-2.

Zhang, J.; Webster, J.; Powers, R.F.; Mills, J. 2008. Reforestation after the Fountain Fire in Northern California: An untold success story. Journal of Forestry. 106(8): 425–430.

Adaptive Silviculture in an Urban Environment: Initial Survival and Design Setup

Marcella Windmuller-Campione, Mary Hammes, Leslie Brandt, Auste Eigirdas, Rebecca Montgomery, Linda Nagel, Courtney Peterson

Overview:

- The floodplain forests of the Upper Mississippi River located in Crosby Farm Regional Park are an urban forest ecosystem where managers are facing impacts from climate change, invasive species, and aging overstory trees; natural regeneration is not occurring.
- Utilizing the framework developed by the Adaptive Silviculture for Climate Change (ASCC) network, we installed the first urban site within the network during the spring of 2020.
- Survival during the 2020 growing season across all three treatments (resistance, resilience, and transition) was high; however, mortality was highest in the transition treatment likely due to poor nursery stock quality.

Summary:

The Crosby Farms ASCC site sits in a Saint Paul Park and Recreation Area, owned and managed by the City of Saint Paul, that is embedded within the Mississippi National River and Recreation Area (MNRRA), a national park. Within the 736-acre park, there has been significant mortality of overstory green ash (*Fraxinus pennsylvanica*) due to the invasive emerald ash borer. Utilizing these already established mortality centers, three areas (or blocks) were identified. Prior to the removal of the mostly dead overstory, pretreatment conditions were measured. Overstory trees were removed during the 2019–2020 winter season. Twenty-four 1/10th acre permanent plots were established and fenced and included an unplanted control (3 blocks x 2 replicates x 4 treatments = 24 plots). We planted each plot with 3- to 6-ft bare root stock at a 10-ft spacing within the resistance, resilience, and transition treatments. Species that constitute each treatment include the following:

(1) Resistance: silver maple (*Acer saccharinum*), American elm (*Ulmus americana*), cottonwood (*Populus deltoides*), hackberry (*Celtis occidentalis*), and river birch (*Betula nigra*) from nurseries in USDA plant hardiness zone 4.

(2) Resilience: silver maple, American elm, cottonwood, black willow (*Salix nigra*), river birch, bur oak, American sycamore (*Platanus occidentalis*), and swamp white oak (*Quercus bicolor*) from nurseries in USDA plant hardiness zone 5, plus silver maple from zone 4.

(3) Transition: silver maple, red maple (*Acer rubrum*), American sycamore, river birch, sweetgum (*Nyssa sylvatica*), southern pin oak (*Quercus palustris*), and tulip poplar *(Liriodendron tulipifera*) from USDA plant hardiness zone 6 nurseries, plus silver maple from zone 4.

First year survival was generally high (86.5%) across all planted treatments; the transition treatment had the lowest survival (68% S.E. 2.8%), with red maple, river birch, and tulip poplar suffering the greatest mortality. Annual monitoring will continue into the future and provide critical information to mangers.

Silvicultural Concepts:

- Large bareroot stock (3 to 6 ft) was planted by volunteers and survival was high.
- Red maple, river birch, and tulip poplar from zone 6 had the greatest mortality. Mortality was likely due to issues with the stock and was related to greater transportation time.
- Competition control was completed during the growing season on herbaceous understory species.
- Long-term monitoring is critical to assess both short-term and long-term survival and growth of this understudied ecosystem and the planting of novel species.

Management Applications:

- The Adaptive Silviculture for Climate Change (ASCC) framework was successfully applied in an urban floodplain ecosystem and highlighted the ASCC's ability to be used in multiple ecosystems and at multiple scales. The initial planning meeting brought individuals from multiple disciplines and organizations together to discuss climate adaptive management within the Upper Mississippi River. This has spurred additional conservation and ideas related to adaptive management outside of the formal experiment at Crosby Farms Regional Park. Additionally, by partnering across multiple organizations, including organizations with extremely active and engaged volunteers, this project can engage citizens within maintenance (upkeep on fences) and data collection, providing opportunity for greater connections among silviculture, climate adaptive management, and future forests.

Figure 1—Example of a transition plot post planting in spring 2020.

Figure 2—The associated mortality areas created by emerald ash borer (red) and location of the twenty-four 1/10th acre plots (blue dots) within Crosby Farms Regional Park.

Table 1—Example of the planting design within the 1/10th acre plot. Each tree species was individually marked and randomly assigned a planting location. Spacing was on a 10 x 10 ft grid. Seedlings were permanently marked after planting and nail polish was used to mark locations for measurements for basal diameter and diameter at breast height (d.b.h.) for repeated measurements. Species code include the first two letters of the genus and species, followed by the planting zone, and then the nursery.

TRANSITION								
Plot 1								
			BENI-Z6-WA	ACSA2-Z4-CR	LITU-Z6-WA			
		ACSA2-Z4-CR	PLOC-Z6-WA	BENI-Z6-WA	ACSA2-Z6-WA	ACRU-Z6-WA		
	ACSA2-Z4-CR	ACSA2-Z4-CR	PLOC-Z6-WA	QUPA-Z6-WA	ACSA2-Z6-WA	ACRU-Z6-WA	LIST-Z6-WA	
LIST-Z6-WA	QUPA-Z6-WA	ACSA2-Z6-WA	BENI-Z6-WA	ACRU-Z6-WA	BENI-Z6-WA	LIST-Z6-WA	LITU-Z6-WA	LIST-Z6-WA
ACSA2-Z4-CR	LITU-Z6-WA	ACSA2-Z4-CR	ACSA2-Z4-CR	ACSA2-Z6-WA	LITU-Z6-WA	PLOC-Z6-WA	ACRU-Z6-WA	ACSA2-Z6-WA
ACSA2-Z4-CR	PLOC-Z6-WA	CAIL-Z5-AL	PLOC-Z6-WA	CAIL-Z5-AL	CAIL-Z5-AL	PLOC-Z6-WA	QUPA-Z6-WA	ACRU-Z6-WA
	BENI-Z6-WA	ACSA2-Z6-WA	QUPA-Z6-WA	LIST-Z6-WA	BENI-Z6-WA	LITU-Z6-WA	LIST-Z6-WA	
		CAIL-Z5-AL	LITU-Z6-WA	CAIL-Z5-AL	ACRU-Z6-WA	CAIL-Z5-AL		
			QUPA-Z6-WA	QUPA-Z6-WA	ACSA2-Z4-CR			

Genetic Resource Management Across the United States

Guidelines for Assisted Migration and Seed Movement in the Eastern United States

Carolyn C. Pike

Overview:

- We are synthesizing literature from genetics trials for 11 major tree taxa native to the Eastern United States for a new guidebook to help managers make decisions related to seed transfer. This guidebook will complement knowledge contained in the Climate Change Atlas (Peters et al. 2020). Two chapters were recently prepublished for jack pine (Pike 2021a) and white spruce (Pike 2021b). Longleaf and shortleaf pine will also be included.
- Yellow birch, white spruce, black spruce, red oak, eastern white pine, and red pine can tolerate transfer distances of 200–300 miles, from south to north. This distance corresponds to a mean annual temperature (MAT) that is 5–7 °F (2–4 °C) cooler. Black walnut and sugar maple should not be moved in excess of 200 miles (5 °F, 2.2 °C), and jack pine should be kept locally with distances not to exceed 100 miles (3.6 ˚F, 1.5 ˚C), especially in the Lake States. MAT estimates for these distances are based on Frenne et al. (2013).
- A new set of seed zones for the eastern United States (ESZF) can be used for assisted migration: Managers can transfer seed from one seed collection zone to the south (from warmer climate) without exceeding 200-mile (5.4 °F, 2.2 ˚C) transfer distances in most locations.
- Eastern Seed Zones (ESZF) were recently added to the Seedlot Selection Tool to help managers identify future climate analogues.

Summary:

Forest managers in the eastern United States need to decide which species and seed sources will be best adapted to current and future climates. This guidebook will synthesize information on genetics, silviculture, and forest health to assist land managers on decisions to seed transfer for major tree species in the eastern U.S.

Silvicultural Concepts:

- The rapid pace of climate change will likely exceed the rate of historical range shifts of native trees.

- Managers are encouraged to plant nonlocal seed sources to improve adaptation in the future, but this practice poses inherent risks to the plantings' success.
- The impact of insects and diseases on future forests are difficult to predict, but their impact may be buffered by using sources with genetic diversity that are adapted to current and future climates.
- Seed sources that are moved too far from their origin may be inadequately synchronized with conditions at the planting site. This asynchrony is likely to be expressed as premature leaf-out in the spring, delayed bud-set in the fall, or low growth rates that result in competitive exclusion.
- In hardwoods, hybridization with related species may alter future phenotypes with unpredictable consequences. These hybridization events may be accelerated or slowed depending on phenology and placement of species in the future.

Management Applications:

- Planting nonlocal seed sources should be done carefully by considering current and future projected climate conditions.
- Forest trees in the eastern U.S. can generally tolerate long-distance movement of seed, but managers need to watch for signs of poor adaptation. These clues may be manifest as premature leaf out or delayed bud-set. Asynchrony of leaf senescence, in hardwoods, is also a sign that a planted seed source is poorly synchronized with conditions at the site.
- Forest managers are encouraged to employ online tools, such as the Seedlot Selection Tool, to identify areas with future climate analogues. Managers are also cautioned that transfer distances that are required to match future analogues may exceed transfer recommendations for different taxa.

References:

Frenne, P.; Graae, B. et al. 2013. Latitudinal gradients as natural laboratories to infer species' responses to temperature. Journal of Ecology. 101: 784–795.

Peters, M.P.; Prasad, A.M.; Matthews, S.N.; Iverson, L.R. 2020. Climate change tree atlas, version 4. Delaware, OH: U.S. Department of Agriculture, Forest Service, Northern Research Station and Northern Institute of Applied Climate Science. https://www.nrs.fs.fed.us/atlas. (March 2021).

Pike, Carolyn C. 2021a. Jack pine: Guidance for seed transfer within the Eastern United States. Tree Planters' Notes. 64(2): 26–32.

Pike, Carolyn C. 2021b. White spruce: guidance for seed transfer within the Eastern United States. Tree Planters' Notes. 64(2): 19–25.

Table 1—Summary table of genetics and forest health concerns for conifers native to the Eastern United States. "Favorable" traits are those that are most likely to improve survival under future conditions.

Conifers	Black spruce, *Picea mariana*	White spruce, *Picea glauca*	Jack pine, *Pinus banksiana*	Red pine, *Pinus resinosa*	White pine, *Pinus strobus*
Genetic diversity	High	High	High	Low	High
Gene flow pollen/seed	High/high	High/high	High/med	High/med	High/high
Primary pests of concern	Spruce budworm, *Choristoneura fumiferana*; dwarf mistletoe, *Arceuthobium pusillum.*	Spruce budworm, *Choristoneura fumiferana.*	Eastern gall rust, *Cronartium quercuum;* jack pine budworm, *Choristoneura pinus.*	*Heterobasium annosum, Diplodia* spp.	Blister rust, *Cronartium ribicola.*
Favorable traits	High genetic diversity, mixed cone serotiny, shade tolerant.	High genetic diversity, highly plastic, shade-tolerant.	Drought tolerant, serotinous cones, fire-adapted.	Highly planted, fire-tolerant.	Broad ecological amplitude, high genetic diversity, shade tolerant.
Unfavorable traits	Relatively slow-growing.	Pests can build up in even-aged stands.	Shade intolerant. Gall rust may become more widespread in the future.	Low genetic diversity, susceptible to several pathogens.	Emerging new pests and pathogens. High sensitivity to air pollutants.

Table 2—Summary table of genetics and forest health concerns for hardwoods native to the Eastern United States. "Favorable" traits are those that are most likely to improve survival under future conditions.

Hardwoods	Red oak, *Quercus rubra*	Yellow birch, *Betula alleghaniensis*	Sugar maple, *Acer saccharum*	Black walnut, *Juglans nigra*
Gene flow pollen/seed	High/moderate	High/high	High/moderate	High/high
Hybridization potential	Hybridizes with other species in the red oak group.	Hybridizes with paper birch where ranges overlap (Lake States).	May hybridize with black maple where ranges overlap.	Does not readily hybridize.
Primary pest of concern	Forest tent caterpillar, *Malacosoma disstria*; *Armillaria* spp.	Bronze birchborer, *Agrilus anxius.*	Forest tent caterpillar, *Malacosoma disstria*; *Armillaria* spp.	Anthracnose, *Gnomonia leptostyla;* thousand cankers disease, *Geosmithia morbida.*
Favorable traits	High genetic diversity. Tolerates a range of site types.	High seed production, small, winged seeds. Few pests.	High seed production, high shade tolerance.	High seed dispersal, high genetic variation.
Unfavorable traits	Prone to defoliation. Shade- and drought-intolerant.	Natural regeneration limited by stringent seed bed requirements.	Low tolerance to drought.	Low tolerance to drought. Relatively shade intolerant.

Developing an Assisted Migration Plan for the Superior National Forest

Stephen D. Handler, Leslie Brandt, Katie Frerker, Joanna Gilkeson, Clinton Gregory, Nicholas Labonte, Carl Layman, Kathleen McTighe, Kaysee Miller, Kyle Stover, Myra Theimer

Overview:

- National forests are interested to implement assisted migration as a climate change adaptation strategy to help forests cope with changing conditions, but no national policy exists on how assisted migration should be carried out.
- The Superior National Forest (Minnesota) is working with partners to create a formal Assisted Migration Plan to ensure that the forest pursues assisted migration decisions in a consistent, informed, and coordinated manner.
- This example will be a useful model for other national forests and land management agencies to tailor to their own specific needs.

Summary:

The Superior National Forest (SNF) is preparing forest ecosystems for the challenges of continued climate change. Covering over 3 million acres in northern Minnesota, the SNF consists of boreal-temperate transition forests including several species expected to decline over the next century, such as jack pine, black spruce, and quaking aspen. As one possible adaptation action, silviculturists on the SNF have been implementing small-scale pilot projects to test assisted migration of tree species, including reforesting with new seed sources of existing species as well as introducing novel species to the forest. These pilot efforts have been limited by a lack of consistent guidance and direction. To ensure that the SNF pursues assisted migration decisions in a consistent, informed, and coordinated manner, SNF is working with partners to create a formal Assisted Migration Plan (AMP). This plan is designed to help SNF staff determine areas on the forest that are appropriate for assisted migration, tree species that may be most suitable for assisted migration, monitoring and logistical considerations, and effective processes for engaging tribal nations and other partners. This presentation will describe the process of creating the AMP, the contents of the plan, and recommendations for

other national forests interested to pursue a similar effort. Assisted migration has the potential to gradually reshape forest ecosystems as we know them, and collaborative planning processes can help ensure that National Forests continue to meet the needs of all partners when deciding how to go forward with these actions.

Silvicultural Concepts:

- Assisted migration is *the human-assisted movement of species in response to climate change*. This general term encompasses different types of assisted migration, including:
  - Assisted population migration (assisted gene flow) = moving seed sources or populations to new locations within the historical species range. This is viewed as relatively low-risk and is not a big departure from current practice on the SNF.
  - Assisted range expansion = moving seed sources or populations from their current range to suitable areas just beyond the historical species range, facilitating or mimicking natural dispersal. This is viewed as a moderate risk and departure from current practice on the SNF.
  - Assisted species migration (species rescue, or managed relocation) = moving seed sources or populations far outside the historical species range, beyond locations accessible by natural dispersal. This is viewed as relatively high risk and would be a significant departure from current practice on the SNF.
- Assisted migration can support a variety of adaptation options. Assisted population migration of new seed sources can contribute to "Resistance" actions by attempting to maintain the current species composition. Assisted range expansion can contribute to "Resilience" or "Transition" actions by introducing additional species diversity into a stand or landscape.
- Contributors to this plan are summarizing existing information on the patterns of genetic diversity of key species and publishing seed transfer guidance in Tree Planter's Notes (see example in References).

Management Applications:

- Climate change is challenging the assumption that "local is best" when it comes to seed sources for reforestation. Conventional reforestation practices may no longer be adequate to meet forest management objectives.
- The Forest Service Eastern Region updated guidance in 2019 to expand tree seed collection boundaries for National Forests based on climate change projections.
- The SNF AMP focuses on the reforestation program. The SNF anticipates higher demand for reforestation with more damaging pest and disease outbreaks and more frequent wildfires.

- The AMP is internal guidance for SNF project planning teams and silviculturists. It does not alter management objectives and it functions within the scope of the existing Forest Plan, and therefore does not require a formal plan amendment.
- Assisted migration guidelines could help sustain priority forest types and ecological functions on the SNF. For example, importing jack pine seed from farther south in Minnesota could introduce more drought- and heat-tolerant genetics for this commonly seeded species.
- Several working groups contributed to sections of the AMP, including Genetic Information, Implementation Guidelines, Seed Sourcing Logistics, and Cultural Considerations.
- The input of partners was critical for the development of the AMP. Key partners included staff from Forest Service's Northern Research Station, academic institutions, Tribes, State agencies, nongovernmental organizations, and forest industry groups.
- Developing the AMP highlighted several needs for collaboration, such as developing new agreements to facilitate seed collection outside the National Forest boundary and discussing assisted migration during formal and informal consultation with Tribal nations.

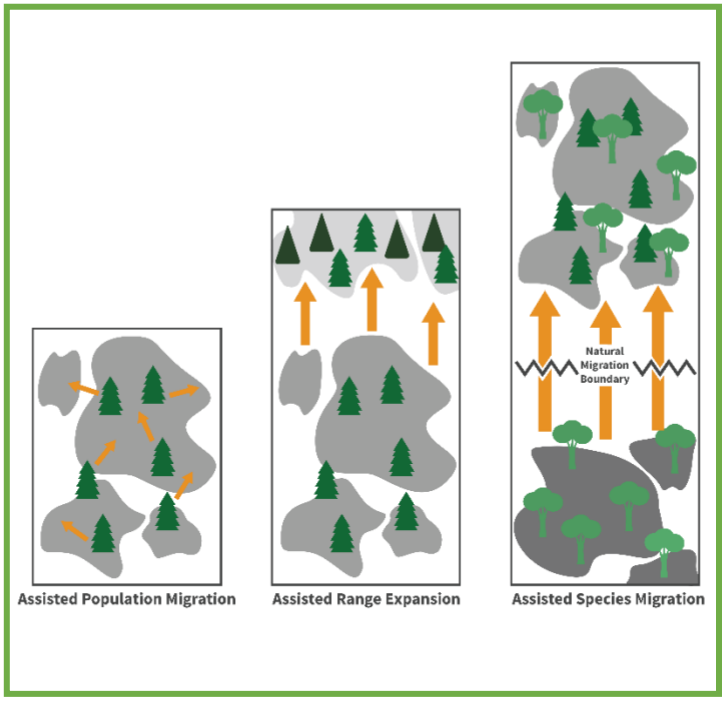


Figure 1—Illustrations of three distinct forms of assisted migration, from the Climate Change Resource Center (Handler et al. 2018).

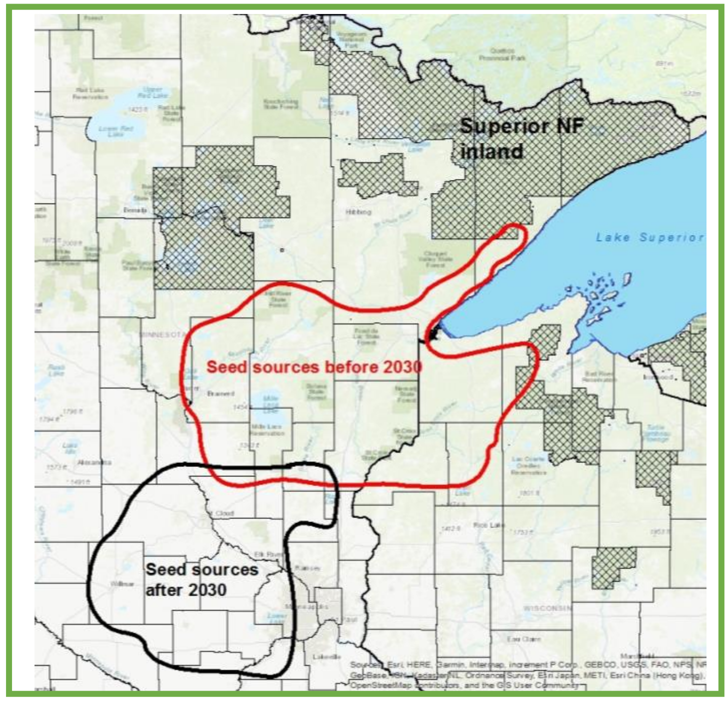


Figure 2—Illustration of revised seed collection zones for the inland portions of the Superior National Forest, from the 2019 revision of the Eastern Region Tree Seed guidebook. Prior collection boundaries followed the forest boundary and limited seed transfer between east and west districts.

Table 1—An overview of several working groups that contributed to the development of the Superior National Forest Assisted Migration Plan.

Working group	Guiding questions	Involved partners
Genetic considerations	• What information exists about the patterns of genetics for focal tree species across the region? • What knowledge gaps exist?	Forest Service State & Private Forestry, University of Minnesota, Minnesota Tree Improvement Cooperative, Minnesota Department of Natural Resources
Cultural considerations	• How might assisted migration affect cultural resources and tribal treaty rights? • How can the SNF involve Tribal nations in assisted migration decisions?	Fond du Lac Band of Lake Superior Chippewa, Grand Portage Band of Lake Superior Chippewa, Bois Forte Band of Chippewa, 1854 Treaty Authority, Great Lakes Indian Fish and Wildlife Commission, University of Minnesota, Northern Research Station, Bureau of Indian Affairs
Seed sourcing logistics	• How can the SNF integrate assisted migration into existing seed collection protocols? • How can the SNF work with nurseries and seed collectors?	Chippewa National Forest, Ottawa National Forest, Chequamegon-Nicolet National Forest, Oconto River Seed Orchard, The Nature Conservancy, Minnesota Counties
Implementation guidelines	• How will the SNF decide when and where assisted migration is appropriate?	Northern Research Station, Pacific Northwest Research Station, University of Minnesota, Minnesota Forest Industries, Minnesota Department of Natural Resources, The Nature Conservancy, Sustainable Forests Education Cooperative
Research and monitoring	• What are priority research questions related to assisted migration? • Will the SNF require additional monitoring of assisted migration efforts?	Northern Research Station, University of Minnesota, University of MN-Duluth, Minnesota Forest Resources Council, The Nature Conservancy, Fond du Lac Band of Lake Superior Chippewa, Minnesota Department of Natural Resources
Communications	• How should the SNF share and discuss this work with partners?	Sustainable Forests Education Cooperative
Silviculture program logistics	• How can the SNF integrate assisted migration into existing reforestation protocols? • What new steps or agreements will be required?	

References

Berrang, P. 2019. Eastern region guidebook: tree seed program. Unpublished document. Milwaukee, WI: USDA Forest Service Eastern Region. 58 p.

Handler, S.; Pike, C.; St. Clair, B. 2018. Assisted migration. USDA Forest Service Climate Change Resource Center. https://www.fs.usda.gov/ccrc/topics/assisted-migration.

Pike, C.C. 2021. Jack pine: guidance for seed transfer within the Eastern United States. Tree Planter's Notes. 64: 2. https://rngr.net/publications/tpn/64-2.

A Proposed Protocol for Prioritizing National Forest Seedlots for Reforestation and Restoration Given Concerns of Climate Change

Claire Ellwanger, Brad St. Clair, Andy Bower, Vicky Erickson, Matt Horning, Scott Kolpak

Overview:

- To ensure that reforestation and restoration treatments yield healthy, productive ecosystems that are adapted to the climates in which they are growing, a protocol has been developed by the U.S. Department of Agriculture, Forest Service, Pacific Northwest Region to match seedlots of forest trees and nontree restoration plants to potential planting sites based on predicted future climate.
- The proposed protocol has two components: (1) a methodology for determining the differences in climate between a planting site and specific seedlots in the Forest Service seed inventory for past and future time periods; and (2) use of web-based tools to visualize the differences in climate and guide both deployment and future collection of seed.
- Climatic factors important for adaptation that are used to guide seed deployment in the Pacific Northwest include winter temperatures, summer aridity, and conditions conducive to needle diseases such as continentality or summer precipitation.

Summary:

Management problem: Healthy, productive ecosystems require diverse plant populations that are adapted to the climates in which they are growing. The concept of local adaptation has been recognized as a critical component to reforestation success and forest productivity for nearly a century, leading to the development of seed zones for forest trees and, more recently, nontree restoration species. Fixed-boundary seed zones, however, assume that climates are static over time, which is no longer the case.

Management need: A protocol for matching seedlots of forest trees and nontree restoration plants to potential planting sites based on predicted future climate is needed. A methodology is needed to evaluate the climatic distance between seedlings and planting sites in order to

determine which seedlots will be suited to future climates while still being within critical climatic transfer distances in the near-term .

Silvicultural Concepts:

- Forest Service geneticists in the Pacific Northwest Region have developed a protocol for prioritizing seedlots for reforestation and restoration (St. Clair et al. in press). The proposed protocol has two components: (1) a methodology for determining the differences in climate between a planting site and specific seedlots in the USFS seed inventory for past and future time periods; and (2) use of the Seedlot Selection Tool (https://seedlotselectiontool.org/sst/) to visualize the differences in climate and guide future collections.

Management Applications:

- Climatic factors important for adaptation in the Pacific Northwest include winter temperatures, summer aridity, and conditions conducive to needle diseases such as continentality or summer precipitation. Seedlots in the Forest Service seed inventory are characterized for adaptation for these climatic factors, and prioritized for revegetation of a site by selecting the sources with a minimum climatic transfer distance for a mid-century warmer climate while still being within critical climatic transfer distances for summer aridity and continentality, as well as for winter temperatures in the near-term to avoid cold damage.

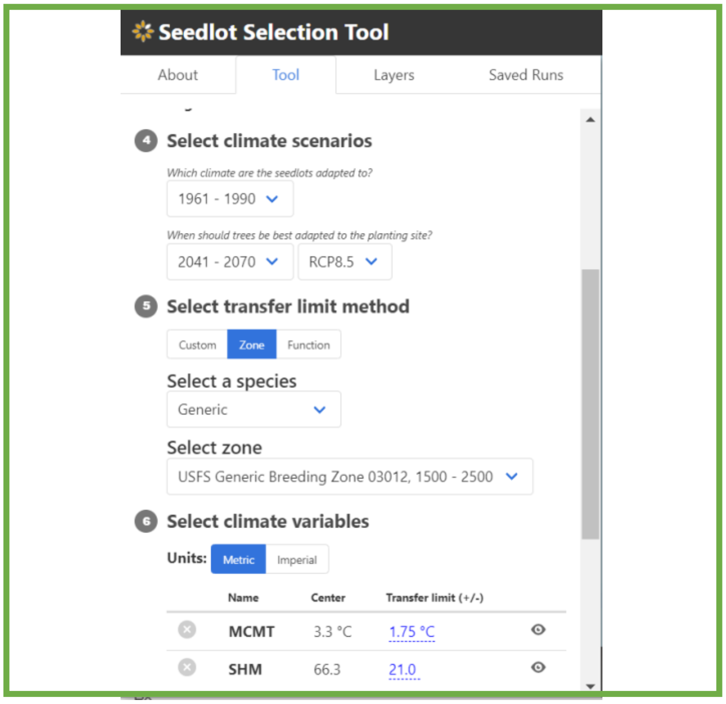


Figure 1—Sample Seedlot Selection Tool settings.

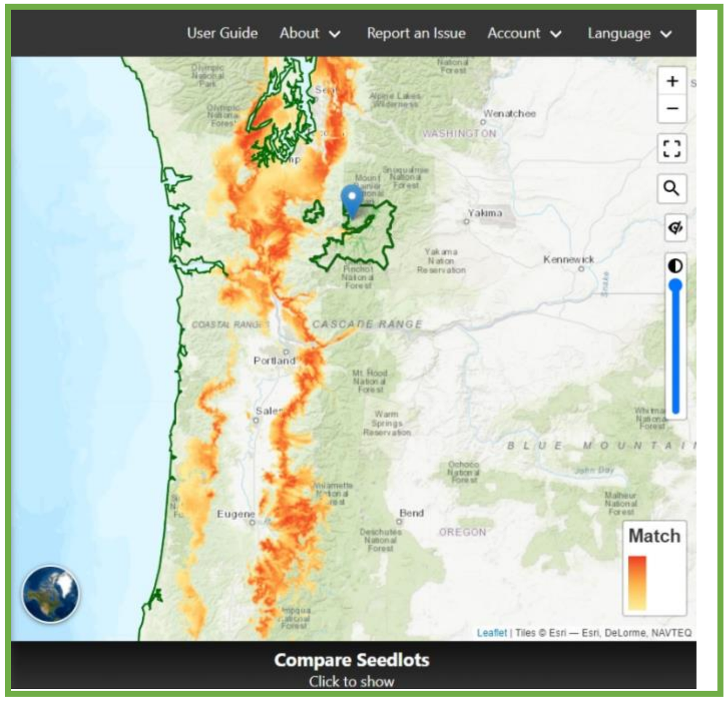


Figure 2—Sample Seedlot Selection Tool mapped output.

Table 1—Example of spreadsheet developed to calculate climatic transfer distance between seedlots in inventory and planting site for recent past and three future time periods.

Climatic Transfer Distances For seedlots in Forest Service inventory westside National Forests					**MCMT** 1961-1990	**MCMT** 2011-2040 RCP8.5	**MCMT** 2041-2070 RCP8.5	**MCMT** 2071-2100 RCP8.5
Climate at planting site:					0.80	2.20	3.40	5.00
Climate change at planting site:					0.00	1.40	2.60	4.20
Sort ID	Seedlot ID	Breeding zone	Elev. band	Species	1961-1990	2011-2040 RCP8.5	2041-2070 RCP8.5	2071-2100 RCP8.5
135	PSME-11-082-01000-20-71	82_2000	2500	PSME	-4.36	-2.96	-1.76	-0.16
226	PSME-12-12031-400-0010-89 SB	12031	5000	PSME	-4.20	-2.80	-1.60	0.00
227	PSME-12-12031-500-85 SB	12031	3000	PSME	-4.20	-2.80	-1.60	0.00
228	PSME-12-12031-502-85 SB	12031	1500	PSME	-4.20	-2.80	-1.60	0.00
221	PSME-12-12021-400-0010-89 SB	12021	3000	PSME	-3.86	-2.46	-1.26	0.34
222	PSME-12-12021-400-0010-90 SB	12021	2000	PSME	-3.86	-2.46	-1.26	0.34

Reference

St. Clair, J.B.; Richardson, B.S; Stevenson-Molnar, N.; Howe, G.T.; Bower, A.D.; Erickson V.J.; Ward, B.; Bachelet, D.; Kilkenny, F.F.; Wang, T. [In press.] Seedlot Selection Tool and Climate-Smart Restoration Tool: web-based tools for sourcing seed adapted to future climates. Ecosphere.

Environmental Indicators in Reforestation and Growth

The Influence of Hydroclimate and Harvest Method on Rates of Forest Regrowth Across the Western U.S.

Zachary H. Hoylman, Kelsey Jencso, Vince Archer, James (Andy) Efta, Zackary Holden, Ashely Ballantyne, Marie Johnson

Overview:

- Forests are subject to a range of management strategies, but it is unclear which practices produce the most rapid rates of regrowth across complex mountain terrain. We analyzed recovery rates of satellite derived net primary productivity (NPP) for 36,233 individual silvicultural treatments across the western U.S. Regrowth was on average 313% higher in wet landscapes with lower annual climatic water deficits when compared to dry landscapes, ranging from 7.63 gC m -2 y -2 - 2.44 gC m -2 y -2 , indicating hydroclimate as a dominant driver of forest regrowth. Differences in stand structure due to silvicultural treatment also strongly controlled rates of regrowth within hydroclimatic settings; microclimates produced by shelterwood treatments maximized regrowth in dry landscapes whereas regrowth following clearcutting was among the fastest in wet landscapes due to enhanced energy availability. In aggregate, this study provides a novel satellite approach for characterizing forest regrowth dynamics across climatic gradients and the common treatment options employed.

Summary:

None provided.

Silvicultural Applications:

- None provided.

Management Opportunities:

- None provided.

REGEN MAPPER: A Web-Based Tool for Predicting Postfire Conifer Regeneration and Prioritizing Reforestation Efforts in the Western United States

Zachary A. Holden, Dallen Warren, Kim Davis, Ellen Jungck, Marco Maneta, Solomon Dobrowski, Vince Archer

Overview:

- Resource managers would use tools for identifying and prioritizing potential planting sites. A web-based decision support system was developed (DSS) to provide spatial information on potential for natural regeneration in postdisturbance environments.
- We use the ecohydrology model ech2o and high-resolution gridded weather data to predict postfire conifer regeneration for areas across the western United States.
- These models are publicly available via a web-based tool and will predict probability of conifer recruitment and return a suite of raster and vector outputs for anywhere in the western United States.
- High surface temperatures following canopy removal can limit recruitment at lower-elevation, warm dry sites.

Summary:

Increasing wildfire area burned and accelerated timber harvest have amplified the need for postdisturbance reforestation; this need has outpaced current capacity. Resource managers would use tools for identifying and prioritizing potential planting sites. A web-based decision support system was developed (DSS) to provide spatial information on potential for natural regeneration in postdisturbance environments. Users can select burn severity information using 1-year postfire data (Monitoring Trends in Burn Severity), or for recent disturbance events using either Rapid Assessment of Vegetation Condition After Wildfire or Soil Burn Severity Layers. The DSS predicts the potential for natural regeneration, based on distance to adult live trees (seed sources) and historical climatic conditions. The tool returns 30-meter resolution gridded raster maps describing the probability of natural seedling regeneration, distance to roads, and a cost-benefit calculation to assist in prioritizing planting areas. Additionally, the tool returns a set of plots visualizing the outputs, as well as Forest Service

Activity Tracking System spatial data indicating where previous management activities mandate reforestation under the National Forest Management Act. Simulations of potential surface temperature, in the absence of any tree canopy cover, are also provided for areas that have been burned. This layer may be useful for identifying where lethal surface temperatures could limit survival of seedlings, such as low-elevation, south-facing slopes.

Silvicultural Concepts:

- Forest structure mediates near-surface microclimates that influence conifer regeneration.
- Physically based model predictions of interactions between overstory vegetation and near-surface conditions can guide reforestation management decisions.

Management Applications:

- The REGEN MAPPER tool provides a means for forest managers to assess and prioritize sites for planting following wildfire or other disturbance.

Regeneration of ‘Iliahi: Hemiparasitic Relationships in Hawaiian Tropical Dry Forests

Emily Thyroff, Travis Idol, Douglass Jacobs

Overview:

- ‘Iliahi (*Santalum paniculatum*), a hemiparasitic tree, can be successfully planted in a plantation of nitrogen-fixing koa (*Acacia koa*) trees as indicated by a 99% survival rate and impressive growth rates.
- After the first growing season, ‘iliahi seedling height and diameter growth (38.89 $\pm$ 1.38 cm and 4.26 $\pm$ 0.11 mm) was greater with greater canopy cover (canopy openness range from 6.2% to 84.7%) (fig. 1 and fig. 2).
- We hypothesize that these results are due to the benefits of a denser host root network outweighing the greater competition for light and soil resources during the establishment phase for these hemiparasitic ‘iliahi seedlings.

Summary:

Management problem: *Santalum* species, including the endemic Hawaiian ‘iliahi (*Santalum paniculatum*), are ecologically distinct as evergreen, hemiparasitic trees. Being hemiparasitic means ‘iliahi can photosynthesize yet require suitable hosts for resource acquisition and long-term survival. Degradation of native tropical dry forests and the unsustainable removal of native tree species has resulted in ‘iliahi and other trees, including potential hosts to ‘iliahi, having greatly reduced populations and distributions.

Management need: Reforestation and sustainable forestry of ‘iliahi in degraded tropical dry forest sites require supporting host plant communities. Planting ‘iliahi among established hosts may increase the probability of making early and abundant hemiparasitic connections, but this must be balanced with competition for limiting resources.

Research purpose: Our experiment aims to improve the survival and establishment of planted ‘iliahi seedlings by better understanding regeneration and establishment tradeoffs between ‘iliahi and koa (*Acacia koa*), a native tree species commonly planted at reforestation and restoration sites.

Silvicultural Concepts:

- In 2010, koa seedlings were planted in a 0.81-ha fenced plot. Patchy survival over 10 years resulted in varying gap sizes, creating a matrix of micro-environments into which 10-month-old seedlings of ʻiliahi were planted using a completely randomized experimental design.
- Underplanting could be a way to not only diversify initial reforestation efforts but also to introduce an endemic species that is hemiparasitic and requires host plants for long-term growth and survival.
- Morphological and physiological measures are being taken to identify parasitic connections and understand drivers of ʻiliahi establishment.
- After the first growing season, ʻiliahi seedlings had high survival and growth rates, with greater height and diameter growth under less open koa canopies. We are still processing and analyzing physiological measures such as gas exchange and stomatal impressions to estimate photosynthesis, resource acquistion, and the balance of competition vs. parasitic transfer of resources.
- There is potentially an optimal range of overstory gap sizes that balances competition for resources and abundant root networks for ʻiliahi to establish hemiparasitic root connections.

Management Applications:

- Our results show that it is possible to have high first-year survival of ʻiliahi seedlings underplanted in an established koa plantation.
- Small gaps or relatively high canopy cover may be suitable to establish ʻiliahi and perhaps preferred for better early growth.
- These results contribute to better understanding ʻiliahi establishment within gaps of established hosts and help improve silvicultural efforts to restore functionally compatible and diverse native dry forests in Hawaiʻi.

Figure 1— 6.2% canopy openness.

Figure 2—84.7 % canopy openness.

Short-Term Effects From Late-Season Freeze on White Oak (*Quercus alba* L.) Acorn Production in the Southeastern Coastal Plain

Walt Thompson

Overview:

- Effects of late season freezes on hard mast
- Novel approach to collecting white oak mast
- Predatory weevil populations dropped off for two years

Summary:

Oak mast collection for reforestation needs is often hampered by elements beyond our control, acceptable mast seasons, insect predation, and weather

Silvicultural Concepts:

- The use of nursery shade cloth netting suspended above ground level to speed up collections.
- The use of suspended nets will also be used in hardwood orchards to help maintain phenotypic qualities desired for reforestation.
- Suspended nets control predation from wildlife, i.e., deer and wild hogs.

Management Applications:

- Streamlined approach to mast collections.
- Collections take place across a wide area of the forest to insure genetic diversity.
- Heavy spring rains and severe late season freezes can affect reforestation program planning.

Figure 1—Frost damage.

Figure 2—Suspended collection net.

Evaluating the Role of Plant Species as Indicators of Climate Change, Disclimax, and Ecotones

Jennifer Costich-Thompson

Overview:

- As our climate changes into the future, we cannot assume habitat types will be static. Rather, habitat types may move across the landscape and plant associations may change over time. Therefore, we must adapt our silvicultural applications to create disturbance-resilient forests and consider other possible indicators of ecotones or shifting plant communities.
- Silviculturists must identify ecotones and predict sites susceptible to disclimax or plant community shifts to determine suitable silvicultural treatments for management objectives and desired forest conditions.
- We often use understory plants as indicators of habitat types because they occur in narrow ecological niches, but some plants may also be useful as threshold indicators.
- Work with plant technicians and botanists to evaluate changing plant communities or sites with limited reforestation success and identify which understory species might indicate possible thresholds, trends, or other management implications.
- These botanical experts can also help evaluate whether the current vegetation classification system adequately describes ecotones and provide suggestions for incorporating any newly identified threshold indicator species.

Summary:

In recent years, Idaho Panhandle National Forests' employees have noted sites with limited reforestation success, as well as ecotones with evidence of plant shifts or longer-term disclimax following disturbance. I propose that we evaluate some of these sites and similar intact communities to identify plant species that may help us predict where such sites occur.

Figure 1.

An iterative process that involves defining thresholds and identifying threshold indicators may be invaluable in successfully managing stands for future resilience.

Figure 3.

I also propose that we: (1) Evaluate ecotones and stands with forest health or reforestation issues to define thresholds between management successes and challenges. (2) Define the thresholds between short-term disclimax and conditions that might indicate a long-term habitat type or plant community shift. Then, (3) work with botanists (and others skilled in plant identification) to identify plant species that may help predict the sites where thresholds and other management issues might occur. (4) Update vegetation classification systems to incorporate modified management strategies (particularly in ecotones) and to include any new threshold indicators. Use those thresholds and new indicators to help guide future classification and management strategies.

Figure 2.

Silvicultural Concepts:

- Vegetation Classification and Habitat Type Classification are systems that describe a geographic area's climax plant communities, based largely upon soils, aspect, elevation, climate, and productivity. These classification systems provide a means of describing plant communities and often determining appropriate management prescriptions.
- Ecotones are transitional zones between different biological plant communities that often exhibit traits of both and, as such, may be some of the first sites to exhibit disclimax and climate change symptoms (such as shifting plant communities).
- Disclimax usually describes a short-term condition for sites temporarily unable to support their predicted climax plant community. Intensive or repeated disturbance often causes disclimax, especially disturbances that affect soils, productivity, or modify climatic influence.
- Indicator species are those plant species described in vegetation classification that distinguish between plant communities or predict specific site characteristics (like droughty soils, cold air drainages, or specific soil parent materials).

Management Applications:

- Many variables can impact reforestation success, including aspect, soils, microsites, climatic variables, nursery stock quality, silvicultural prescription, and site preparation. However, some site conditions or plant community changes may require us to reconsider and modify traditional stocking prescriptions.
- Where reforestation success has been problematic or forest health conditions are widespread, assess whether those issues are driven by stand stocking/structure or could be related to short-term disclimax variables (like organic matter, soils, increased wind or insolation, etc.) or possible long-term climate-related plant community shifts, particularly associated with ecotones.

Figure 4.

    - Define thresholds for reforestation success on various habitat types.
    - Define thresholds between disclimax and longer-term plant community shifts.
    - Define objectives for ecotones and shifting plant communities.
    - Identify understory species that might correlate with reforestation issues on various habitat types (typically cold, warm, or dry site indicators) or might predict ecotones and potentially shifting plant communities.
    - Evaluate or reevaluate whether your traditional prescriptions (stocking—both species and density, structure, and function), as well as tools and practices are still suitable for those sites.
- Evaluate whether current vegetation classification systems still accurately describe local plant communities and adequately guide management for resilient plant communities.
    - Consider whether additional data collection, monitoring, and analysis should be conducted at local or regional scales (fine- and coarse-scale).
- Consider amending your classification system to include expanded descriptions of ecotones, thresholds, threshold indicators, and management implications.

Figure 1—Dry site ecotone on Idaho Panhandle National Forests, illustrating limited reforestation.

Figure 2—*Collomia heterophylla,* which is associated with dry ponderosa pine forests in northern Idaho.

Figure 3—*Hydrophyllum capitatum,* which is associated with ponderosa pine, Douglas-fir, and grand fir forests in northern Idaho.

Figure 4—*Arenaria congesta,* which is associated with very droughty soils in northern Idaho.

Forest Opening Influence on Seedling Establishment and Growth

Theresa Jain, John Byrne

Overview:

- Early seral species can regenerate and grow under a wide range of different canopy openings
- At 55 percent canopy opening, western white pine has competitive advantage, growing faster than western hemlock. At 92 percent opening, western white pine is free to grow, meaning it will likely become the dominant tree in the canopy. Optimum growth begins at 8 acres.
- One entry will require units that contain minimum opening sizes that favor 92% canopy opening (≥ 1 acre, ≤ 40 ft2/acre ≤ 20 Trees/acre).
- The number of sunflecks that affect a seedling has a negative relationship with growth. Group trees to decrease number of sunflecks.

Summary:

Management problem: For centuries, western white pine (*Pinus monticola*) dominated moist forests of the northern Rocky Mountains. The fast-growing species, which can reach heights of 150 feet, was once an economic driver in the region. However, not much of the former forest remains. A combination of blister rust, beetles, and logging severely reduced the range of white pine during the 20th century.

Management Need: Managers have traditionally used large clearcuts followed by broadcast burning to grow western white pine and other early seral species. While this approach can be an effective and efficient way to get white pine on the landscape, clearcutting can come at the expense of other objectives, such as aesthetics, wildlife habitat, and water management.

Research purpose: Over a decade of research by Rocky Mountain Research Station scientists Terrie Jain and Russell Graham is now providing updated guidelines for regenerating and establishing white pine on the landscape by focusing on factors such as forest openings and visible sky.

Silvicultural Concepts:

- The response of white pine under different canopy openings varied depending on whether there was a local source of water. On large slopes with lots of streams dissecting it, white pine did better across the opening sizes versus slopes that were not dissected by streams and creeks.
- For western white pine, there is a lot of mortality in the first 6 years of establishment, but after 6 years the trees that are still there have a good chance of remaining. After 6 years, if western white pine is established, it "captures the site," outcompeting grand fir and hemlock to become the dominant canopy species.
- At 55 percent canopy opening, western white pine has competitive advantage, growing faster than western hemlock. At 92 percent opening, western white pine is free to grow, meaning it will likely become the dominant tree in the canopy (table 1).
- A sunfleck is a short period of direct sunlight. The number of sunflecks that affect a seedling has a negative relationship with growth. Jain and Graham found it is best to leave overstory trees in clumps rather than evenly spaced. This decreases the number of sunflecks and increases the period of direct sunlight reaching the established trees.

Management Applications:

- James Pass, Forest Silviculturist: "It is possible to leave 40 square feet of basal area in the overstory, and leave the trees as dispersed or aggregated." If you distribute the trees in a dispersed pattern where you have a tree every 40 feet, that's not a good light environment for western white pine or larch. What you want to do is create aggregations and some clumps so there are fewer sunflecks hitting the ground and lasting only for a short period. If you have a clumped-up, aggregated retention, then you'll have longer periods of sunlight hitting the seedling and it will grow better. The research helps people actually put themselves in place—as weird as it may seem— to think like a seedling and imagine the influence exerted on a seedling by its surroundings,"
- Jason Jermon, District Silviculturist: "The idea is to get enough light in the openings to get the seedlings established, then establish more seedlings in the second entry, but make sure the original seedlings achieve free-to-grow status. They can actually gain competitive advantage and free-to-grow status because we've expanded the opening and increased the amount of visible sky to the seedlings.

Table 1—Costs associated with stand improvement accomplishments in fiscal year 2020.

Figure 1—55 percent visible sky

Figure 2—92 percent visible sky

Table 1—For each opening threshold there are practical estimates of a range of basal areas, stand density indices, trees per acre, and opening sizes.

Threshold name	Threshold value (visible sky)	Basal area (ft^2/acre)	Stand density index	Trees/ acre	Opening size (acres)
55% regeneration establishment	25%	100 to 120	425	80 to 100	0.1
80% regeneration establishment	45%	80 to 100	350	60 to 80	0.25
Competitive advantage	55%	40 to 80	300	20 to 60	0.3
Free to grow	92%	≤ 40	≤ 120	≤ 20	1

References:
Jain, Theresa B.; Graham, Russell T.; Morgan, Penelope. 2004. Western white pine growth relative to forest openings. Canadian Journal of Forest Research. 34(11): 2187-2198.

Jain, Theresa B.; Graham, Russell T.; Morgan, Penelope. 2002. Western white pine development in relation to biophysical characteristics across different spatial scales in the Coeur d'Alene River basin in northern Idaho, U.S.A. Canadian Journal of Forest Research. 32(7): 1109-1125.

It's all up from here: Forest openings and seedling growth in western white pine restoration. 2020. Fort Collins, CO: U.S. Department of Agriculture, Rocky Mountain Research Station, Science You Can Use Bulletin, July/August: 41: 11 p.

Trends in Stand Improvement Needs and Treatments on National Forest System Lands

Trends in Stand Improvement Needs and Treatments on National Forest System Lands

David Gwaze and Theresa Jain

Overview:

- The National Forest Management Act (NFMA) of 1976 states it is the policy of Congress that all forested lands in the National Forest System be maintained in appropriate forest cover with species of trees, degree of stocking, rate of growth, and conditions of stand designated to secure the maximum benefits of multiple use sustained yield management in accordance with land management plans.
- Stand improvement treatments (also referred to as stand tending), such as thinning trees and removing competing vegetation, are critical for increasing the growth rate, disturbance resilience, shift species composition, and meeting management objectives such as timber production or other resource uses such as creating wildlife habitat.
- The acres that need stand improvement have been increasing nationally each year over the past few decades; unfortunately, for a variety of reasons the number of acres that are treated have been declining over the same period. This dilemma is creating a national imbalance in stand improvement needs versus implementation that is inconsistent with statutory direction contained in NFMA.
- This paper summarizes the growing stand improvement acres that need treatments, the shortfall in implementation of stand improvement treatments, and the estimated costs and commitment associated with meeting stand improvement needs over the next 10 years.

Summary:

Acres needing stand improvement, except for 2009, have consistently remained above 2.0 million acres per year from 2010 through 2019 (fig. 1a). Most of the acres consist of precommercial thinning (70%) followed by release (26%) with only a small portion of acres needing pruning and/or fertilization (4%). However, the proportion (an average of 11.7%) of acres treated are much smaller when compared to the acres that need treatment (fig. 1a, dark line). This is causing a critical imbalance concerning stand tending that is inconsistent with statutory direction contained in the National Forest Management Act.

Stand improvement accomplishments varied from 198,000 to 364,000 acres per year over the last 10 years (FY 2009–2019) and has been constant over the last 4 years (fig. 1b). Precommercial thinning accomplishments are normally the largest followed by release and/or weeding accomplishments (fig. 1b). In FY 2019, the agency accomplished 198,206 acres of precommercial thinning, release, pruning, and fertilization. SI (stand improvement) treatments are significantly fewer than acres diagnosed for treatment. In fact, the agency has been treating only between 9 and 15% of the SI needs over the 10-year period (fig. 1b).

In 2020, stand improvement cost $33.7 million dollars with precommercial thinning (68.2%) absorbing most of the cost followed by release and weeding (30.4%) with the remainder being spent on pruning and fertilization (1.4%) (table 1). Average cost per acre depended on the specific activity but ranged as low as $9 dollars per acre (fertilization) to $244 per acre for precommercial thinning.

Silvicultural Concepts:

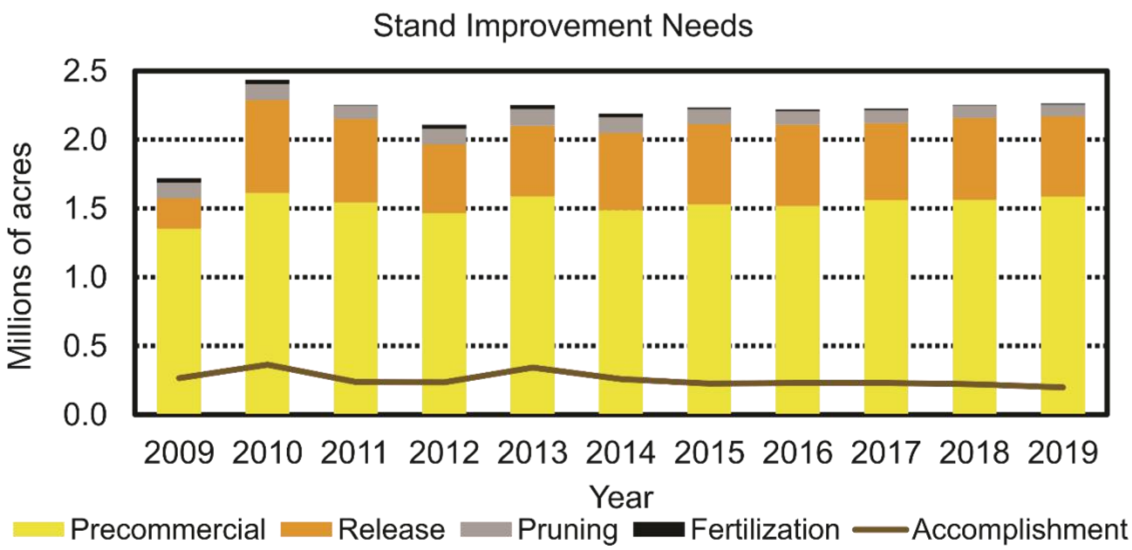
- Terminology associated with stand improvement can be confusing. In this paper we refer to stand improvement, precommercial thinning (also referred to as noncommercial thinning), weeding, cleaning, releasing, and other terms such as liberation and crop tree release. The FACTS database (Forest Service Activity Tracking System) uses terminology documented in the Dictionary of Forestry (Deal 2018) and was the source of the data discussed in this manuscript. Therefore, using consistent terminology is critical if we are to successfully enhance stand improvement opportunities. For example, stand improvement is a category of intermediate treatments (synonym is stand tending) that are applied to improve the composition, structure, condition, health, and growth of a stand (table 2).
- Precommercial thinning (sometimes referred to as noncommercial) is a catch-all phrase that is often used to reflect that the material being removed is not yet commercial size (table 2)—such as when suppressed trees (sometimes up to 6 inches d.b.h.) are removed beneath old ponderosa pine. But this phrase can also include treatments often only applied in stands not past the sapling stage (liberation, cleaning, weeding).
- Pruning is primarily used to reduce blister rust infection and tree mortality in white pine. Pruning removes the lower branches where infections are most likely to occur.
- Fertilization was used to improve growth of pine plantations in the past but recently its use has been rare.

Management Applications:

There are several strategies we can use to balance SI needs with accomplishments:

- Increase line officer support by designating targets for stand improvement at all levels in the agency.
- Demonstrate the value of SI in meeting the Agency's mission and obligation to NFMA and resource management to ensure long-term leadership commitment and sustainable funding.
- Secure long-term funding for SI by (1) emphasizing the importance of funding these activities in future FS budgets, (2) use innovation to identify funding opportunities for SI activities such as those being used to fund reforestation, and (3) because successful reforestation is dependent upon meeting stand improvement needs.
- Seek opportunities with state, tribal, private, and non-profit partners to leverage expertise, resources, and capacities to augment stand improvement by using mechanisms such as Shared Stewardship Agreements, Good Neighbor Authority, Stewardship Contracting, and Agricultural Conservation Experienced Services.
- Explore the potential to utilize nontraditional sources of funding by working with other key staffs (i.e., WO-Biological & Physical Resources; WO-Forest Health Protection; WO-Fire and Aviation Management) to determine the potential for funding SI work to meet habitat objectives, watershed objectives, and reduction of wildfire risk.
- Increase SI program staff capacity to respond to current and future SI needs.

a



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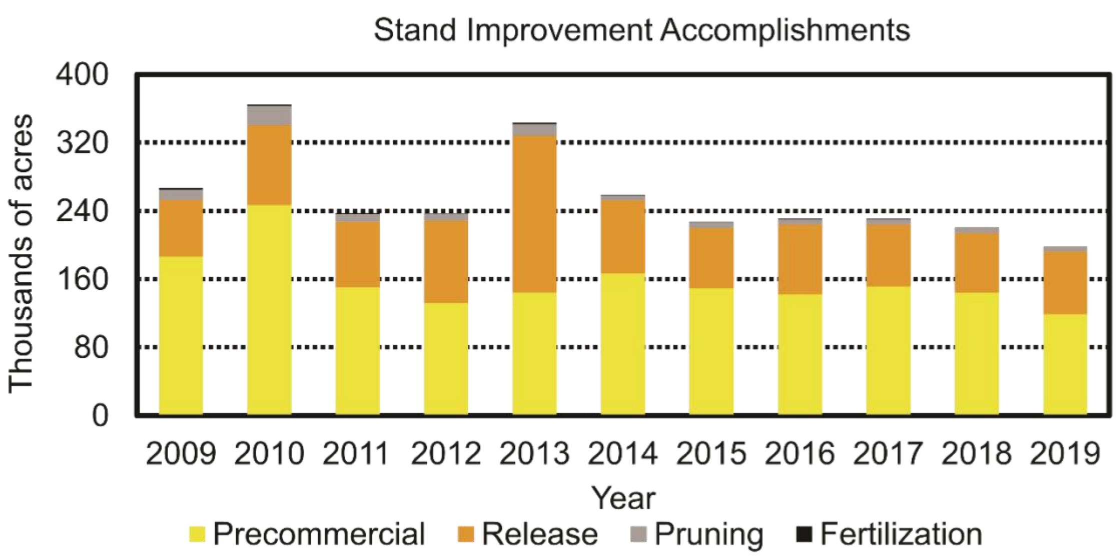


Figure 1—National stand improvement needs and distribution of types of tending needs (a) versus the accomplishments in stand improvement by distribution of types of tending accomplished (b).

Table 1—Costs associated with stand improvement accomplishments in fiscal year 2020.

Activity	Total cost ($)	Average cost per acre ($)
Tree release and weed	10,262,337	225
Precommercial thin	22,974,371	244
Prune	468,705	116
Fertilization	730	9
Total cost	33,706,143	--

Table 2—Terminology associated with tending treatments and definitions adapted from the Dictionary of Forestry (Deal 2018).

Terminology	Definition
Stand improvement	A category of intermediate treatments intended to improve the composition, structure, condition, health, and growth within a stand.
Precommercial thinning (sometimes also referred to noncommercial thinning)	A tending treatment that reduces density and spaces crop trees in stands, *where the material being removed* is not yet of commercial size, typically done as an investment and may be combined in the practice with liberation, weeding, or cleaning and can occur past the sapling stage.
Release	A treatment that is applied to provide growing space to young trees inhibited by undesirable, usually overtopping, competing vegetation.
Liberation	A release treatment that is applied in stands not past the sapling stage, to provide growing spaces to favored trees inhibited by competition with older and often trees that overtop the favored tree.
Cleaning	A release treatment that is applied in any age class not past the sapling stage, to provide growing space to favored trees that are inhibited by less desirable individuals of the same age class that either overtop or are likely to overtop the favored trees.
Weeding	A release treatment that is applied in stands not past the sapling stage, that eliminates or suppresses undesirable vegetation regardless of crown position.
Crop tree	Any tree selected to remain a component of the stand until the end of the rotation, usually after being released from competition in a tending treatment.

Disturbance as a Tending Option

Effects of Flooding on Survival and Performance of Potential Replacement Species in Black Ash Swamp Hardwood Forests

Gwendolen Keller, Robert Slesak, Dustin Bronson, Marcella Windmuller-Campione

Overview:

- Flood Duration Experiment
  - In 2020, 18 species of tree seedlings were exposed to water tables at the soil surface for 3, 6, 9, 12, and 15 weeks. Basal diameter growth, height growth, and survival were assessed to determine suitability to flooded conditions.
  - American elm (*Ulmus americana*), river birch (*Betula nigra*), and bald cypress (*Taxodium distichum*) had the highest and most consistent height and basal diameter growth across flooding duration treatments.
- Water Table Depth/Shade Experiment
  - In 2021, 23 species of tree seedlings were exposed to three water table depths (0, 14, 27 cm below soil surface) and three light reduction levels (0%, 40%, 70% reduced) assigned in a 3 x 3 factorial design. Basal diameter growth, height growth, gas exchange rates, and survival were assessed to determine suitability to flooded conditions.
  - Depth of water table below soil surface during the growing season has a greater effect on seedling growth and gas exchange rates than light reduction.
- In the water table depth/shade experiment, bald cypress had the highest and most consistent height growth and photosynthetic rates across water table depth and light reduction treatments.

Summary:

Black ash (*Fraxinus nigra*) swamps represent 4.5% of the forested area in the western Great Lakes region (Michigan, Minnesota, Wisconsin). Within the swamp hardwood cover type, black ash comprises 40% to almost 100% of the canopy cover and acts as a foundational species, impacting hydrologic regime, nutrient cycling, and wildlife habitat. The dominance of

black ash in these stands makes them particularly vulnerable to the invasive emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire) (Coleoptera: Buprestidae). EAB infestation can result in a mortality rate of up to 99% for ash species within 5 to 7 years. Due to the threat EAB invasion poses to the structure and function of black ash forests, research is being conducted to determine adaptation strategies for managers. One such strategy is to increase tree species diversity through artificial regeneration (from planting). However, there is limited information available on how potential replacement tree species respond to flooding and available light (shade).

Silvicultural Concepts:

- Flood Duration Experiment
    - Silver maple (*Acer saccharinum*), river birch, American elm, sycamore (*Platanus occidentalis*), and bald cypress showed the highest and most consistent height and basal diameter growth rates across flood duration treatments.
    - Red maple (*Acer rubrum*), yellow birch (*Beluta alleghaniensis*), swamp white oak (*Quercus bicolor*), and tamarack (*Larix laricina*) exhibited high and consistent height and basal diameter growth rates after having been flooded for 3 to 9 weeks.
- Water Table Depth/Shade Experiment
    - Bald cypress had the highest and most consistent height growth and photosynthetic rates across water table depth and light reduction treatments.
    - Black spruce (*Picea mariana*), white spruce (*Picea glauca*), tamarack, trembling aspen (*Populus tremuloides*), northern white cedar (*Thuja occidentalis*), red maple, American basswood (*Tilia americana*), American elm, yellow birch, silver maple, hackberry (*Celtis occidentalis*), river birch, swamp white oak, and sycamore exhibited high and consistent growth and gas exchange rates after having been exposed to water table depths 14 cm below soil surface for 15 weeks.
- In the water table depth/shade experiment, bald cypress, tamarack, trembling aspen, river birch, and sycamore exhibited the highest transpiration rates.

Management Applications:

- Managers can use the results of this study to choose a suite of species that will establish successfully under the local conditions in their black ash wetlands threatened by emerald ash borer.

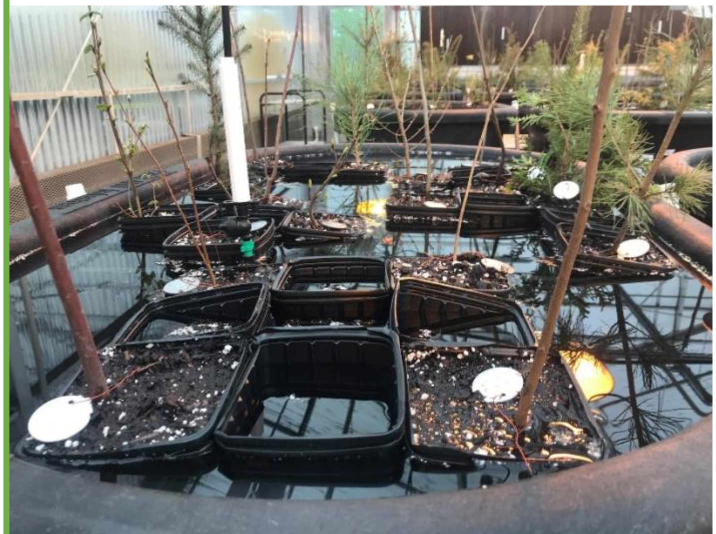


Figure 1—During the flooding duration experiment, flooding was simulated by filling stock tanks with tap water up to the soil surface.

Figure 2—For the water table depth/shade experiment, water table depth treatments (simulated in stock tanks) were nested within light reduction treatments. Gas exchange measurements were taken with both the Licor 6400 and 6800.

Table 1—Survival percentage for each species in the flood duration experiment.

	Treatment				
Species	**3-week flood**	**6-week flood**	**9-week flood**	**12-week flood**	**15-week flood**
Red maple	100	100	100	88	50
Sugar maple	25	0	13	25	13
Silver maple	100	100	100	100	100
Yellow birch	88	100	75	75	38
Bitternut hickory	75	63	100	100	100
River birch	88	100	100	100	100
Black walnut	0	13	0	0	13
White oak	88	88	63	63	63
Swamp white oak	100	100	88	88	100
American elm	100	100	100	100	100
Tamarack	63	100	38	100	38
White spruce	63	38	50	50	38
Black spruce	75	50	0	50	38
Red pine	100	88	38	75	50
White pine	100	88	63	63	88
Northern white cedar	75	50	75	88	100
Sycamore	100	100	100	100	100
Bald cypress	100	100	100	100	100

Sprout-Origin Hardwood Reproduction Dominates After Multiple Prescribed Fires on the William B. Bankhead National Forest, Alabama

Callie Schweitzer, Daniel Dey, John Craycroft

Overview:

- Upland mixed pine-hardwood forests on the William B. Bankhead National Forest (BNF) in the southern US are being managed to move them towards more hardwood dominance using thinning and prescribed fire.
- Cultivating the reproduction cohort so that desired species such as oaks are favored over less-desirable species such as red maple is challenging for these contemporary stands, which have not been disturbed for many years. This lack of disturbance has resulted in a failure of small oak seedlings to recruit into more competitive positions for eventual release into a new overstory canopy while red maple densities and larger sized seedlings have increased.
- Both thinning and multiple prescribed fires are needed to stimulate reproduction growth and recruitment; oak and red maple reproduction densities are highest under the most disturbance, one thin to a residual 50 basal area and five fires.
- Large (4.5 ft tall up to 1.5 inches dbh) red maple seedling sprouts are dominating the reproduction cohort.
- Five prescribed fires have not eliminated the red maple in favor of oak reproduction.

Summary:

Management problem: Widespread failure of oak regeneration and subsequent loss of the oak component has been reported across Eurasia and the Americas. The oak regeneration issue has been linked to changing disturbance regimes, including the lack of fire. Burning used in combination with stand thinning creates conditions that should be conducive to oak regeneration establishment and recruitment, including increased understory light and decreased woody plant competition.

Management need: Managers are using thinning and prescribed fire prescriptions aimed at restoring hardwood dominance in upland pine-hardwood mixed-woods. While prescribed fire has been purported to sustain the dominance of oaks, contemporary forests have altered species composition and structure and responses to these current disturbances are unknown.

Research purpose: We examined the sprouting dynamics of the reproduction cohort in response to one thinning and multiple prescribed fire treatments. While sprouting by both oak and red maple after being top-killed by fire is expected, the competitive dynamics of the sprouting response is unknown. We examined the origin (natural reproduction seedling or sprout), densities and size classes of oaks and red maple in response to a combination of thinning and burning.

Silvicultural Concepts:

- Treatments: We used the BNF's Forest Health and Restoration Project's parameters of thinning (with a residual basal area ranging from 75 to 50 square feet per acre, BA) and prescribed fire (with a return interval ranging from 3 to 9 years) to plan and implement a study with a randomized complete block design with a 3- by 3 factorial treatment arrangement and four replications of each treatment (see Schweitzer and others (2016) for study details).
- Fire treatments: All fires are dormant season fires. While management and research are done at the stand level, prescribed fire is done at the landscape scale, and burn sizes ranged from 150 to 3,000 acres (60–1,200 ha). The "research burns" were embedded within a larger burn plan on the BNF. Fire behavior was variable across stands and years. Thermocouples measured fire temperatures and showed a range of average maximum temperatures from 207 ºF to 486 ºF (table 1).
- Treatments covered in this review include:
    - Stands thinned once to a residual basal area of 50 BA
    - Within 13 years, thinned stands received no fire, 2 fires (infrequent fire, with a return interval of 9 years) or 5 fires (frequent fire, with a return interval of 3 years)
    - Control stands were neither thinned nor burned
- Using permanent sample plots, we assessed the reproduction cohort by species, size class and origin (sprout or seedling) after 13 years.
    - Oaks (*Quercus alba, Q. coccinea, Q. prinus, Q. rubra, Q. stellata, Q. velutina*) are desired production and red maple (*Acer rubrum*) is a primary woody competitor.
    - Across all treatments total reproduction was 35% red maple and 18% oaks.
    - In thinned stands with no fire red maple and oak were 49% and 11% of total reproduction, respectively; for thinned stands with frequent fire, 47% and 36%, respectively.
    - Sprout origin stems dominated the burns stands, with greater than 80% of red maple and oak reproduction sprouts (figs. 1 and 2).

- For the frequent fire stands, reproduction in the largest size class, 4.5 ft tall up to 1.5 in DBH, were red maple sprouts 26% (1105 SPA) compared to only 3% oaks (90 SPA). (figs. 1 and 2).

Management Applications:

- Many managers in the Southeast use prescribed fire in either pine or hardwood systems as a part of integrated management plans.
- We are using thinning and burning tools to move pine-hardwood mixed-woods towards forests that are more hardwood dominated.
- Our study on the BNF is a true Forest Service partnership between the National Forest System and Research and Development.
- Managing hardwood systems is nothing like managing southern pines.
- Restoring the historic disturbance regime, which included fire, is paramount to successful restoration of healthy and resilient hardwood forests.
- As we continue to burn these stands, we are observing that red maple seedling sprouts are dominating the regeneration cohort.
- A management consideration would be to consider other tools to control the red maple, such as herbicide treatment, coupled with thinning and fire.
- Understanding the feedback system of fire, whereby vegetation influences flammability and fire effects and fire effects influence future vegetation, is paramount in using fire in a restoration capacity.
- Fire does have a role to play in the restoration and sustainability of southeastern oak forests.
- Along the way, we demonstrated that coproducing science isn't really that daunting. The partnership of research and management is foundational to identifying research problems in forestry and to developing practical science-based solutions to problems of high priority to forest managers.

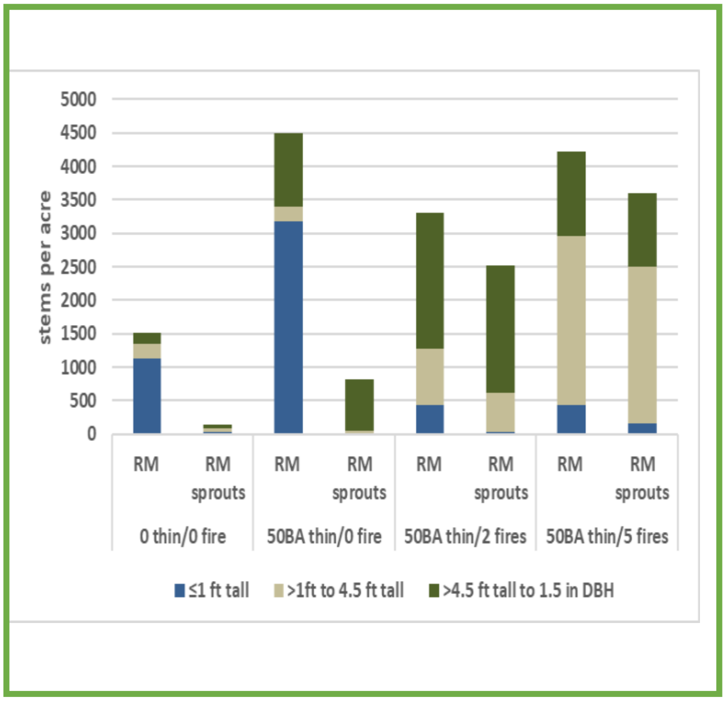


Figure 1—From four treatments on the Bankhead National Forest, Alabama, red maple reproduction by all tallies and tallies that are sprouts.

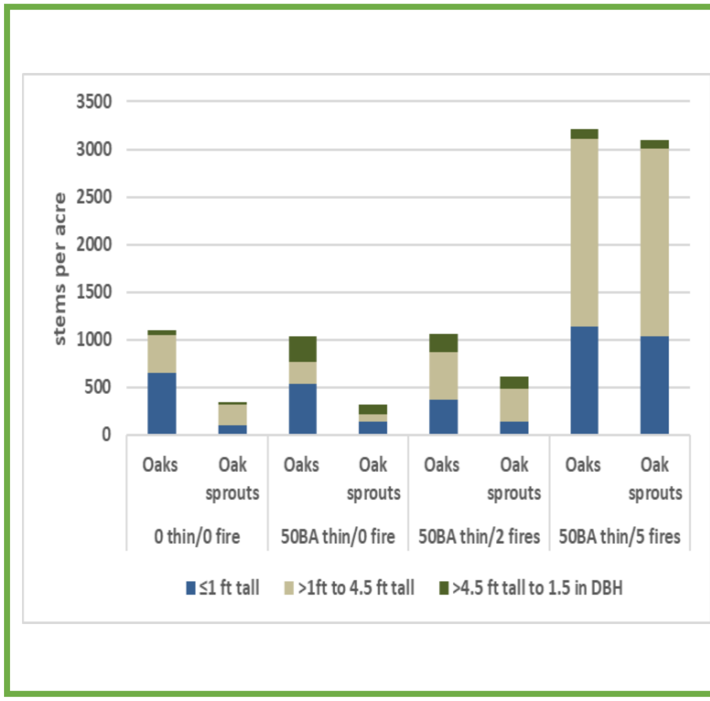


Figure 2—From four treatments on the Bankhead National Forest, Alabama, oak reproduction by all tallies and tallies that are sprouts. Note y-axis differs from figure 1.

Table 1—Fire temperature data (average maximum and standard deviation) collected from thermocouples systematically placed in prescribed fire stands on the William B. Bankhead National Forest, Alabama.

Year	Fire (Rx)	Average	StdDev	Average by Rx	StdDev by Rx
		Max temp (°F)	Max temp (°F)	Max temp(°F)	Max temp(°F)
2007	Rx1	216.2	176.1	211.7	136.7
2008		207.3	97.4		
2009		211.4	91.2		
2010	Rx2	195.8	81.1	267.9	95.2
2011		396.7	113.4		
2012		353.8	123.0		
2013	Rx3	397.4	177.9	412.7	147.4
2014		486.9	141.3		
2015		291.3	106.4		
2016	Rx4	355.0	168.3	374.7	153.6
2017		477.9	186.0		
2018		367.6	121.3		
2019	Rx5	331.3	126.7	332.8	125.6
2020		299.5	128.6		

References

Schweitzer, C.J.; Dey, D.C. 2021. Coproducing science on prescribed fire, thinning, and vegetation dynamics on a national forest in Alabama. Fire Management Today. 79(1): 43–51. https://www.fs.usda.gov/treesearch/pubs/62086.

Schweitzer, C.J.; Dey, D.C.; Wang, Y. 2019. White oak (*Quercus alba*) response to thinning and prescribed fire in northcentral Alabama mixed pine-hardwood forests. Forest Science. 65(6): 758–766. https://doi.org/10.1093/forsci/fxz031.

Schweitzer, C.J.; Dey, D.C.; Wang, Y. 2016. Hardwood-pine mixedwoods stand dynamics following thinning and prescribed burning. Fire Ecology. 12(2): 85–104. https://doi.org/10.4996/fireecology.1202085.

Smoke, Goats, and Oaks: Effects of Goat Browsing and Prescribed Fire on Woodland Structure and Floristic Composition in Ozark Hardwoods

Gina R. Beebe, Lauren S. Pile Knapp, Michael C. Stambaugh, Brian K. Davidson, and Daniel C. Dey

Overview:

- In eastern U.S. woodlands, targeted browsing, separately and in concert with prescribed fire, holds the potential to meet woodland restoration objectives of increasing the diversity and abundance of ground flora while reducing the density of understory woody stems.
- Targeted browsing had to neutral to positive influence on the coverage of herbaceous species while having minimal impact on nonnative cover. Targeted browsing in combination with prescribed fire significantly increased the coverage of forbs.
- A single targeted browsing event had little impact on tree reproduction density. When combined with prescribed fire, targeted browsing was effective at reducing the density of stems < 1 m tall and > 3.8 cm d.b.h., indicating a fire effect; our results did not suggest that the effects of browse + fire were additive.
- Goats are not picky eaters, and the seasonality of browsing played a minimal role in browse forage preferences. Goats consumed all tree genera although oaks and hickories were least preferred. The one exception observed was that stems less than 10 cm tall were minimally consumed by goats.

Summary:

Management Need: In eastern woodlands, frequent, low-intensity disturbances are needed to achieve desired woodland management objectives: an abundant and diverse ground flora, rich with herbaceous and graminoids species and minimal or isolated-dense patches of woody mid-story cover. These traits are integral to the structure and function of woodland communities. Prescribed burns are commonly used to meet these objectives; however, prescribed fire use can be limited by many constraints (e.g., risk, smoke, limited seasonality, legality), especially at the wildland-urban interface. Targeted goat browsing may have the potential to be used as a supplemental or alternative tool to aid in woodland restoration efforts when prescribed fire is not viable or mechanical mastication is too expensive.

Research Purpose and Design: Our goal was to understand whether targeted goat browsing, a controlled, herbivore-driven disturbance, separately and in conjunction with fire, could be an alternative and effective method of reintroducing disturbances and restoring woodland communities. We investigated goat browse preferences and the effects of treatments on

woody stem densities and plant functional group composition. We tested six treatments: (1) a spring browse (late May), (2) fall browse (late September), (3) dormant bud + fall browse (early April + late September; repeated browse disturbance), (4) a dormant season prescribed fire (February), (5) a spring browse + prescribed fire (late May + February; repeated disturbance), and (6) an untreated control. For each browsing treatment, goats were held in experimental units until approximately 85% of all vegetation was browsed to maintain consistency across treatments, which depending on treatment size, was generally reached within a few days.

Silvicultural Concepts:

- The response of ground flora to treatments was neutral to positive. Broadly, the percent cover of grasses and forbs increased in all browsing treatments. There was significant treatment effect for forb cover in the fire and browse + fire treatments (forb cover increased approximately 9% in both treatments after a single year). This likely indicates that fire has a stronger immediate effect on forbs and repeated browsing disturbance may be needed to mimic this effect.
- Broadly, land managers should expect everything present within their site to be browsed by goats. Trees less than 10 cm tall were not browsed (this can likely be extrapolated to other functional groups less than 10 cm tall). Oaks and hickories will be browsed, but will be qualitatively less browsed (i.e., moderately browsed versus severely browsed) than most other tree species unless goats are not removed.
- Midstory (i.e., stems > 1 m tall and < 3.8 cm d.b.h.) declined significantly in the fire and browse + fire treatments but did not change in the browsing-alone treatment. Goats are not impacting trees enough to cause mortality or the top-killing stems. With repeated browsing disturbance, effects may become more pronounced.

Management Applications:

- In spatial or temporal conditions where prescribed fire is not conducive, targeted goat browsing can aid in reaching woodland management objectives by increasing the abundance of diversity of herbaceous species. In areas where prescribed fire is conducive, targeted goat browsing in concert with prescribed fire may speed restoration efforts by limiting understory woody stem density and recruitment into the midstory.
- Our study utilized a ‘flash graze’ or ‘mob graze’ methodology one to two times during a calendar year. This methodology did not result in significant impact on woody stems. Most impact was directed towards lateral and apical shoots. However, it likely that repeated browse events during a year or extended over the course several years may have a greater effect on woody stems.

- Compared to a single browse, a single prescribed fire is more effective than browsing at increasing herbaceous cover and reducing the density of woody stems.
- Though are short-term results did not demonstrate that the results of browsing + fire were additive, other research suggests that when applied on the landscape over time, stronger effects may come to light.
- Managers can also use the principles of this research and extrapolate them to live fuel management.

Figure 1—Goat browsing wild plum (*Prunus americana*).

Figure 2—Untreated unit (left) and after the fall targeted goat browsing treatment (right).

Tackling Competitive Vegetation

Effects of Logging-Debris Removal, Vegetation Control, and Site Quality on Stand Characteristics of Coast Douglas-Fir

Robert A. Slesak, Timothy B. Harrington

Overview:

- Pronounced positive effects of logging-debris retention and vegetation control influence 15-year survival and growth of Douglas-fir in western Pacific Northwest forests.
- Effects mediated by soil quality: logging-debris retention and vegetation control had greater efficacy at the site with low soil quality (low nutrient and water availability).
- Removal of logging debris facilitated establishment of invasive Scotch broom (*Cytisus scoparius*) on the site with low soil quality, which caused cascading negative effects on soils and native plant communities.
- Trees growing in proximity to mini logging-debris piles had greater survival and growth compared to those located away from piles.

Summary:

Silvicultural establishment practices can influence survival and growth of the succeeding stand, including effects on stand productivity and plant community composition. Vegetation control and logging-debris manipulation are two common practices that influence reforestation success, but their effectiveness is likely to vary with soil quality and its influence on plant resource supply. We established an experimental manipulation of logging debris (removed, retained, or piled) and vegetation control (initial site preparation or annual herbicide application for 5 years) at two sites that contrasted strongly in soil quality. Tree growth and survival, vegetation communities, and soil properties were monitored for 15 years to assess the effects of treatments. At both sites, annual vegetation control increased Douglas-fir volume, ranging from a 30% to 160% increase at the low-quality site depending on logging-debris treatment, and by 30% on average at the high-quality site. In general, effects of logging debris were more pronounced at the low-quality site. At that site, debris removal led to higher cover of the invasive Scotch broom (~55% greater than debris retained treatments) and concurrent increases in Douglas-fir mortality, and logging-debris retention favored establishment of native species cover and abundance (fig. 1). Trees growing in proximity to piled logging debris had greater survival (by 16%)

than those growing more distant, which was associated with increased amounts of available N and nutrients under the piles. Taken together, we conclude that cultural practices that influence competitor abundance and resource availability are critically important on low quality sites, but may not be necessary at high quality sites where resource availability is less constrained.

Silvicultural Concepts:

- Early growth of planted seedlings is constrained by the availability of nutrients and water, which is strongly controlled by soil properties and local climate.
- Cultural practices, such as logging-debris manipulation and vegetation control, can channel limited resources to planted seedlings, increasing their survival and growth (fig. 2).
- The efficacy of these practices is greatest at sites where resource availability is inherently constrained, including sites with soils that have low nutrient pools and available water.
- Retention of logging debris can benefit planted seedlings by modifying the growing environment of competing vegetation (inhibiting establishment of competitive grasses and Scotch broom and other nonnatives) and improving soil quality as organic matter is incorporated into the soil or provides a mulching effect to increase water availability.

Management Applications:

- Forest managers can utilize logging debris to increase reforestation success where retention does not conflict with other management objectives such as reducing short-term fire risk or keeping planting costs low.
- Logging debris may also inhibit establishment of nonnative plant species and provide other benefits such as reduced browsing.
- Higher costs of sustained vegetation control may not be warranted at higher quality sites since early benefits to growth appear to lessen with time as the stand develops.
- Findings are being operationally applied to increase survival of Douglas-fir and inhibit establishment of Scotch broom on droughty forest soils in western Washington.

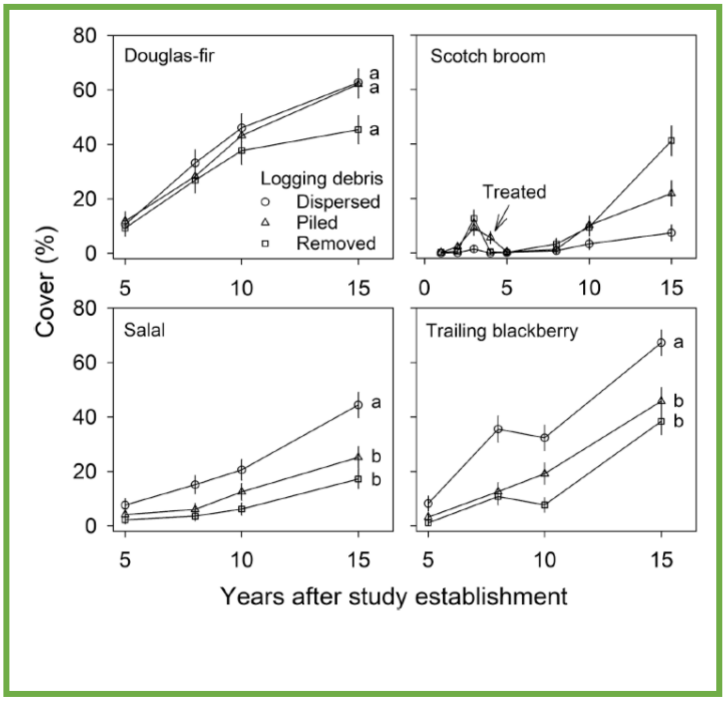


Figure 1—Cover of Douglas-fir, the invasive Scotch broom, and native salal and blackberry by logging-debris treatment at the low-quality site.

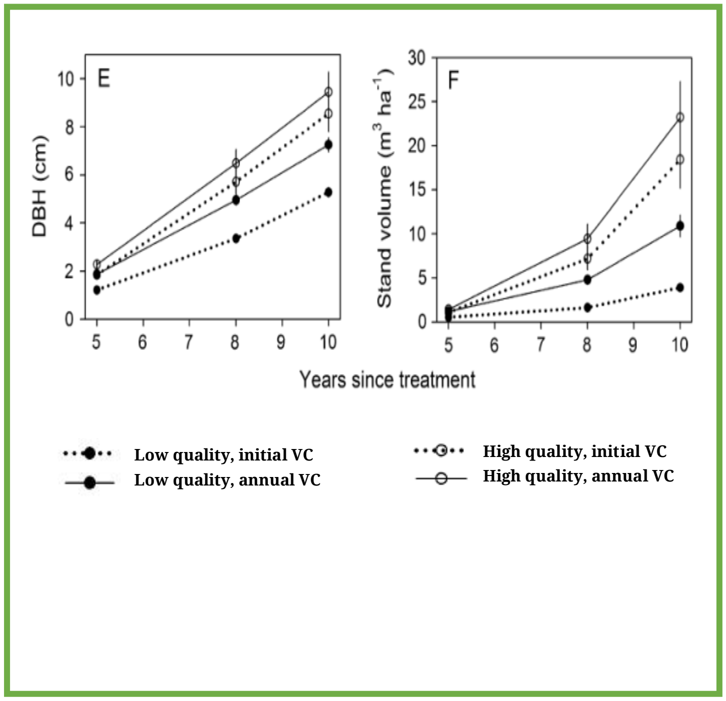


Figure 2—Douglas-fir survival (panel A), height (panel B), DBH (panel E), and stand volume (panel F) by vegetation control (VC) treatments (initial = site preparation; annual = sustained for 5 years) at high- and low-quality sites

Seven-Year Response of Planted Northern Red Oak (*Quercus Rubra*) Seedlings to Regeneration Harvesting, Burning, and Herbicide Treatments in Western North Carolina

Stacy L. Clark, Scott E. Schlarbaum, Tara Keyser, and Arnold M. Saxton

Overview:

- We tested high-quality, locally adapted seedlings (1-0) of northern red oak (*Q. rubra*) planted in four silvicultural treatments on high quality sites in western North Carolina: prescribed fire (Rx-burn), midstory-removal (MR), shelterwood-burn (SWB), and a control.
- The most efficacious treatment was the SWB where trees had more than 80% survival after 7 years and had maximum heights of 20 ft. Prescribed burning at year 5 in the SWB treatment negatively affected planted seedlings, however, reducing survival by 8% and height by 7 ft.
- Seedlings planted in noncommercial treatments (control, MR, Rx-burn) were short (averaging less than 4 ft) and had poor survival (< 51%) after 7 growing seasons.

Summary:

Management problem: Oaks have been difficult to regenerate for the last 50 years, primarily due to changes in the disturbance regime, herbivore pressure, a wetter climate, and lack of proven management prescriptions. Oak reproduction must be relatively large (e.g., > 3–4 ft) prior to overstory removal to be competitive, and understory light regimes in undisturbed forests are too low for small oaks to recruit into larger size classes. Treatments that target the midstory and understory, such as burning and herbicide, increase light levels that favor oak regeneration and reduce competitors, but planting in these treatments have not been adequately tested.

Management need: Oak planting offers a potential solution to mitigate the oak regeneration problem, but artificial regeneration has not been widely studied in productive forests of the eastern United States. Technological advancements that produce high-quality, improved

nursery seedlings have only been recently developed and tested. Availability of dependable, locally adapted seed sources are still mostly lacking, and planting can be expensive; therefore, planting should be conducted using the most efficacious methods available.

Research purpose: We planted high-quality (e.g., height averaged > 3 ft) northern red oak seedlings in four replicated silvicultural treatments—prescribed burn only (Rx-burn), midstory removal (MR), shelterwood-burn (SWB), control—on Cold Mountain Game Lands in western North Carolina. Sites were productive (site index > 80 ft for red oak). The Rx-burn treatment was implemented in the late dormant season just prior to planting and again 5 years after planting. The midstory removal was a noncommercial herbicide (Garlon® 3A) injection applied just prior to planting to remove the midstory canopy layer (all non-oak and hickory trees between 2 to 10 inches d.b.h.). The shelterwood harvest (residual BA = 50 ft^2 per acre) was implemented just prior to planting and was burned once during the late dormant season 5 years after planting.

Silvicultural Concepts:

- Noncommercial treatments designed to improve the development of natural oak reproduction in the understory (e.g., Rx-burn, MR) were not beneficial to underplanted oak seedlings. Trees in these treatments generally lost height through dieback of the main stem and had relatively low survival (fig. 1), presumably due to low light levels.
- The SWB treatment was the most beneficial treatment after 7 years. Seedlings averaged 6.6 ft in height but could be as tall as 22 ft (fig. 1). Approximately half of the seedlings in this treatment were free-to-grow (no competition was above their terminal bud). Seedlings that were burned over had similar free-to-grow status as trees that escaped fire (47%).
- Prescribed burning was not beneficial for planted seedlings in the Rx-burn or in the SWB treatments. Fire burned 96% of trees in the Rx-burn treatment, killing 24% of trees that were burned, while 65% of trees in the SWB were burned, resulting in a mortality of 8%. Larger size trees in the SWB were better able to withstand fire, compared to the smaller size trees in Rx-burn only treatment. Seedlings that sprouted after top-kill from burning were less than half of the height of unburned seedlings 2 years following the fire (fig. 2).

Management Applications:

- Prescribed burning is becoming increasingly popular to improve ecological diversity, reduce fuel loads, and benefit the oak regeneration process (Arthur et al. 2012). Our results demonstrated that prescribed fire was not beneficial to planted northern red oak seedlings in the shelterwood harvest or as a stand-alone treatment. A targeted practice, such as crop-tree release, might be more beneficial to release planted oaks than a prescribed fire in even-aged regeneration systems.

- Planting can be expensive and difficult, but our results show that it can directly improve the density of competitive oak reproduction in a shelterwood harvest. We used relatively large seedlings (representing the top 50% of seedlings from the nursery) from locally adapted seed sources, which contributed towards their success (Clark et al. 2016).
- Because of the costs and resources required to implement artificial regeneration, we do not recommend prescribed fire following planting until seedlings have bark thick enough to resist top-kill. Uneven fuel distributions from logging contributed toward a patchy fire in the SWB treatment, allowing some trees to escape fire and develop relatively large sizes. The Rx-burn treatment was less patchy, and most seedlings that were burned resprouted following fire. In both the Rx-burn and SWB treatments, seedlings did not obtain their original height prior to the fire.
- Planted seedlings will perform best in a regeneration harvest and will not perform well planted in noncommercial treatments, as implemented in this study. We postulate that light levels were too low to maintain photosynthetic demands required to sustain seedlings' relatively large root systems.

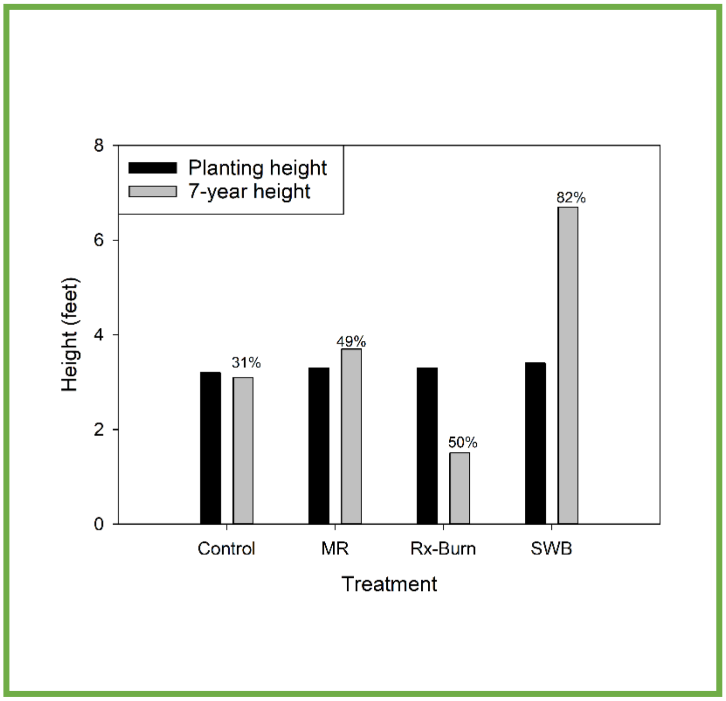


Figure 1—Mean height of planted northern red oak in each silvicultural treatment. Numbers above 7-year height bars are mean survival. MR = midstory-removal, Rx-Burn = prescribed burn, SWB = shelterwood-burn.

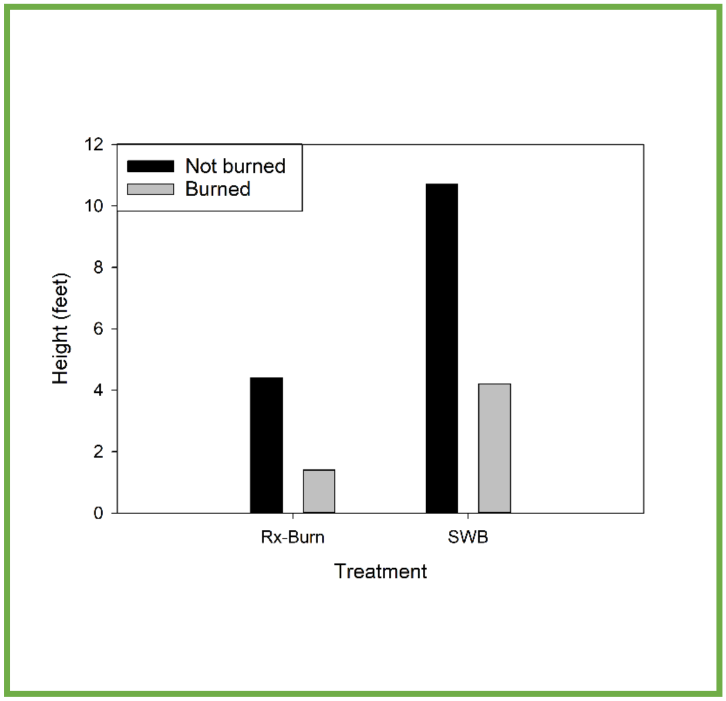


Figure 2—Mean height for the prescribed-burn (Rx-burn) and shelterwood-burn (SWB) treatments for planted northern red oak seedlings that were burned over or that escaped fire.

References

Arthur, M.A.; Alexander, H.D.; Dey, D.C.; Schweitzer, C.J.; Loftis, D.L. 2012. Refining the oak-fire hypothesis for management of oak-dominated forests of the eastern United States. Journal of Forestry. 110: 255–266.

Clark, S.L.; Schlarbaum, S.E.; Keyser, T.L.; Schweitzer, C.J.; Spetich, M.; Simon, D.; Warburton, G.S. 2016. Response of planted northern red oak seedlings to regeneration harvesting, midstory removal, and prescribed burning. In: Proceedings of the 18th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-212. Asheville, NC: US Department of Agriculture, Forest Service, Southern Research Station. 457–464.

Developing Advance Reproduction of Intermediate Light-Tolerant Species Such as White Oak: A Focus on Midstory Removal

Wayne K. Clatterbuck and Canaan J. Dugger

Overview:

White oak regeneration is both disturbance dependent and advanced growth dependent (Clatterbuck 2019). “The answer to the question of how to ensure oak regeneration … is not the development of some radically new method of cutting, but recognition that all cutting operations in a stand, from the very first, should have as some of their objectives the creation of an environment, largely light conditions, favorable for oak regeneration … and furthermore … ensure that cuttings occur frequently enough to maintain growth of oak regeneration” (Hodges 1989).

Regenerating oak is a process that must be cultured and not an event. For oak regeneration to be successful, advance reproduction of oak must be present before the disturbance (natural or anthropogenic) to give them an initial growth advantage over competing seedlings that regenerate after the disturbance. The oak seedling growth strategy prioritizes root over top growth causing slower aboveground (top) growth initially. Growth of many competing species with opposite growth strategies often displaces the development of slower-growing oak seedlings before oaks can emerge into the overstory unless intermediate light conditions are provided that benefit growth of oak reproduction and discourage growth of competing species.

Several practices are available to provide these intermediate light conditions favorable for oak, including shelterwood, variable overstory retention (thinnings), midstory removal, various small opening sizes (groups, edges, islands, clusters), expanding gap or femelschlag, and deferment cuts (two-age). The present research involves midstory removal to promote the partial light conditions favorable for the growth and development of advance oak reproduction while impeding the growth of other competing species.

Summary:

White oak is a keystone species for both wildlife and wood products. The sustainability of white oak is in question considering the regeneration difficulties associated with the species (fig. 1). Although white oak is plentiful in the older age classes (> 40 years) in the near term, the younger age classes are deficient. The issue is with the intermediate light tolerance of the species. Too much sunlight (such as clearcuts or low basal area retentions) supports much faster-growing, sun-loving species while too little sunlight (closed canopy, nondisturbed areas) favors more shade-loving species. Creating the environmental conditions with those intermediate conditions that favor white oak regeneration and development compared to other species has been challenging on both private and public lands.

This study capitalizes on 2nd-year white oak germinants following a bumper white oak acorn crop that exceeded animal predation during the summer of 2018 near Oak Ridge, Tennessee. The release of 2nd-year advance reproduction of white oak through a midstory control treatment is being evaluated to determine whether white oak seedlings may gain a growth advantage that they would not otherwise receive (fig. 2).

Silvicultural Concepts:

Research by Loftis (1983) suggests that without disturbances to create these intermediate light conditions, survival and height growth of northern red oak reproduction diminishes (fig. 3). If these light conditions are established, seedling survival and size are projected to increase. This study tests this premise with white oak with the establishment of 26, 6.5-foot square plots, with 13 plots receiving a midstory release and the other 13 plots remaining as an undisturbed control with closed canopies. The release treatments were 0.4 acres, which involved cutting the midstory canopy level, regardless of species, and overstory beech, maple, and yellow-poplar trees were cut or injected with herbicide to limit future seed production. All cut stumps were treated with herbicide to inhibit sprouting. The overstory white oak mother trees remained casting some partial shade. Available light (photosynthetic active radiation – PAR) was measured with ceptometers twice on each plot.

Preliminary results indicate that there was no difference in total height of white oak seedlings between treatments after one complete growing season (2021), although we anticipate height differences in the future. In the control treatment, seedlings were more etiolated and seedling survival numerically diminished, but not significantly. Additional competing species or number of seedlings in the midstory release treatment were not encountered. At this early growth stage, white oak advance reproduction with midstory release do not appear to be influenced by growth of other, competing species although intraspecific influence among the abundant white oak seedlings was apparent.

Available light levels of 20 to 30% are accepted for enhanced growth of oak reproduction (refer to Clatterbuck 2019 for reference compilation). Available sunlight based on PAR in this study averaged less than 5% in the closed canopy control plots and ranged from 15 to 42% with a mean of 33% in the release treatments, well within the available light range in the literature.

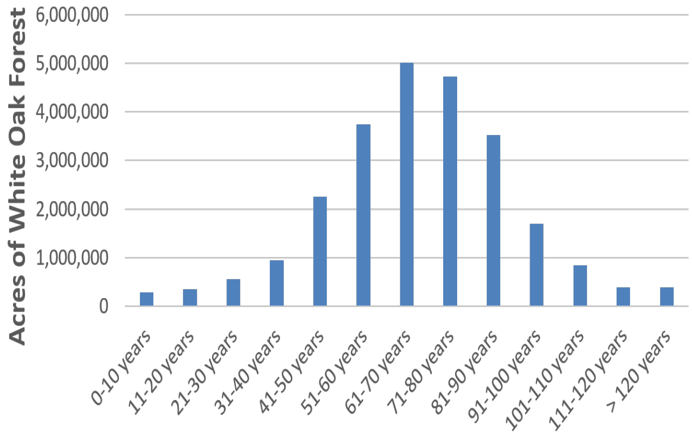
Management Applications:

Regeneration of white oak and most oaks are advance growth dependent. Oak seedlings are one of the slowest growing species. Advance reproduction gives oaks an early advantage over faster-growing, intolerant species that seed in after a disturbance or existing shade-tolerant seedlings that otherwise would not occur.

Oak is also disturbance dependent. Disturbances, whether natural or anthropogenic, should occur more frequently to maintain the partial sunlight and more open stands that are beneficial for oak seedlings to grow and to retain an adequate number of seedlings. Closed canopies without frequent disturbances are detrimental to successful oak reproduction.

Maintaining intermediate light conditions in more open-canopied stands is challenging. The intermediate amount of light that favors oak seedlings, also discourages the growth of species that require greater amounts of sunlight (intolerants) or more shade-tolerant species. Most stands progress to full stocking in time with closed canopies. More frequent disturbances are necessary to maintain these more open stands to benefit development of oak regeneration.

Previously mentioned practices, similar to midstory removal outlined in this research, should provide the partial light conditions that allow white oak advance reproduction to grow and eventually become a component of the overstory.



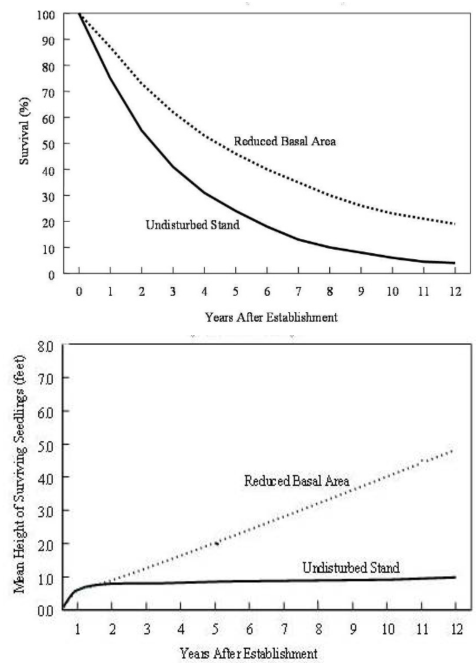


Figure 1—Number of acres of white oak-dominated forests by age class across Illinois, Indiana, Kentucky, Missouri, Ohio, and Tennessee, 2021. Source: Assessment and Conservation Plan. *www.whiteoakinitiative.com.*

Figure 2—Hypothesized survival (top) and height (bottom) response of northern red oak advance reproduction to reductions in basal area (Loftis 1983).

Figure 3—Examples of a midstory control (left) and control (right) treatments.

References

Clatterbuck, W.K. 2019. What do we know about oaks? Keystones of oak silviculture. In: Clark, S.L.; Schweitzer, C.J., eds. Oak symposium: sustaining oak forests in the 21st century through science-based management. e-Gen. Tech. Rep. SRS-237. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 3-12.

Hodges, J.D. 1989. Regeneration of bottomland oaks. Forest Farmer. 49(1): 10–11.

Loftis, D.L. 1983. Regenerating red oak on productive sites in the southern Appalachians: A research approach. In: Jones, E.P., Jr., ed. Proceedings of the second biennial southern silvicultural research conference. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 144-150.

Intensity, Frequency, and Seasonality of Prescribed Burning to Control Survival and Growth of Red Maple

Edward C. Yost, Wayne K. Clatterbuck

Overview:

- Red maple (*Acer rubrum* L.) is a shade tolerant species in the Central Hardwood Region of the eastern United States. Red maple is found across a wide range of environments from valleys to ridgetops, and in open and closed forest canopy conditions. Red maple sprouts with rapid height growth after natural or anthropogenic disturbance.
- The use of prescribed fire to control red maple in different seasons of the year has had mixed results.
- A research plantation of red maple was established to determine how the season of burning, fire intensity, and frequency of fire impacts red maple seedling survival and growth.
- Prescribed fires during the late winter season increased red maple sprouting and fires during the spring and summer season reduced sprouting.
- The diameter of the root collars and height of sprouts after late winter fires were generally larger than after fires in the spring and summer seasons.

Summary:

Management problem: Red maple was once a minor component of eastern deciduous forests. It is now the most abundant and widespread tree species in the eastern United States (Oswalt et al. 2019). The increase in red maple is attributed to its adaptability to a wide range of environments and the current management policy of forest fire suppression (Abrams 1992). On most sites, red maple seedlings tend to outgrow the regeneration of more desirable species, especially oaks.

Management need: Managers seeking to reintroduce fire to the natural landscape have had mixed results in controlling shade tolerant species including red maple. Fire has variable effects in different seasons. Single burns produce different effects from multiple burns in the same forest. A greater understanding of fire intensity, seasonality, and frequency of burning is necessary to achieve management goals to reduce understory competition.

Research purpose: The purpose of this research was to determine the effects of prescribed burning on red maple seedling survival and sprouting. A plantation was established to

provide uniform site conditions for research at the University of Tennessee Forest AgResearch and Education Center in Morgan County, Tennessee. A randomized complete block design was used to explore different combinations of fire intensity (high and low amounts of forest fuels), season of burning (three different seasons), and frequency of fire (single fires in alternate years).

Silvicultural Concepts:

- Natural fires serve an ecological role in the development of oak forests of the Central Hardwood Region. Fire suppression programs have interrupted the historic cycle of fire. The reintroduction of fire on the landscape has given variable results to increase oak regeneration and to reduce red maple competition.
- Fires during the late winter caused red maple to sprout profusely. This may be because nutrient reserves are higher in the dormant season. Fire causes less damage at that time as there is no immediate impact to vegetative structures or physiological functions of actively growing seedlings.
- Red maple sprouts that were burned in the winter had a larger basal diameter and height than seedlings burned in the spring or summer season. Seedlings burned during the late winter season produced a greater number of sprouts (fig. 1).
- Increased sprouting capacity prior to spring emergence mitigates stem loss due to fire. The emergence of red maple sprouts early in the growing season creates intense, interspecific competition with the sprouts from other more desirable hardwood species.

Management Applications:

- Ed Yost, Natural Resources graduate student: “The timing of prescribed fires has different effects on hardwood trees. My research revealed that dormant season burns did not reduce red maple sprouting as much as growing season burns (fig. 2).”
- Many trees sprout after disturbance by fire. Tift and Fajven (1999) suggested that red maple produces coppice sprouts and grows rapidly in response to increased sunlight in canopy openings.
- Red maple responds to disturbance and damage by lateral stem growth. The tendency for red maple to bush allows it to rapidly regain photosynthetic capacity after stem loss.
- Prescribed burning during the dormant season to achieve understory removal of red maple may require additional silvicultural treatment such as manual cutting or herbicide application.
- Forest management prescriptions to discourage red maple should include options for burning when red maple is actively growing to achieve desired results.

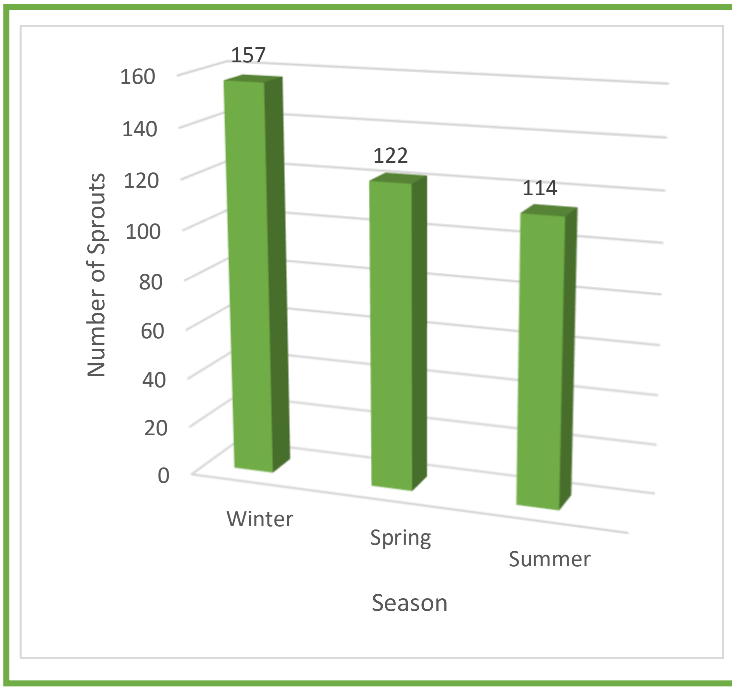


Figure 1—Number of red maple sprouts in plots that were burned biennially by season of burning.

Figure 2—Red maple seedlings during growing season burn with MicroEpsilon ThermoImager to record fire temperatures.

References

Abrams, M.D. 1998. The red maple paradox: What explains the widespread expansion of red maple in eastern forests? BioScience. 48(5): 355–364.

Oswalt, S.N.; Smith, W.B.; Miles, P.D.; Pugh, S.A., coords. 2019. Forest resources of the United States, 2017: a technical document supporting the Forest Service 2020 RPA Assessment. Gen. Tech. Rep. WO-97. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 223 p.

Tift, B.D.; Fajven, M.A. 1999. Red maple dynamic in Appalachian hardwood stands in West Virginia. Canadian Forest Journal of Forest Resources. 29: 157–165.

Climate Resilience

Stand Tending Dilemmas—A Decision Tree for Climate Resilience and Adaptation

Robyn Darbyshire

Overview:

- For at least 20 years, Region 6 has been recommending low planting densities to avoid the need for non-commercial thinning. The rationale for this has been two-fold: (1) lack of funding to pay for non-commercial thinning and (2) and changes in management direction from the Northwest Forest Plan and the Eastside Screens that emphasize the development of old forest characteristics and, in the case of the Northwest Forest Plan, no harvest in stands more than 80 years old in some land allocations. With an increased emphasis on climate change resilience and adaptation, it is time to rethink this approach, particularly with an increase in fire-caused reforestation needs. A decision tree is presented to identify stand objectives related to climate resilience and adaptation and how that might create some additional considerations for stand tending in Region 6 and perhaps elsewhere.

Summary:

None provided.

Silvicultural Applications:

- None provided.

Management Opportunities:

- None provided.

Adapting Gingrich Stocking Guides for Managing Oak Woodlands and Savannas

John M. Kabrick, Brice B. Hanberry, Daniel C. Dey, Benjamin O. Knapp, David R. Larsen, Lauren S. Pile Knapp

Overview:

- Gingrich's stocking guide is a stand density diagram based on the minimum tree-area ratio equation for oaks and hickories that incorporates information about the number of trees, the basal area, and the quadratic mean diameter of a stand relative to the maximum that can be sustained according to the principle of self-thinning.
- Because Gingrich's stocking guide identifies the maximum and minimum stand density for full growing space occupancy, the chart identifies the optimal stand densities for maximizing diameter growth of individual trees while maintaining a high stand-level volume for sawtimber production.
- However, stocking guides also can be used to manage oak woodlands, savannas, and other open forests where density and structure are manipulated to create understory light levels and other conditions favorable for the growth of native graminoids, forbs, and legumes.
- To make Gingrich's stocking chart more useful for woodland and savanna management, additional stocking thresholds were needed. We proposed that closed-canopy woodland stocking ranges from the B-level up to about 75%, open-canopy woodland stocking ranges from 30% to the B-level, and savannas have stocking < 30%.
- These stocking thresholds can be used for planning savanna and woodland thinning or for evaluating stand density reductions from prescribed fire treatments.

Summary:

Management problem: Despite growing interest in restoring and managing oak woodlands and savannas, few silvicultural guidelines and tools are available, particularly for evaluating or adjusting woodland or savanna stand density and overall structure. Gingrich's Stocking Guide has been used for managing oak-hickory forests for several decades, but important density thresholds are intended for use in forests where maintaining full growing space occupancy is the goal during thinning.

Management need: Stocking guides modified to identify important density thresholds will inform the management of the more open structures of oak woodlands and savannas. Woodlands and savannas are managed at lower stocking levels than oak forests and therefore have unique stocking thresholds that are tailored to biodiversity goals rather than timber production objectives.

Research purpose: We present stocking thresholds for oak woodlands and savannas and discuss how they were derived through empirical measurements.

Silvicultural Concepts:

- Growing space availability strongly affects the growth rate and form of trees. Trees grown under lower stand densities grow at faster rates and develop larger, fuller crowns than trees grown under higher stand densities. For oak-hickory forests, Gingrich's has been the most widely used stocking guide for managing stand density.
- Key thresholds on Gingrich's guide include the average maximum density (the A-line, 100% stocking) and the minimum density of full growing space utilization (the B-line, 55 to 58% stocking). The A-line indicates average maximum growing space occupancy (stocking) occurring in undisturbed oak-hickory stands originally derived from the minimum tree area equation. The B-line indicates the average minimum growing space occupancy that would occur with open-grown trees where all the growing space is fully occupied; this was originally derived from the maximum tree area equation but also has been found to be at 57 to 59% stocking for trees 4 to 20 inches d.b.h. A third line, the C-line, is the stocking level on an average site that will grow to the B-line in 10 years.
- We propose that Gingrich's Stocking Guide can be used for managing savannas, woodlands, and other similar open forests where timber management is not the primary goal. To do this, stocking thresholds were identified to define the growing space for savannas and woodlands. Thresholds were identified empirically using witness tree data from the General Land Office and data from contemporary experiments (table 1).
- **Closed-canopy woodlands** have stocking ranging from the B-line to 75% (fig. 1). The upper bound corresponds to the stocking of a closed-canopy forest that has had the mid-story and understory trees removed through thinning or repeated prescribed fire (Knapp et al. 2017). The lower boundary is defined by the B-line because, by definition, all growing space is occupied, and crown closure occurs at this stocking level. **Open-canopy woodlands** have stocking below the B-line, and therefore below the point of crown closure. The lower boundary of open woodlands—30% stocking—is somewhat arbitrary but is the stocking level where woodlands transition into **Savannas**, as supported by density estimates made with witness tree data from the General Land Office surveys (Hanberry et al. 2014).

- Stocking levels can also be used to estimate crown closure and understory light levels, two important factors for managing ground layer vegetation in oak woodlands and savannas (fig. 2).

Management Applications:

- Stocking thresholds can be used for evaluating the density of unmanaged savannas and woodlands to determine the stocking adjustments that are needed for their restoration. They can also be used for evaluating stand density reductions from prescribed fire treatments or for planning thinning treatments to meet savanna or woodland stocking goals.
- Because canopy closure and light transmission can be predicted with stocking, woodland and savanna stocking goals can be identified for meeting the physiologic needs of specific understory plants.
- Marking guides can be prepared where stocking goals are translated into target basal area thresholds to facilitate tree marking with a prism.
- These thresholds provide a more objective way for defining savannas and woodlands using structural attributes, for identifying the stand density adjustments that are needed, and for explicitly communicating how to thin stands to meet restoration goals.

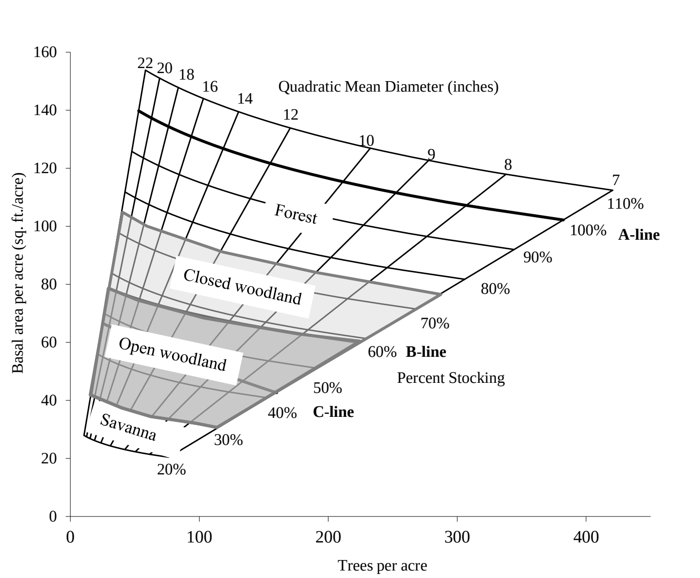


Figure 1—Stocking thresholds used for managing savannas and woodlands compared to forests. Woodlands can be further divided into those with closed (light grey shading) or open (dark grey shading) canopies.

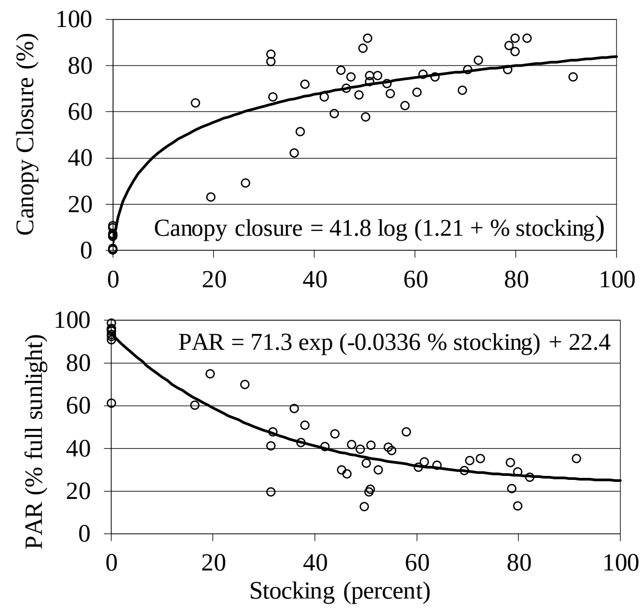


Figure 2—Relationship between percent stocking and canopy closure and photosynthetically active radiation (PAR) in recently thinned unmanaged stands (adapted from Blizzard et al. 2013).

Table 1—Stocking and density thresholds for oaks and pines (> 5 inches d.b.h.) using witness tree data from General Land Office records from the Missouri Ozark Highlands (adapted from Hanberry et al. 2014).

Vegetation type	Stocking (%)	Density (per acre)	Oak (%)	Pine (%)
Prairie	< 10	< 20	--	--
Oak savanna	< 30	< 40	≥ 30	--
Open oak woodland	< 55	< 70	≥ 30	--
Closed oak woodland	< 75	< 100	≥ 30	--
Oak forest	≥ 75	≥ 100	≥ 30	--
Oak-pine savanna	< 30	< 40	≥ 30	≥ 30
Open oak-pine woodland	< 55	< 70	≥ 30	≥ 30
Closed oak-pine woodland	< 75	< 100	≥ 30	≥ 30
Oak-pine forest	≥ 75	≥ 100	≥ 30	≥ 30
Pine savanna	< 30	< 40	--	≥ 30
Open pine woodland	< 55	< 70	--	≥ 30
Closed pine woodland	< 75	< 100	--	≥ 30
Pine forest	≥ 75	≥ 100	--	≥ 30
Other forest	≥ 75	≥ 100	< 30	< 30

References

Blizzard, E.M.; Kabrick, J.M.; Dey, D.C.; Larsen, D.R.; Pallardy, S.G.; Gwaze, D.P. 2013. Light, canopy closure, and overstory retention in upland Ozark forests. In: Guldin, James M., ed. 2013. Proceedings of the 15th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-GTR-175. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 73–79.

Hanberry, B.B.; Jones-Farrand, D.T.; Kabrick, J.M. 2014. Historical open forest ecosystems in the Missouri Ozarks: Reconstruction and restoration targets. Ecological Restoration. 32: 407–416.

Knapp, B.O.; Hullinger, M.A.; Kabrick, J.M. 2017. Effects of fire frequency on long-term development of an oak-hickory forest in Missouri, U.S.A. Forest Ecology and Management. 387: 19–29.

Introducing Diversity Through Tending

Early Stand Improvement for Multiple Ecosystem Services Using Adaptive Complexity Thinning

Andrew J. Larson, Michael S. Schaedel, Justin S. Crotteau, David K. Wright, Rebecca Durham, Alexander V. Kumar, John Fothergill, Michael McTee, L. Scott Mills, Anne Orlando, Philip Ramsey, Andrew Reed, James Sparks

Overview:

- Rocky Mountain forests with simple structure are poorly poised to provide the ecosystem services that society expects in a warming climate.
- Adaptive complexity thinning (ACT), an ecological approach to precommercial thinning in young stands, has the potential to kick-start development of forest complexity, delay snowmelt, and provide hiding cover for snowshoe hares and other wildlife.
- ACT treatments are being implemented on The Nature Conservancy, Bureau of Land Management, and Forest Service lands using active adaptive management.

Summary:

Montane and subalpine forests in the Northern Rocky Mountains produce wood fiber for products, store water in the snowpack, sequester carbon, and provide wildlife habitat, including for threatened Canada lynx and their primary prey, the snowshoe hare. Use of precommercial thinning (PCT) in potential lynx habitat is restricted on federal lands due to short-term reduction of forage and hiding cover for hares. However, dense young forests are slow to develop multiple canopy layers (fig. 1)—habitat preferred by hares and lynx—yet silvicultural thinning can accelerate development of multiple canopy layers and complex structure, a tension between short-term and long-term objectives. Additionally, forests with dense canopy cover accumulate less snow and have shorter snow cover duration than areas of low canopy density. Shorter snow duration can increase predation risk for snowshoe hares when their winter white coat is mismatched against snowless ground.

Agency specialists have identified the need for information about long-term PCT treatment responses and new management options in dense young forests regenerating after high-severity fire or even-aged harvest to balance competing societal expectations for ecosystem services. We present new results for vegetation structure and hare relative abundance and habitat use following PCT. Horizontal cover (2-m coverboard) was not significantly different between thinned and unthinned stands 17–34 years post-treatment; live tree density was higher in unthinned stands, while live tree diameter was larger in thinned stands. Snowshoe hare pellets were present in every stand, but pellet relative abundance was significantly higher in unthinned stands. In a separate long-term experiment, Griffin and Mills 2007 designed to test effects of PCT treatments with embedded unthinned reserves (PCT-R) and found significantly more hare pellets at locations adjacent to reserve patches compared to areas > 50 m from reserves, suggesting hares preferentially use dense reserve patches within thinned areas. Treatment-wide average horizontal cover was higher in unthinned control stands, lowest in uniformly thinned PCT treatments, and intermediate for PCT-R treatments.

Silvicultural Concepts:

- Based on findings from these long-term studies and Kumar et al. (2018), we developed a novel silvicultural approach called adaptive complexity thinning (ACT). ACT is a form of variable density thinning (fig. 2) designed to accelerate the development of complex multistory forest structure preferred by Canada lynx and snowshoe hares (and other wildlife species) while also balancing objectives for snow accumulation and duration, potential fiber production, carbon sequestration, and short-term hare habitat suitability. ACT recognizes forests as complex adaptive systems and is designed to foster long-term ecological resilience and provision of ecosystem services.
- We developed two ACT treatments—focal tree release or “daylighting” in an unthinned matrix, and retention of unthinned reserves within a thinned matrix—forming a continuum of treatment intensity (fig. 2). In ACT treatments, focal codominant trees are released, but smaller shade-tolerant trees and shrubs are retained for wildlife cover and forage in the short-term and to accelerate development of multiple canopy layers in the long-term.
- Thinning the overstory allows for greater potential snow accumulation and duration due to reduced canopy interception and lower total radiation (shortwave plus longwave) reaching the snowpack. ACT increases forest heterogeneity further by incorporating unthinned areas, which provide high-cover habitat for snowshoe hares, as well as high carbon sequestration potential.

Management Applications:

- New operational-scale ACT treatments are being implemented on Forest Service, Bureau of Land Management, and The Nature Conservancy lands using an adaptive management (AAM) framework to assess effectiveness. AAM uses principles of experimental design to test alternative management approaches at operational scale (Larson et al. 2013).
- Contract language was codeveloped with project partners for seamless integration into a standard federal precommercial thinning contract. The goal was to create contract language that is simple to understand and successfully creates the desired complex stand conditions.
- Where and how to lay out retention patches is a practical management concern. Expert opinion was used to select "hot spots" for actual or potential hare habitat (e.g., especially dense conifer patches) within ACT treatment areas. GIS polygons delineating reserve locations (2.5-acre and 5-acre squares oriented in the cardinal directions) balance the requirement for simple, systematic layout and coverage of identified hotspots. Contractors are expected to lay out retention areas to a specified precision. This approach was designed to reduce agency staff time required for layout while creating specifications that can be administered in the field.
- Thinning contracts commonly include a minimum tree height for thinning, though that height varies by forest type, ownership, and local management practices. Managers on the Flathead National Forest noted that not thinning understory regeneration below 2 feet is typical in operational PCT contracts, while the BLM Missoula Field Office usually does not thin below 1 foot in height. ACT retains seedlings up to 4-feet tall outside reserve areas to promote development of multiple canopy layers, which also may reduce contractor hours and costs. The minimum height of cut trees can vary based on stand structure.
- Collaboration has been at the heart of this project from the beginning, which currently spans three forest ownerships and even more partners. The knowledge coproduction model used here has been integral for developing and implementing management-relevant research in potential Canada lynx habitat, but long-term commitment will be necessary to reap the benefits of this work.

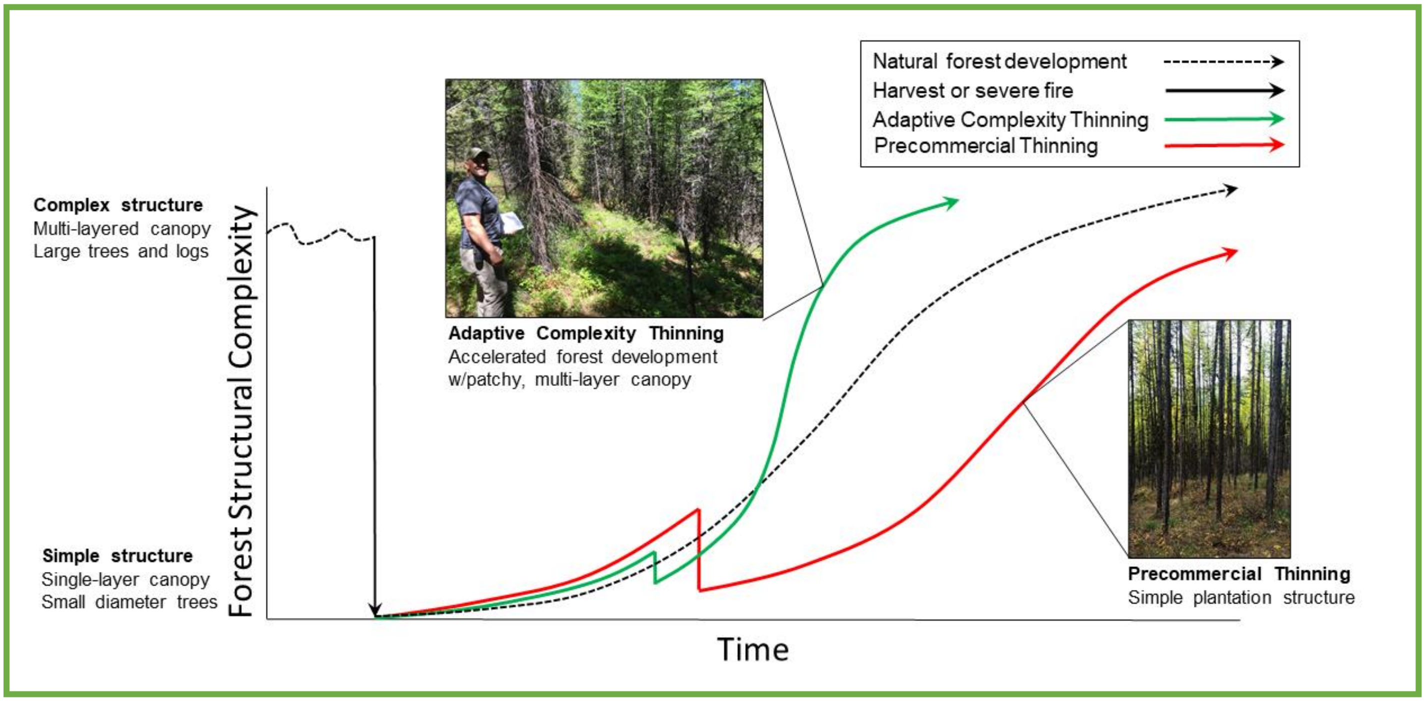


Figure 1—Conceptual model showing forest structural complexity (vertical axis) as a function of time (horizontal axis) and treatment history (different curves).

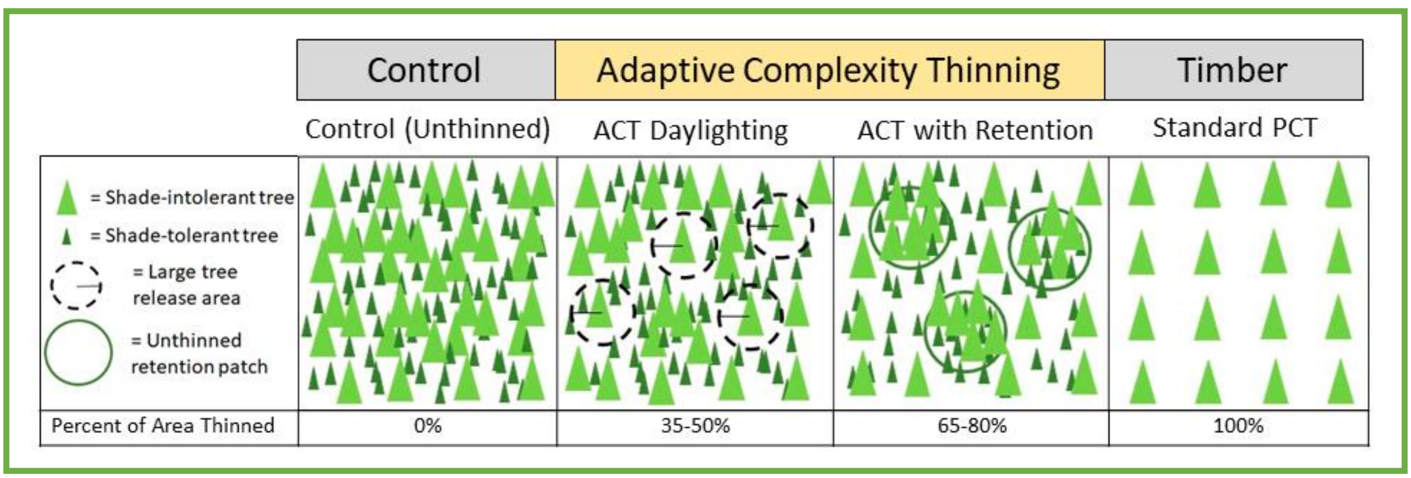


Figure 2—Conceptual diagram of the Adaptive Complexity Thinning (center two panels) methods being implemented using active adaptive management experimental treatments on Forest Service, Bureau of Land Management, and The Nature Conservancy lands.

References

Kumar, A.V.; Sparks, J.R.; Mills, L.S. 2018. Short-term response of snowshoe hares to western larch restoration and seasonal needle drop. Restoration Ecology. 26: 156–164. https://doi.org/10.1111/rec.12533.

Larson, A.J.; Belote, R.T.; Williamson, M.A.; Aplet, G. 2013. Making monitoring count: Project design for active adaptive management. Journal of Forestry. 111(5): 348–356.

Griffin, P.C.; Mills, L.S. 2007. Precommercial thinning reduces snowshoe hare abundance in the short-term. Journal of Wildlife Management. 71: 559–564.

Effect of Pruning in Sitka Spruce-Western Hemlock Forests in the Pacific Temperate Rainforest

Kellen Nelson, Jeff Barnard, Preston Massingham, Justin Crotteau

Overview:

Two experiments were designed to evaluate the effect of tree pruning on Sitka spruce tree characteristics and understory vegetation production.

Pruning lift height experiment:

- Experimental pruning treatments were applied to all trees within 0.2 hectare (0.5 acre) treatment plots at four sites on Prince of Wales Island, Alaska, USA. Pruning prescriptions included 2.4 m (8 ft), 3.6 m (12 ft), and 5.2 m (17 ft) lift heights and a no pruning control. Plots there thinned to 420 trees ha^{-1} (170 trees $acre^{-1}$) immediately prior to pruning treatment. Plots were measured after establishment in 1991, 1992, and 1993, and remeasured in 1999, 2012, and 2021.
- The abundance of epicormic sprouts rose with pruning lift height in the first decade after treatment, but progressively diminished in all treatments after 20 and 30 years.
- Pruning lift height had no effect on understory biomass or deer forage when compared against the no pruning control treatment.
- Pruning reduced butt log taper.

Thinning and pruning experiment:

- Experimental thinning and pruning treatments were applied across 19 sites. Prescriptions included thinning but no pruning, thinning and pruning of 25% of trees, thinning and pruning of 50% of trees, and a no thinning/no pruning control. The thinning treatment was 420 trees ha^{-1} (170 trees $acre^{-1}$) and pruning lift height was 2.4 m (8 ft). Plots were measured in 2008, 2013, and 2019.
- Thinning resulted in a significant increase in understory biomass and deer forage; however, supplemental pruning treatments did not increase understory vegetation production over thinning alone.

Summary:

Timber management in Sitka spruce / western hemlock temperate rainforests is increasingly focused on secondary even-aged stands that re-established after primary forest removal during the 20th century. After clear-cut harvest, abundant natural regeneration fosters rapid stand initiation forming dense, close canopy forests. Understory vegetation declines rapidly after canopy closure and is nearly absent during the prolonged stem exclusion phase of stand development. Productive understory vegetation is important for wildlife habitat and subsistence food resources across the ecoregion. Precommercial thinning is widely used to enhance crop tree growth and preserve or improve understory plant communities by reopening the canopy and increasing light transmission. Tree pruning can improve wood quality and may also enhance understory production through additional canopy light transmission. An improved understanding of the effects of silvicultural pruning is needed to guide management application of related prescriptions across Sitka spruce / western hemlock forests of North America. In this study, we utilize two long-term stand manipulation experiments on the Tongass National Forest, Alaska, USA to evaluate (1) how pruning lift height and (2) the proportion of trees pruned affects crop tree characteristics and understory plant communities.

Silvicultural Concepts:

- Pruning of Sitka spruce can improve live log characteristics by removing large branches that cause knots and reducing taper of the butt log. A more cylindrical tree bole is achieved because branch removal reduces growth on the lower stem but does not affect growth on the upper stem where branches remain.
- Epicormic branching exhibited a positive response to thinning and pruning in the first decade after treatment; however, epicormic branches declined after this initial flush (fig. 1). The abundance of large epicormic branches (i.e., > 3 mm diameter) was positively associated with pruning lift height during the first decade after treatment (not shown).
- Tree pruning at any intensity (i.e., 100%, 50%, or 25% of trees) does not appear to improve understory biomass or deer forage beyond the benefits of thinning treatment alone (fig. 2).
- A minor reduction in diameter growth increment was found in treated trees.

Management Applications:

- Tree pruning is an intensive silvicultural tending approach that can improve tree characteristics. In southeast Alaska, pruning treatments have been implemented with the intent of improving understory vegetation production for wildlife forage, but the efficacy of this application is understudied. Evidence from two long-term experiments on the Tongass National Forest, Alaska, suggest that tree pruning provides little, if any, additional enhancement to understory vegetation beyond that of thinning alone. Pruning of Sitka spruce did improve tree characteristics through a reduction in butt log taper; however, Sitka spruce's tendency for epicormic branching may reduce benefits gained through pruning application. Ultimately, wood quality and grade need to be evaluated in a milling and sort yard study to fully understand the effects of pruning on clearwood development and knot reduction. Precommercial thinning and pruning are costly management strategies. Where management objectives aim to provide both merchantable timber and understory vegetation for wildlife habitat, managers should consider that thinning produces more observable benefits.

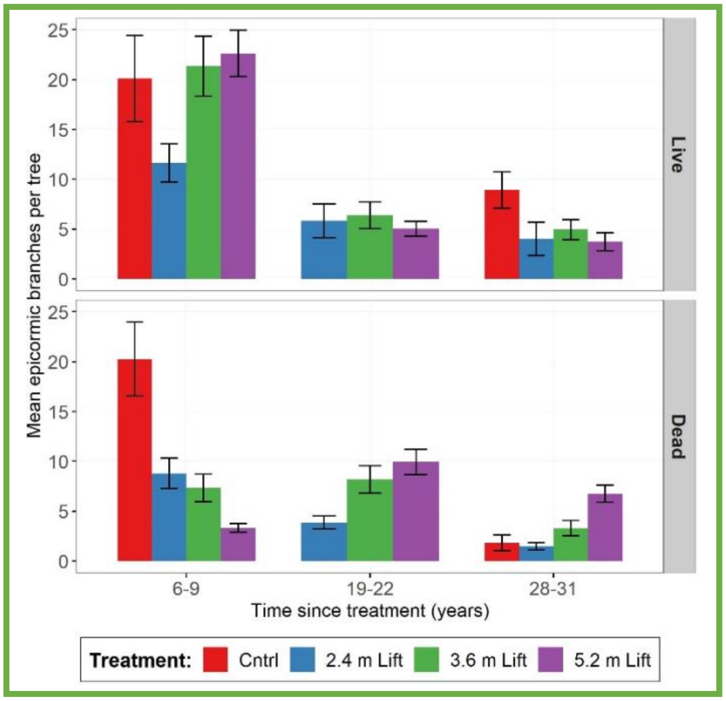


Figure 1—Epicormic branch formation on Sitka spruce was greatest in the first decade following experimental pruning lift treatments but steadily declined in the second and third decades after treatment on the Tongass National Forest, Alaska, USA.

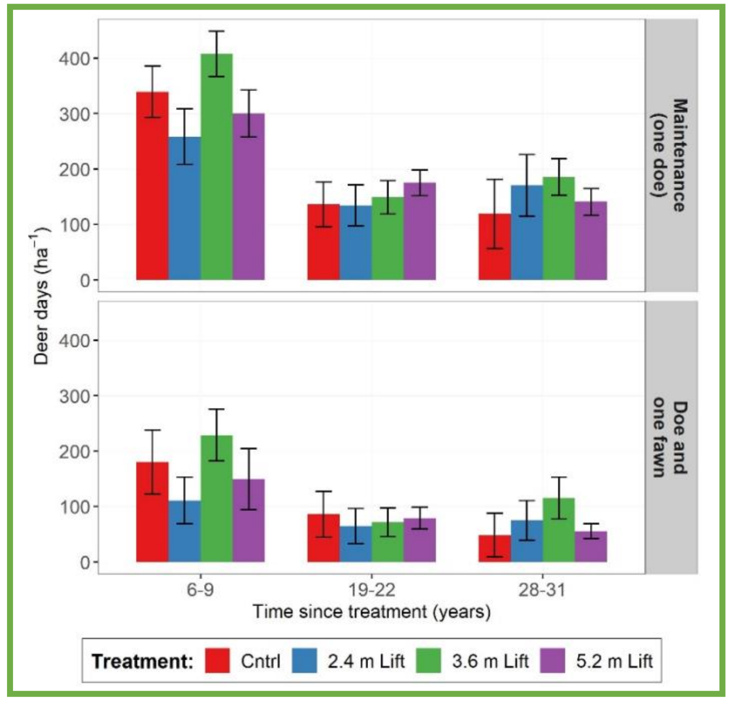


Figure 2—Pruning height does not affect deer forage. Deer days computed using understory biomass measured in experimental pruning lift treatments and the FRESHDeer model developed on the Tongass National Forest, Alaska, USA.

Regenerating and Tending Under the Vision for Resilience and Function in the Free Selection System

Justin Crotteau, Theresa Jain, and Jason Reinhardt

Overview:

- *What is free selection?*
  The free selection silviculture system is a multi-aged stand-to-landscape management strategy where the primary objective is to strategically create compositional and structural patterns that contribute to a disturbance resilient landscape (adjusting frequency, size, and juxtaposition of patches and stands) that will produce a variety of goods and services.
- *Where and why is free selection a good option?*
  Free selection is an option in mixed species forests that contain shade-tolerant and intolerant species with different levels of disturbance resistance and a plurality of environmental adaptation (e.g., moist mixed-conifer forest). It is also an option in forests with fewer tree species (e.g., longleaf pine, ponderosa pine) where the goal includes managing for understory vegetation (grass and shrubs), surface and ladder fuels, or other ecosystem attributes. Furthermore, free selection is an option that is best suited for large patches or landscapes as the management unit. It is designed to cross stand boundaries and to create and maintain a diversity of forest cover and species.
- *What are new developments?*
  A diversity of new tending treatments are being developed and designed to create wildlife habitat, reflect historical conditions, or manage clumps of trees, but traditional silvicultural systems are not suited for this variety of complex tending strategies. The free selection system integrates regeneration, tending, and harvesting in an appropriate manner through time; fulfills basic requirements of a silvicultural system; and provides the necessary context to house treatments for irregular and variable retention harvests, variable-density tending methods, and regeneration methods.

Summary:

Management problem: Forest management goals and objectives have vastly expanded in recent decades. Many managers and silviculturists are challenged to produce more than just timber from our nation's forests. Future forests are expected to deliver complex and often integrated management objectives such as providing a unique sense of place and naturalness,

wildlife habitat and forage, and resilience to disturbance and global change—all in addition to renewable forest products.

Management need: Multi-aged silviculture can meet many of today's diverse management needs but successfully implementing the regeneration and tending phase of these silvicultural systems in western dry to mesic mixed-conifer forests has been challenging. Classic uneven-aged systems were not designed to fulfill objectives such as regeneration of early seral shade tolerant species or to create diversity in structure and composition. To meet the new suite of management objectives and avoid those problems, Graham and Jain (2005) introduced the hybrid multi-scale concept of the free selection silvicultural system in the journal *Forest Ecology and Management*, wherein system parameters were qualitatively characterized with a "vision" (i.e., desired future condition) of resilience to disturbance and functioning ecosystem components. Since then, developments in ecological silviculture and studies of treatment effects have prompted the need to reestablish relevance and further parameterize this system.

Research purpose: This work describes the free selection system in the context of contemporary management drivers, integrates newly developed silvicultural strategies under the umbrella of the free selection system, and synthesizes recent research that quantifies regeneration and tending phase treatments.

Silvicultural Concepts:

- The free selection system was designed to meet complex management objectives, where timber is an important but secondary objective to other ecosystem services. This system was developed to promote ecosystem function and resilience in mixed-conifer forests, prioritizing residual vegetation composition and structure. It is a hybrid system that contains concepts of even-aged and multi-aged silvicultural methods. While free selection can be applied at a single stand scale, the system uniquely and explicitly links stands to landscapes, and can be used to create treatment mosaics at the landscape patch scale.
- The free selection system is flexible to accommodate regenerating and tending strategies such as the variable-retention approach, irregular shelterwoods, variable-density thinning, ICO, daylighting, ghosting, etc. Each of these strategies (or combinations thereof) could be used in the context of this system, as the ecosystem and stand development require.
- New research on these ecological silviculture methods quantifies structure and response and is useful for parametrizing options in the free selection system. For instance, Larson and Churchill 2012 discuss what spatial patterns might arise when prioritizing structural retention for fire-resilient forests. Jain et al. 2001 and Smith and Beese 2021 evaluate regeneration growth under different canopy gap sizes and

overstory retention levels. Puettmann et al. 2016 and Willis et al. 2018 elaborate on the structural effects and growth tradeoffs of variable-density thinning to create forest complexity.

Management Applications:

- Complex, multi-objective and multi-scale forest management requires flexible and creative use of many tools, like the free selection system. However, agency silviculturists often need to document management activities according to rigid reporting categories (e.g., FACTS database) or coarse summary attributes (e.g., retention basal area). These restrictions often exist at the stand level. Successful free selection prescriptions and marking guides can be developed outside of such restrictions to best meet landscape and ecosystem needs and objectives if managers find creative ways to shoehorn treatments into more typical reporting categories.
- Examples from the scientific literature function as useful tools managers can use to piece together a customized, hybrid silvicultural system best suited for the site's ecological objectives. While adoption of new techniques may immediately benefit managed ecosystems, couching them in the vision (desired conditions through time) of a system like free selection promises the long-term benefits of sustainability and desired future conditions through future decades.

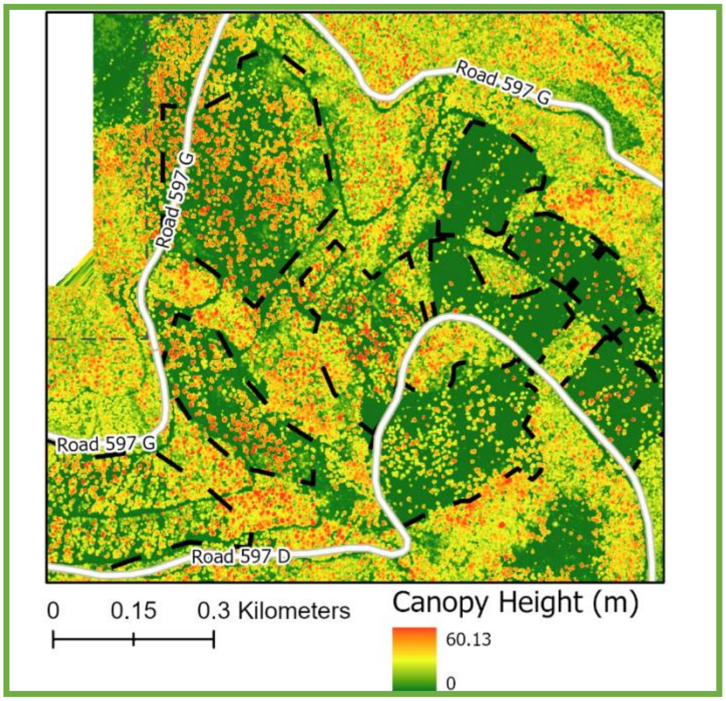


Figure 1—Example of landscape management (approximately 109 ha or 270 ac in this snapshot) using free selection in the Canyon Creek watershed of Priest River Experimental Forest. In this image, greens represent openings or forest understory, yellows represent midstory, and reds represent overstory trees. Note the complexity and heterogeneity at the tree neighborhood scale within each unit boundary, among units, and in the retention space between unit locations.

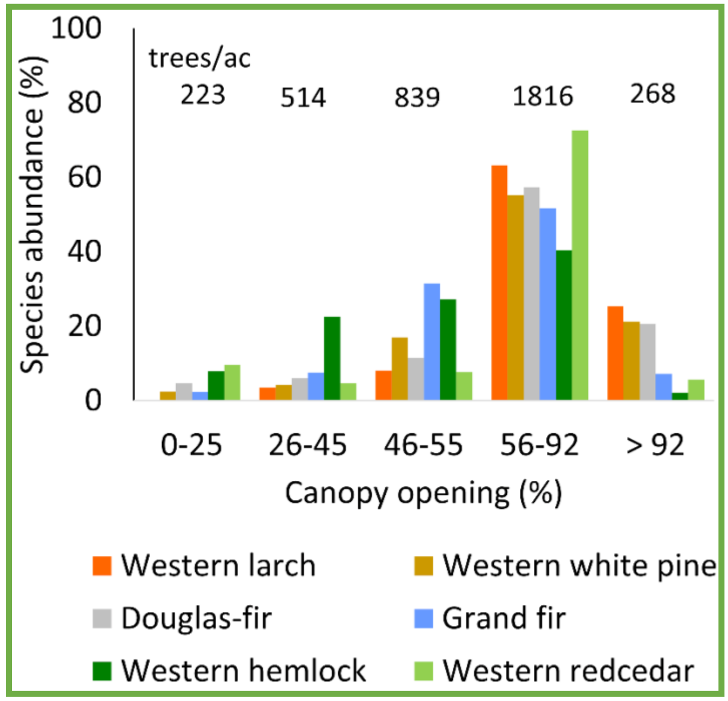


Figure 2—Relative abundance by canopy opening in the Canyon Creek watershed of Priest River Experimental Forest, a decade after free selection harvests. Percent abundance on y-axis references total abundance (by species) across canopy opening classes. These data represent recent findings and developments that parameterize examples of free selection and associated silvicultural treatments.

Table 1—Example of free selection system regulated by condition class in a dry forest stand or landscape.

Condition class	Description	Desired portion of stand	Maintenance	If current proportion exceeds desired	If current proportion less than desired
A	Mature, multi-cohort	45%	Selection harvest and ladder fuel tending, Rx fire	Thinning from below to create [B], patch cutting to create [C], or overstory removal to create [D]	Patch cutting in [B]
B	Mature, single-cohort	20%	Variable-density thinning, Rx fire	Patch cutting to create [A] or [C], or overstory removal to create [D]	Variable-density thinning in [C]
C	Young, single-cohort	15%	Variable-density (noncommercial?) thinning	Variable-density thinning to create [B]	Regeneration harvest in [A] or [B], or planting in [C]
D	Open	15%	Rx fire	Plant seedlings to create [C]	Overstory removal in [A], [B], or [C]
E	Reserve	5%	No action		

References

Jain, T.B.; Graham, R.T.; Morgan, P. 2004. Western white pine growth relative to forest openings. Canadian Journal of Forest Research. 34: 2187–2198. https://doi.org/10.1139/x04-094.

Larson, A.J.; Churchill, D. 2012. Tree spatial patterns in fire-frequent forests of western North America, including mechanisms of pattern formation and implications for designing fuel reduction and restoration treatments. Forest Ecology and Management. 267: 74–92. https://doi.org/10.1016/j.foreco.2011.11.038.

Puettmann, K.J.; Ares, A.; Burton, J.I.; Dodson, E.K. 2016. Forest restoration using variable density thinning: lessons from Douglas-fir stands in Western Oregon. Forests. 7(12): 310. https://doi.org/10.3390/f7120310.

Smith, N.J.; Beese, W.J. 2021. Effects of small aggregates of mature tree retention on adjacent planted coastal Douglas-fir growth and survival. Forest Ecology and Management. 480: 118613. https://doi.org/10.1016/j.foreco.2020.118613.

Willis, J.L.; Roberts, S.D.; Harrington, C.A. 2018. Variable density thinning promotes variable structural responses 14 years after treatment in the Pacific Northwest. Forest Ecology and Management. 410: 114–125. https://doi.org/10.1016/j.foreco.2018.01.006.

How a "Fuzzy" Approach to Old Growth Can Provide Silvicultural Clarity

Don C. Bragg

Overview:

- Fuzzy set mathematics offers a novel approach to address the issue of old growth identification and management, including restoration and stand tending practices.
- Rather than a binary (old growth or not old growth) approach, fuzzy set theory applies a fractional membership in a condition, thereby allowing for a stand to be considered for its similarity to the attributes associated with clearly defined examples of old and young growth (including those with regeneration).
- In addition to permitting both variability and uncertainty, a fuzzy set approach can be used to develop silvicultural prescriptions to increase the stand's "apparent age" and its membership in (consistency with) the set of old growth.
- Southern pines provide good examples of how a fuzzy set approach can be adapted to restoration-driven management activities, including those designed to ensure the perpetuation of the desired forest condition.

Summary:

Old growth continues to be a vexing issue for National Forest managers. Although set-aside policies adopted over the decades have protected large blocks of uncut forest in the western United States, such options are rare in the East. Furthermore, outside of mesic forests, whose succession is driven by shade tolerance and small-scale disturbance, reserving stands without supporting treatments inevitably leads to a new set of issues (such as densification and mesophication) that degrades the quality of these set-asides. Managers and stakeholders also frequently disagree on the condition or status of candidate stands, including what can or should be done to restore and tend them.

"Fuzzy" set characteristics, identified by clear examples of both young and old stands, can be used to define a continuum where any stand, regardless of age, can be assigned a fractional membership (Bragg 2002). This avoids the issue of binary reality of "crisp" sets, where a stand is either old growth or not old growth. Fractional membership can be used to identify the

factor(s) that influence a stand's old growth set membership—for example, an overabundance of trees or the presence of nonnative tree species—and treat that stand to improve its status.

Fuzzy sets also provide a restoration-driven means to consider any stand condition (even those not intended to produce old-growth) by how closely the stand emulates desirable aspects of the condition across the landscape. Longleaf pine (*Pinus palustris*) (fig. 1) and shortleaf pine (*Pinus echinata*) provide excellent examples of once dominant tree species that national forests of the southern United States are seeking to renew on a large scale. Both pines occupied fire-prone historical landscapes, and both have experienced widespread declines in abundance due to past overharvesting, land clearing, and the loss of frequent surface fires.

Silvicultural Concepts:

- Old growth is a stand-level condition that can be managed for using a range of approaches, from relying exclusively upon natural processes to achieve and sustain the condition to active silvicultural interventions as a replacement or supplement to nature.
- In most fire-prone environments, management practices (especially fire control) and landscape fragmentation have altered stand conditions to the point that many reserved old-growth stands are now overstocked by less fire-tolerant species.
- Restoration and stand tending practices are usually tiered towards targeted density reductions but need to be more holistic to ensure better emulation of old-growth conditions (fig. 2).
- A fuzzy set approach to old-growth delineation allows for multiple attributes or indicators (such as those noted by Nordman and others [2021] for shortleaf pine; table 1) to be adapted into a single quantitative measure of stand condition amenable to silvicultural treatments.

Management Applications:

- This is a new concept with no on-the-ground applications (yet). However, examples of longleaf and shortleaf pine given in this presentation can be used to demonstrate the nature of the baseline information required and how specific treatments can influence the apparent age of the stand. Clarifying the nature of old growth using fuzzy sets can help National Forest managers meet stand condition goals by intervening where needed.

Figure 1—Virgin longleaf pine stand (circa 1903) from southern Georgia. Note the open nature of this nearly pure longleaf stand, including the grass- and forb-dominated understory, lack of a midstory, and sparse overstory. Dead wood volumes are also relatively limited due to the actions of termites, rapid decay, and frequent fires. Tree regeneration is present, but almost exclusively as the longleaf's "grass stage." Such stands can help define the old-growth stand conditions targeted for using fuzzy set classification. USDA Forest Service photo by E.S. Block, negative #40845.

Figure 2—Contemporary example of old-growth longleaf pine on the Greenwood Plantation in southern Georgia. Still nearly pure longleaf, with grass- and forb-dominated understory and little dead wood; however, note a greater amount of longleaf pine regeneration than in figure 1. Most of this stand is actively managed to produce small amounts of high quality sawtimber and good quail (*Colinus virginianus*) habitat; this limited extraction helps to foster more tree regeneration without excessive densification. In fuzzy set terms, this stand has high membership in the set of old-growth longleaf pine. USDA Forest Service photo by Don C. Bragg.

Table 1—Some canopy metrics for assessment of the quality (from excellent to poor) of open shortleaf pine (SLP)-oak forests in the West Gulf Coastal Plain from Nordman and others (2021; table 4) that could be adapted for use in fuzzy set assessments of old-growth. These metrics are only for the canopy and are not specific to old growth, but rather open forests; some adjustments to certain metrics and use of other metrics will still need to be made.

Metric	Measured by	Excellent	Good	Fair	Poor
SLP canopy basal area (BA, in m^2/ha)	Pine BA	8.0 to 17.2 m^2/ha	6.9 to 8.0 or 17.2 to 20.7 m^2/ha	2.3 to < 6.9 or > 20.7 to 25.3 m^2/ha	< 2.3 or > 25.3 m^2/ha
SLP canopy cover	Percent pine cover	> 25 to 70%	> 20 to 25 or > 70 to 80%	10 to < 20 or > 80 to 90%	< 10 or > 90%
SLP stand size structure	BA of pines ≥ 35 cm DBH	> 4.6 m^2/ha	2.3 ≤ BA < 4.6 m^2/ha	< 2.3 m^2/ha but SLP present	SLP absent
Fire-tolerant hardwood BA	BA of fire-tolerant hardwoods	< 4.6 m^2/ha	4.6 ≤ BA < 6.9 m^2/ha	6.9 ≤ BA < 9.2 m^2/ha	≥ 9.2 m^2/ha

Metric	Measured by	Excellent	Good	Fair	Poor
Stand density index	SDI range for all spp.	55 to 155	35 to 55 or 155 to 205	20 to 35 or 205 to 225	< 20 or > 225

References

Bragg, D.C. 2002. Fuzzy set classification of old-growth southern pine. In: Doruska, P.F.; Bragg, D.C., eds. Proceedings of the 2001 Southern Mensurationists' Conference. Monticello, AR: Arkansas Forest Resources Center: 37–43.

Nordman, C.; Faber-Langendoen, D.; Baggs, J. 2021. Rapid ecological integrity assessment metrics to restore wildlife habitat and biodiversity for shortleaf pine-oak eco12: 1739. 32p. systems. Forests. 12: 1739. 32 p. https://doi.org/10.3390/f12121739.

Crop Tree Release in Western White Pine Plantations

Kyla Berendzen, Theresa Jain, John Byrne

Overview:

- Throughout the Inland Northwest, a primary management objective is to restore early seral forests once dominated by western white pine, western larch, and ponderosa pine. To meet this objective, the U.S. Department of Agriculture, Forest Service, Northern Region has planted over 300,000 acres of western white pine and western larch.
- Early seral species achieve better survival and growth with young stand tending, which releases desirable species and individual trees from surrounding competition from shade tolerant tree species and shrubs. Although typical tending treatments optimize spacing among the crop trees in a stand, these treatments create uniform surface fuels and may not provide sufficient cover for some wildlife species.
- Crop tree release is an established tending treatment that clears openings around the most desirable species or individuals without treating the entire stand and is an alternative method particularly if there are limited resources or do not meet management objectives.
- This paper describes results from a study conducted on Deception Creek Experimental Forest on the Idaho Panhandle National Forests and provides a comparison between the full clean and crop tree release.
- When crop tree release is applied, table 2 can provide the number of trees per acre that are released to maintain a cost-effective treatment.

Summary:

- Traditionally, the primary focus of cleaning has been to equally space residual trees to maintain full stocking (e.g., 12 x 12 ft or 14 x 14 ft) by removing competition. Preferred species are western white pine, western larch, and ponderosa pine; however, when these species are not sufficiently abundant, shade tolerant species are left to maintain full stocking.
- Although there are over 300,000 acres of western white pine and western larch plantations, funding limitations are forcing decisions to leave some plantations untreated. As a result, initial planting investments are sacrificed, and ultimately untreated stands do not meet desired forest conditions and/or management objectives.
- As an alternative to full cleaning and weeding treatments, crop tree release was applied to young early seral western white pine and western larch stands in Deception Creek

Experimental Forest (fig. 1). The crop tree release treatment focused on maximizing growing space for a small number of selected western white pine and western larch to enhance their growth and vigor by reducing the surrounding competition.

- This study reports posttreatment 5-year diameter increment growth of trees growing in the gap, edges of the gap, and untreated patches of crop tree release treatments compared to untreated control and fully cleaned stands.

Silvicultural Concepts:

- The crop tree release resulted in a mosaic of cleared and untreated patches of varying sizes creating a diverse patch structure. Untreated patches containing multistoried conditions existed with early-seral species in the overstory and shade-intolerant species in the understory (fig. 2a).
- One year following treatment, Berendzen (2015) found that micro-environments (e.g., air temperature, relative humidity) in gaps within the crop tree release treatment had similar micro-environments as trees that were in the full cleaning. Trees in the untreated areas of the crop tree release had similar micro-environments as those in the untreated control. The trees on the edges had a diversity of micro-environments.
- Full cleaning created drier microclimates with increased wind movement; in contrast, the crop tree-release tended to have lower wind speeds in the gaps; however, significant ladder fuels exist in the untreated areas.
- Five-years after treatment:
  (1) Five-year diameter increment prior to treatment significantly affected 5-year diameter increment after treatment in all conditions and treatments.
  (2) Western white pine and western larch that were growing in the untreated patches and edges of the crop-tree release behaved similar to the trees in the untreated control (fig. 2b).
  (3) Trees in gaps in the crop-tree release had similar diameter increment growth as the trees in the full clean (fig. 2b).
- However, western larch had more variation (greater standard errors) than western larch growing in the full clean while western white pine had similar 5-year growth increment to the full clean.

Management Applications:

- Crop tree-release does not replace a full cleaning when sufficient funding exists, but this treatment does provide an option if limited funds exist and is preferrable to not tending at all.

- Crop tree-release may meet management objectives associated with meeting wildlife habitat such as providing cover for snowshoe hares.
- Mixed-dry conifer forests may introduce surface fuel diversity within a given stand, potentially providing conditions that may contribute to a mixed fire severity.
- Contracts required some initial communication and instruction but were then implemented successfully. An example of contract language for a crop tree release (referred to “daylighting” in documented contracts on the Idaho Panhandle National Forests): *Crop-tree release – the removal of competing live trees greater than 2 feet tall in a fixed radius circle, e.g., 8 ft, 10 ft, 12 ft around selected desirable leave trees. Release radius shall be measured from the bole of the leave tree to the branch tips of the surrounding trees. However, it is preferable to create “clumps” of release radius 5–8 trees in closer proximity (figure 1a), rather than individuals spaced evenly throughout the unit.*

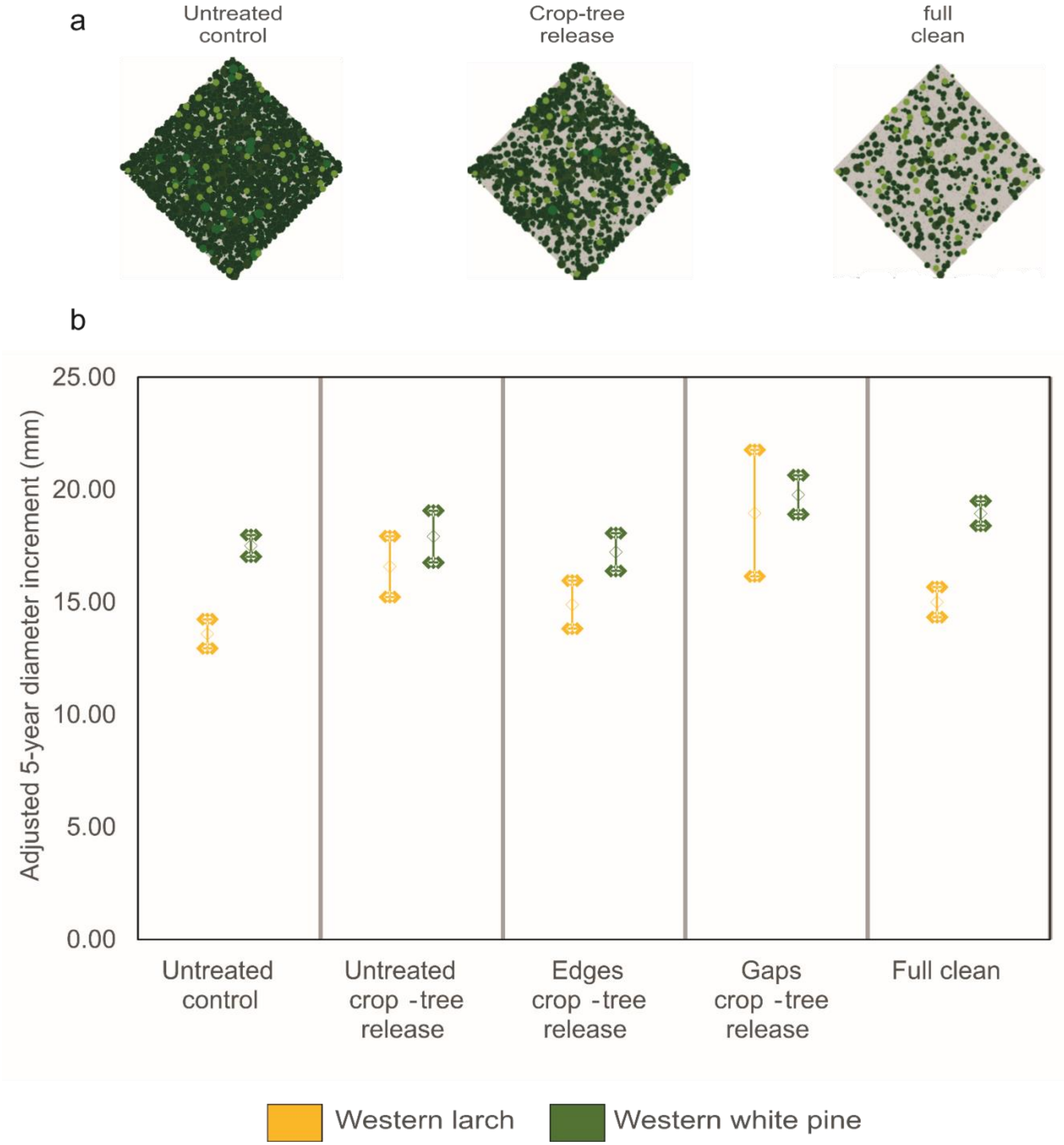


Figure 1—Analysis of covariance was conducted where 5-year growth increment prior to the treatment significantly influenced posttreatment 5-year increment growth for the control, full clean, and crop-tree release. Example of treatments are illustrated (a). Comparisons of adjusted mean 5-year diameter growth increment of western larch (yellow bars) and western white pine (green bars) after treatment (b).

Table 1—Comparison between a full clean and a crop-tree release.

Full clean	Crop-tree release
Preferred treatment when: · Funding and other resources are plentiful to treat all the acres that need treatment. · Historically applied to maximize volume production. · Ladder fuels are reduced. · Stands where desired trees species are abundant but need to be released from competition.	Preferred treatment when: · Funding resources are limited and, therefore, treatments need to be prioritized. · There is a need to fulfill wildlife habitat management objectives that require a mosaic of treated and untreated patches. · Desired tree species are unequally distributed throughout the stand. · Drier forest types where ingrowth of shade-tolerant species is not as great of a concern.
Implementation: · Entire unit is treated to create evenly spaced trees. · Weeds out undesirable tree species from understory throughout the entire stand.	Implementation: · A proportion of the stand is treated. · Fewer selected crop trees are treated, at prescribed densities (table 2). · Removes surrounding competition and understory from within a radius or in groups.
Treatment outcomes: · Creates open stands with uniform spacing and surface fuel distribution. Improves individual tree growth throughout the entire stand. · Creates more open, drier conditions and alters understory communities. Temporarily creates abundant fine dead fuels. · Fuel development will vary overtime.	Treatment outcomes: · Creates a mosaic of treated and untreated patches (fig. 1a). · Improves growth only of released trees or trees that are not affected by understory competition. · Maintains moist, shaded understory conditions. · Fuels are not reduced throughout the stand, only altered somewhat in the crop tree radii.
Lower cost per tree treated	Higher cost per tree treated, but fewer trees so greater total area.
Contracts are currently used widely and are easily understood.	Contracts are being developed and implemented. Not widely used or common.

Table 2—The proportion of area treated by crop tree release based on the radius of opening in addition to the number of trees per acre. Values in this table assume no overlap of openings. Realistically, the release openings' radii would overlap some, especially with more trees per acre that are treated. The orange-highlighted area is where crop tree release is the most cost effective: thinning crews release 20 to 60 trees per acre, and up to 37% of the stand is treated. In the yellow-highlighted area, cost effectiveness declines as released tree densities are increased, but this may still be an option depending on current conditions and management objectives. The densities treated in the unshaded areas are so high the entire stand is affected, so crop tree release is no longer a practical option, and it would be more beneficial to clean the entire stand.

	Crop tree release (trees per acre)												
Radius	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**	**140**
	Percent of stand treated												
9	12	18	23	29	35	41	47	53	58	64	70	76	82
10	14	22	29	36	43	50	58	65	72	79	87	94	100
11	17	26	35	44	52	61	70	79	87	96	100	100	
12	21	31	42	52	62	73	83	93	100	100			
13	24	37	49	61	73	85	97	100					
14	28	42	57	71	85	99	100						
15	32	49	65	81	97	100							
16	37	55	74	92	100								
17	42	62	83	100									
18	47	70	93										

References

Berendzen, K. 2015. Providing young stand management alternatives and enhancing spatial heterogeneity through daylight cleaning in mixed-conifer forests. Thesis. Moscow, ID: University of Idaho. 42 p.

Transitioning From Even-Aged to Multi-Aged Forest Structure in Second-Growth Ponderosa Pine

Shelagh Fox, Cheri Hartless, Sharon Hood, Justin Crotteau

Overview:

- Uneven-aged management in ponderosa pine is of increasing interest; however, there is little experience in the Northern Rockies with how to transition from even-aged stands to multi-aged stands, especially where it requires multiple entries and years of forward thinking. Barriers to implementation include the scarcity of examples, inertia against doing something new, perceived administrative red tape (e.g., FACTS terminology), and leeriness of continuous cover forestry in wildfire-prone forests.
- We share an example of multi-aged management of ponderosa pine in the Bitterroot National Forest in its adolescence, and pair that with plans to deliberately transition nearby young plantations to multi-aged stands.
- This research-management partnership at the Lick Creek Demonstration/Research Forest builds on a legacy of collaboration for ecosystem restoration and fuels management dating back to 1991. We are developing a planning guide to aid in implementing stand tending treatments designed to shift even-aged ponderosa pine-dominated forests to multi-aged for multiple benefits.

Summary:

Management problem: Throughout the range of ponderosa pine (*Pinus ponderosa*), clearcut harvesting and planting through the late 20th century resulted in widespread even-aged forests, which excelled at regenerating shade-intolerant species and producing wood in an operationally simple way. Two decades into the 21st century, timber production objectives are now also balanced with a variety of nontimber objectives such as increasing resistance and resilience to disturbances and managing wildlife habitat.

Management need: One way to attain these objectives is to improve structural diversity by restoring multi-aged forests, similar to the structure created historically by frequent, low-severity wildfires. Multi-aged management in ponderosa pine in the Northern Region is growing, but the concept remains novel and unexplored because of various constraints. For example, there is little experience in the region with how to transition from even-aged stands to multi-aged stands, especially where it requires multiple entries, and few local examples exist to build from and spur creative management solutions. Furthermore, nontraditional management techniques are difficult to document in agency reporting databases (e.g., FACTS). Additionally, it is unclear how managers might balance fire hazard reduction with the development of forests with multiple canopy layers. Taken together, there is a need to gain momentum to make multi-aged management a more common practice.

Purpose: We are developing a planning guide to aid in implementing stand tending treatments designed to shift even-aged ponderosa pine-dominated forests to multi-aged. We will include case studies from both naturally regenerated forests and plantations on the Bitterroot National Forest of southwestern Montana.

Silvicultural Concepts:

- In multi-aged forestry at least two age cohorts are cultivated and managed within a stand. This type of silviculture is advantageous because it retains cover through harvest, improves opportunity for genetic adaptation to local climate by producing new regeneration, and generates a diversity of timber size classes. Yet, high stocking often associated with multi-aged forests may be a disadvantage to stands facing insect, drought, or wildfire stressors. Therefore, stocking must be carefully managed to optimize resilience to multiple disturbances, as was the case in some historical stands with intact fire regimes.
- We are using studies from both naturally regenerated forests and plantations on the Bitterroot National Forest of southwestern Montana to demonstrate how naturally regenerated and planted stands can be moved towards uneven-age structures with harvesting and prescribed burning.
- The natural regeneration study at the Lick Creek Demonstration/Research Forest consists of a uniform shelterwood with reserves regeneration harvest with and without prescribed burning, which induced a second cohort underneath an 80- 85-year-old, second-growth ponderosa pine overstory in 1991. Regeneration is patchy and dependent on past burning. Re-entry cutting and burning treatments are planned for 2022 to foster another cohort, remove shade-tolerant Douglas-fir advance regeneration, and reduce surface fuels.
- Also in the Lick Creek watershed, numerous even-aged ponderosa pine plantations were established after harvesting and planting between 1979 and 1986. Plantations were thinned one to two times as recently as 2004, and will now receive different cutting and burning treatments to tend the overstory and develop a second cohort of ponderosa pine.

Management Applications:

- This project is useful for demonstrating possible transition treatments and reentries to increase complexity and resilience to future disturbances in frequent-fire ponderosa pine ecosystems.
- There are very few places in the Northern Region that use prescribed burning in plantations towards creating multi-aged structures. This project will provide examples of the effects of different burning and harvesting treatments to meet multi-aged management goals in ponderosa pine.
- The long-term studies at the Lick Creek Demonstration/Research Forest have provided a demonstration viewing area for several public tours to show what treatments look like. Additionally, the Bitterroot National Forest has used the study data and results in NEPA documents to support local ponderosa pine management.

Figure 1—Light Douglas-fir regeneration beneath ponderosa pine 23 years after 1991 uniform shelterwood with reserves overstory at Lick Creek Demonstration/Research Forest.

Figure 2—Ponderosa plantation aged at 35 to 40 years old in the Lick Creek drainage of the Bitterroot National Forest. Note the dense, regular spacing and abundant Douglas-fir in the understory.

500 years? Who Has Time for That? Accelerating Forest Succession With Reforestation and the Role of Port-Orford-Cedar on the Rogue River-Siskiyou National Forest

Kathryn Schwindt

Overview:

- Port-Orford-cedar (POC) is endemic to Southwest Oregon and Northern California
- In the 1970s, *Phytopthera lateralis* was discovered to be infecting POC and was killing the trees. This disease is spread through water and soil.
- The Dorena Genetics lab tested samples from the forest to find naturally occurring genetic resistance. They have identified disease-resistant trees and produce seed with a containerized seed orchard.
- Port-Orford-cedar is a significant shade-tolerant species for developing multistoried late-successional forests. Our main objective in Late-Successional Reserves is to accelerate the development of late-successional structure and species composition in Douglas-fir plantations. With other species such as western hemlock or grand fir, as long as there is a good seed source around the harvest, unit enhancement planting is unnecessary; however, with POC, planting of disease-resistant seedlings is needed.

Summary:

Reforestation on the Rogue River-Siskiyou National Forest on the Powers and Gold Beach Ranger Districts is driven by the need to accelerate the development of late successional habitat in stands less than 80 years old. Prior regeneration harvest emphasized clear-cutting with regeneration of Douglas-fir. Douglas-fir is not a shade tolerant species and will not regenerate naturally under canopy cover. Therefore, to develop a multilayered canopy, reforestation of shade-tolerant species like western hemlock, grand fir, and Port-Orford-cedar is needed. Multilayered canopies provide habitat for many species including the Northern flying squirrel, an important prey species of the Northern spotted owl. To promote long term success of Port-Orford-cedar and its contribution to the late-seral habitat, it is important to plant disease resistant seedlings for long-term success. There is a Port-Orford-cedar seed program at the Dorena genetics lab that produces *Phytophthora lateralis*-resistant Port-Orford-cedar seed. Container and bare root seedlings are grown at the JH Stone Nursery and planted in January/February each year.

Silvicultural Concepts:

- Genetic resistance
- Shade-tolerant species
- Cultivating multicanopy forests
- Accelerating succession

Management Applications:

- Port-Orford-cedar has been heavily impacted by an invasive root disease.
- Our ability to restore late-successional forest conditions depends on our ability to restore native species diversity.
- Restoration of native species diversity is also important for climate change adaptation. Port-Orford-cedar grows on a wide variety of soil types (including serpentine soils) and is important ecologically and economically.

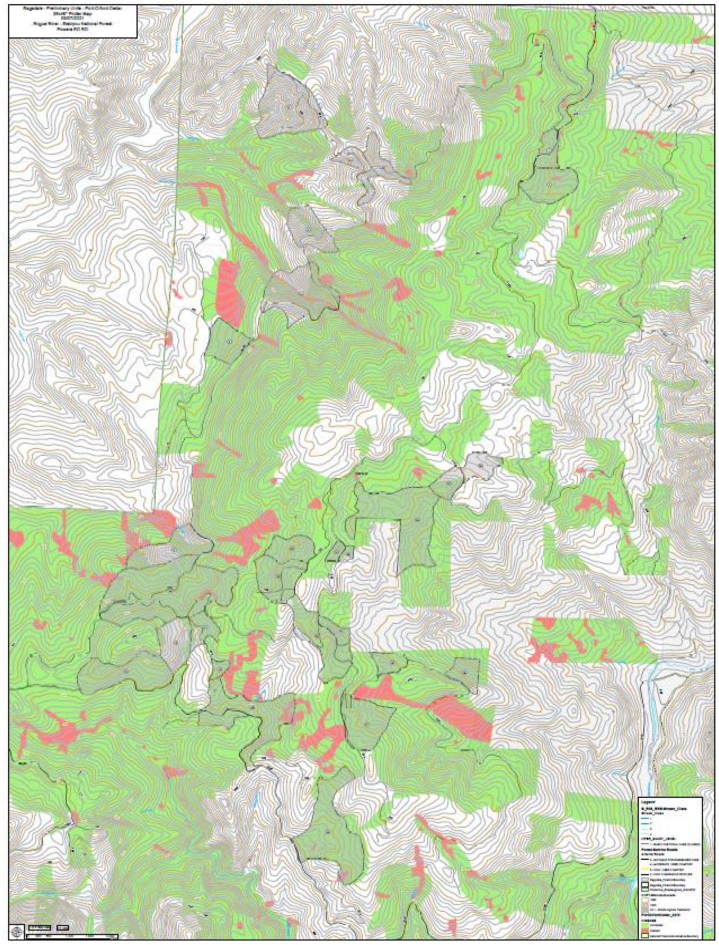


Figure 1— Dead Port-Orford-cedar in wet area on the Powers Ranger District.

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Figure 2— Project area map of Port-Orford-cedar habitat and infested areas.

Long-term Thinning Research

Evaluating Long-Term Ponderosa Pine Seedling Growth Across Densities Using Nelder Plots and the Forest Vegetation Simulator in the Black Hills, South Dakota

W.T. Tinkham, M.A. Battaglia (speaker), and C.M. Hoffman

Overview:

- Competition is known to regulate small-tree growth and accurately representing this growth in simulation models is important for developing management plans.
- In 1969, a Nelder plot was established on the Black Hills Experimental Forest to examine the influence of site preparation and planting density had on ponderosa pine seedling growth (fig. 1).
- After 45 years of growth, ponderosa pine seedlings planted at low planting densities had diameters 2.5–3x larger than the most densely planted seedlings.
- Depending on the planting density, the Forest Vegetation Simulator (FVS) underpredicted diameter at breast height (d.b.h.) by 0 to 35%.

Summary:

Management problem: In the Black Hills of South Dakota and Wyoming, establishment of natural ponderosa pine regeneration can be prolific. The density of trees in the early stages of stand development affects their growth and sets the basis for future forest dynamics. Underestimation of growth by simulation models could delay scheduling of precommercial thinning and lead to loss of growth or stand stagnation.

Management need: It is clear that a better understanding of how small tree density influences growth and refining the growth and yield simulation models is needed. This information will lead to better management decision-making such as assessing fuel treatment effectiveness and sustainable harvest scheduling.

Silvicultural Concepts:

- Growth rate of natural or artificial ponderosa pine regeneration is influenced by competition.
- Differences in density dependent growth were apparent at age 12 when comparisons between site preparation methods were examined. At age 12, areas that received herbicide application at time of planting were 3 feet taller and 0.6 to 1.9 inches larger in diameter than the areas which were only scalped.
- The effect of site preparation was no longer apparent by age 45.
- At age 45, d.b.h. at the lower densities were substantially larger; however, height growth was no longer different (fig. 2; table 1).
- High densities of ponderosa pine seedling establishment led to a reduction in growth and stand stagnation.

Management Applications:

- This research provides land managers with rationale to implement precommercial thinning activities to facilitate faster transition from the seedling stage to the sawtimber stage.
- The use of FVS to predict growth of ponderosa pine regeneration was insensitive to density levels and underpredicted tree diameter and height growth at age 12 and 45.
- Table 1 provides planting densities and potential diameter at age 12 and 45 for ponderosa pine seedlings for the Black Hills National Forest across site indices of 55 to 65 base age 100.

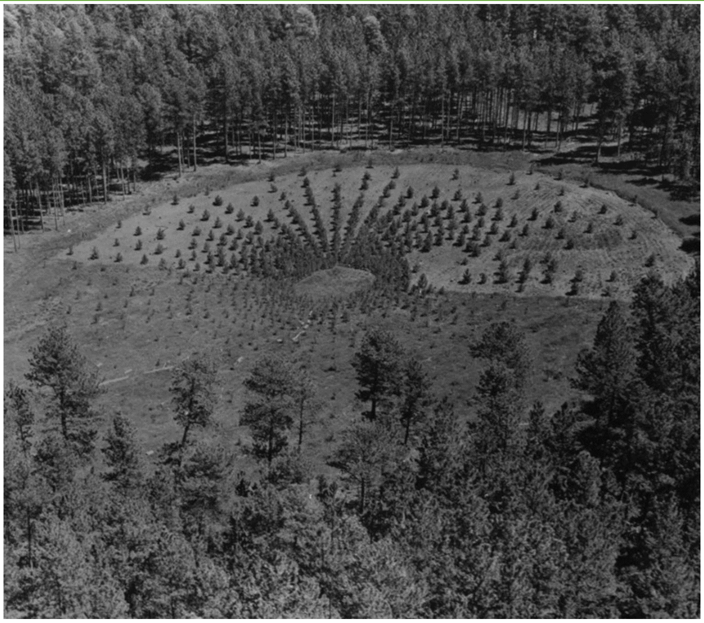

Figure 1—Aerial view of a Nelder plot on the Black Hills Experimental Forest around 1970.

Figure 2—Cross-sections at d.b.h. of the ponderosa pine trees grown at different spacings in the Nelder plots after 45 years.

Table 1—Quadratic mean diameter (QMD) of Black Hills ponderosa pine planted at different spacings at age 12 and 45.

Initial spacing (ft)	Initial trees per acre	QMD (inch) at age 12	QMD (inch) at age 45
19	120	1.4	10.4
16.7	153	1.5	10.8
15.1	194	1.4	10.3
13.1	248	1.4	9.8
11.8	315	1.5	9.3
10.5	401	1.3	8.6
9.2	511	1.6	8
8.2	651	1.4	7.5
7.2	828	1.4	6.6
6.6	1,055	1.4	6.3
5.6	1,345	1.5	5.9
4.9	1,712	1.4	5.2
4.6	2,181	1.4	5.6
3.9	2,780	1.3	4.4
3.6	3,545	1.2	4.0
3	4,507	1.2	4.0

History of Stand Improvement Practices at the Fort Valley Experimental Forest

W. Keith Moser, Russell T. Graham, Andrew Sánchez Meador, Jianwei Zhang, Lance Asherin, Eric Merrill

Overview:

Forest management is best served by data, information, and knowledge generated from long-term and large-scale studies (Zhang et al. 2020). Permanent plots followed over a long time can help us detect and quantify ecosystem changes (Sánchez Meador and Moore 2011). U.S. Department of Agriculture, Forest Service experimental forests, such as Fort Valley Experimental Forest (FVEF) outside of Flagstaff, Arizona, have provided this valuable service for over 100 years. FVEF was established in 1908 in the southwestern ponderosa pine belt with an initial research focus on natural and artificial regeneration, timber stand improvement, forest stand dynamics, and determining which factors influenced tree species distribution (Sánchez Meador and Moore 2011). In the unharvested ponderosa pine forests, stands were historically spatially aggregated (Iniguez et al. 2019; Sánchez Meador et al. 2009). With an eye on improving timber production, researchers at FVEF installed studies evaluating different types of harvesting, such as method-of-cutting studies, which were harvested using three different harvesting systems in 1913 (seed tree, group selection, and light selection) (Sánchez Meador and Moore 2011) or selection management studies (Edminster unpublished report 1991). Not willing to rely on variable density measurements of natural stands, in 1962, the Forest Service installed an intensive density management study of ponderosa pine at Taylor Woods on the FVEF (Bailey 2008; Schubert 1971). This last study guided our understanding of ponderosa pine density management and formed the basis for the ponderosa pine model of the Central Rockies variant within the Forest Vegetation Simulator. All three studies examined the interaction between climate influences and tree response in variable-density and multi-aged stands.

Summary:

- Silvicultural practice is founded on density and composition management and the potential for individual tree and stand volume growth (Smith 1962). Thinning reduces overall stand volume but, in the process, releases more growing space for the residual trees. In situations where economic markets are positive, such reallocation of growing space takes advantage of the price increases as a function of diameter (Assmann 1970) and increasing total value per area.

- The purpose of the method of cutting (MoC) studies at FVEF was to evaluate the feasibility of seed tree, group selection, and light selection regeneration harvests on tree regeneration and growth (Sánchez Meador and Moore 2011). From a stand development viewpoint, the seed trees responded more to release as there were fewer residual trees. The copious regeneration from the early 1900s eventually affected the growth of the residual trees. Light selection stands responded in a manner similar to their pretreatment behavior. Group selection treatments created a mix of dense stands and open areas. There were varying structures, and the patterns were not spatially random.
- Similar to the MoC studies from 1913, the 1924 initiation of a long-term study of uneven-aged management examined tree growth and regeneration patterns. Recent analysis suggests that the size and spatial pattern of the nearest neighbor trees significantly influence focal tree growth. While these competitive effects increased with tree density, the influence was highly variable in open, often more aggregated, conditions. Further analysis found that while drought conditions affected trees regardless of tree density, those in low density or aggregated stands responded more quickly when the drought ended (Moser et al. unpublished data).
- As part of a west-wide study of the level of growing stock and tree response in ponderosa pine stands, the Taylor Woods (TW) LOGS study was established on the Fort Valley Experimental Forest (Schubert 1971). TW was less productive than other locations, so this research provided an example of tree response on aridland forests of the Southwest. As stated above, the original forest at Taylor Woods was primarily composed of trees of the 1919 regeneration event (Bailey 2008; Pearson 1950; Schubert 1971). Three replicated blocks of six density levels were thinned to their target densities in 1962 to establish the study. After remeasurements, each block was thinned to maintain the approximate density level. Stand density did not affect height. Basal area responded to thinning, making it hard to maintain the target Growing Stock Level (GSL) in this study and illustrating the challenge in meeting BA targets in large stands or forests. Lower densities produced larger QMDs, with each GSL being significantly different up to 100 ft^2 ac^{-1}. The stand cubic volume for each GSL was similar to what Meyer (1938) predicted. Merchantable volumes were greatest at the 100, 120, and 150 GSLs. Most thinnings produced merchantable volumes, but over the life of the study, there have been limited markets for those products (Moser et al. unpublished data).

Silvicultural Concepts:

- Silvicultural systems are a planned set of treatments to regenerate, manipulate, and harvest trees, considering the site, climate, and species present (Tappeiner et al. 2007). For example, in more mesic eastern forests, trees in the upper strata only compete with each other and are less influenced by the trees in the midstory and understory (Kelty 1984; Kittredge 1986; Oliver 1975). However, the dry conditions of the Southwest mean that trees in the mid- and understory can impact trees in the upper strata due to competition for soil moisture (Pearson 1950).

- Common treatments that relied upon natural regeneration included seed tree and shelterwood cuts (even-aged) and selection system (uneven-aged) treatments. In a seed tree cut, most of the trees in a stand are removed except those left standing singly or in groups to provide seed to restock the cleared area, which are later removed when satisfactory stocking is achieved. Usually, no more than 10% of the original overstory is left (Hawley 1937). Unfortunately, the overwood was often not removed in practice, resulting in sites like FVEF having very high densities and facilitating the propagation of pests like dwarf mistletoe.
- A shelterwood cut involves the removal of the stand through a series of partial harvests, resembling thinnings, over a relatively short period compared to the total rotation (Hawley 1937). A variant of this treatment practiced on FVEF, and the adjacent Coconino National Forest, was the strip shelterwood, where the stand is not treated uniformly but rather concentrates the harvests in strips adjacent to the residual stand, which provides the seed source to regenerate the newly opened area (Hawley 1937).
- On the uneven-aged side, selection system silviculture is intended to maintain all-aged or uneven-aged stands. Selection silviculture is defined by the residual or target overstory condition instead of the even-aged systems' focus on the successful reinitiation of the stand (Ashton and Kelty 2018).

- In the early era of forest research, the management of young-growth ponderosa pine forests was in its infancy. Results from studies conducted in one area seemed to have limited use in another area. Questions arose about the best way to grow timber: even-aged or uneven-aged management. What silvicultural treatments could best deal with the already burgeoning dwarf mistletoe problem? Method of cutting studies were established at FVEF in the 1910s and 1920s to help answer these questions.
- From the 1930s through the 1950s, research determined that precommercial thinning of dense stands of ponderosa pine was desirable from a timber management perspective (Harmon 1955; Pearson 1950; Smith 1962). As a result, studies of density and growth in prominent species, including ponderosa pine, were established throughout the West (Tappeiner et al. 2015), including at FVEF.
- The 1913, MoC studies determined that seed tree harvest resulted in the most available growing space for a new cohort and the greatest release of residual trees. The BA increments of the two selection treatments seemed to parallel their responses with group selection providing more available growing space for the recruitment of new cohorts. Light selection was closest to a uniform thinning and therefore displayed the more consistent post-treatment increment. Historically intensive harvesting resulted in a stand structure that converted aggregated spatial conditions to those that were more random in pattern. Less intensive harvests accentuated patchiness, homogenized tree size, and removed predominantly larger tree sizes. The 1924 uneven-aged MoC study observed that lower density stands recovered from drought faster than higher density stands.

Figure 1— In the background is a ponderosa pine LOGS control plot in 2017 (photo credit: J. Zhang).

Figure 2— Ponderosa pine LOGS 80 ft^2 ac^{-1} plot in 2017 (photo credit: J. Zhang).

1913 2006

Figure 3— Group selection site in the Method of Cutting study. (Photo credit: 1913: H. Krauch; 2006: A. Sánchez Meador.)

References

Ashton, M.S.; Kelty, M.J. 2018. The practice of silviculture: applied forest ecology. New York: John Wiley & Sons. 758 p.

Assmann, E. 1970. The principles of forest yield study. Oxford: Pergamon Press. 506 p.

Bailey, J.D. 2008. Forty years later at Taylor Woods: merging the old and new. In: Olberding, S.D.; Moore, M.M., tech cords. Fort Valley Experimental Forest: a century of research 1908–2008. Proc. RMRS-P-55. Fort Collins CO: USDA Forest Service, Rocky Mountain Research Station.

Bates, C.G. 1919. Effects of thinning in Black Hills yellow pine. Progress report for 1919. Unpublished paper on file with: U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, Moscow, ID. 46 p.

Curtis, R.O.; Marshall, D.D. 1986. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 8—The LOGS study: twenty-year results. Res. Pap. PNW-356. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 113 p.

Hawley, R.C. 1937. The practice of silviculture. New York: John Wiley & Sons. 252 p.

Kelty, M.J. 1984. The development and productivity of hemlock-hardwood forests in southern New England. New Haven: Yale University. Ph.D. Dissertation. 206 p.

Kittredge, D.B. 1986. The effect of stand structure on the growth of red oaks in mixed hardwood stands. New Haven: Yale University. Ph.D. dissertation.

Kolb, T.E.; Flathers, K.; Bradford, J.B.; Andrews, C.; Asherin, L.A.; Moser, W.K. 2020 stand density, drought, and herbivory constrain ponderosa pine regeneration pulse. Canadian Journal of Forest Research. 50(9): 862–871.

Oliver, C.D. 1978. The development of northern red oak in mixed stands in central New England. New Haven: Yale University. School of Forestry Bulletin 91. 63 p.

Roeser Jr., J. 1937. The role of timber stand improvement in the Black Hills. Black Hills Engineer. 24(1): 48–54.

Sánchez Meador, A.J.; Moore, M.M. 2011. Lessons from long-term studies of harvest methods in southwestern ponderosa pine–Gambel oak forests on the Fort Valley Experimental Forest, Arizona, USA. Forest Ecology and Management. 261(5): 923–936.

Sánchez Meador, A.J.; Moore, M.M.; Bakker, J.D.; Parysow, P.F. 2009. 108 years of change in spatial pattern following selective harvest of a Pinus ponderosa stand in northern Arizona, USA. Journal of Vegetation Science. 20(1): 79–90.

Schubert, G.H. 1971 Growth response of even-aged ponderosa pines related to stand density levels. Journal of Forestry. 69(12): 857–860.

Smith, D.M. 1962. The practice of silviculture. New York: John Wiley & Sons. 532 p.

Tappeiner II, J.C.; Maguire, D.A.; Harrington, T.B.; Bailey, J.D. 2015. Silviculture and ecology of western U.S. forests. Corvallis, OR: Oregon State University Press. 447 p.

Zhang, J.; Oliver, W.; Graham, R.T.; Moser, W.K. 2020. The Level-of-Growing-Stock (LOGS) study on thinning ponderosa pine forests in the U.S. West: a long-term collaborative experiment in density management. Journal of Forest Science. 66(10): 393–406. https://doi.org/10.17221/72/2020-JFS.

Short- and Long-Term Growth Responses of Northern Rocky Mountain Conifers to Varying Thinning Intensities

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Overview:

- Dendrochronology (i.e., tree ring analysis) was used to examine diameter growth responses to different precommercial thinning intensities over 50 years after treatment in the moist mixed-conifer forests of northern Idaho. Data were paired with inventory data 11 and 50 years after thinning.
- All species showed immediate diameter growth releases, but releases for grand fir and western hemlock were weaker and shorter term than western redcedar and western larch. While growth slowed in the no thinning treatment for western larch and western redcedar as time proceeded, growth of both species remained significantly greater over a 30–40 year period in all thinning treatments compared to the no thinning treatment.
- This is the first study to follow an experimental precommercial thinning experiment in the moist mixed-conifer forests of northern Idaho 50 years after thinning. The species-specific responses provide guidance on species that should be selected as residual trees after thinning to maintain rapid tree growth and desirable species composition (i.e., western larch and western redcedar) to meet a variety of management objectives including timber, carbon sequestration, and restoration of early successional forest composition.

Summary:

Moist mixed-conifer forests of the northern Rocky Mountains often contain thousands of stems per acre following stand-replacing disturbance. Many of these trees are shade tolerant species such as grand fir and western hemlock, even though current management objectives aim to increase density of early seral species such as western larch. Managers are faced with questions on how best to manage these overstocked stands and thinning is often a proposed solution. Knowledge on changes in stand structure over long periods of time following thinning are limited in these forests. This study applied various thinning intensities to 27-year-old naturally regenerated stands on the Priest River Experimental Forest. The study was resurrected in 2017 when 50-year post-thinning measurements were collected. Results from

the tree core analysis showed species-specific responses to thinning (fig. 1). Western larch and western redcedar showed substantial increases in growth immediately after thinning that persisted multiple decades into the future. Comparatively, grand fir and western hemlock did increase in growth, but the increase was not as great and did not persist as many years into the future. The 50-year remeasurement of the inventory plots found that the density of large trees (≥ 5 in d.b.h.) and basal area remained lower in the thinned plots compared to the unthinned plots (table 1). Stand structure modified by the thinning remained 50 years after thinning with the unthinned plots containing a much greater density of trees in suppressed and intermediate crown classes, while trees in the thinning treatments were more concentrated in the codominant crown class (fig. 2).

Silvicultural Concepts:

- Thinning is a frequently applied silvicultural treatment that can be used to achieve various silvicultural objectives, including shifting species composition, increasing and maintaining growth of residual trees, and modifying stand structure. Thousands of acres across the moist forests of the Northern Rockies are in need of thinning and budget constraints often limit treatment to a single application. Long-term results from thinning studies in the region are helpful in providing justification for early thinning. Results from this study show growth responses of western larch and western redcedar were sustained 30–40 years after thinning. This is promising given these species are often considered desirable for contemporary management objectives across the National Forests in the Northern Rockies. Thinning also resulted in long-term shifts in stand structure towards stands dominated by codominant trees. The intensity of thinning had minimal impact on changes in tree growth or stand structure over time.
- Analysis of tree cores is a powerful tool for understanding changes in growth in response to silvicultural treatments without access to frequent inventory data that can be costly to collect. The method of tree ring analysis used in this study was able to detect sustained growth responses over a 40-year period following treatment when compared to trees in plots that were not thinned.

Management Applications:

- Thinning in naturally regenerated moist mixed-conifer forests of the Northern Rockies can shift trajectories in individual tree growth that vary by species and stand structure. Thinning from below can increase growth of residual trees in these forests. By favoring western larch and western redcedar as residual trees, growth will be sustained multiple decades after treatment. Since growth is related to vigor, thinning can result in sustained resistance to biotic attack.

- One-time application of thinning in young, naturally regenerated stands has the potential to result in stands where a majority of trees persist in the upper canopy and potentially minimize continual regeneration of shade tolerant western hemlock and grand fir.
- Results from this study suggest that the intensity of thinning did not matter after 50 years in terms of individual tree growth or stand development after 50 years. Instead, performing any type of thinning provides the opportunity to alter structure.

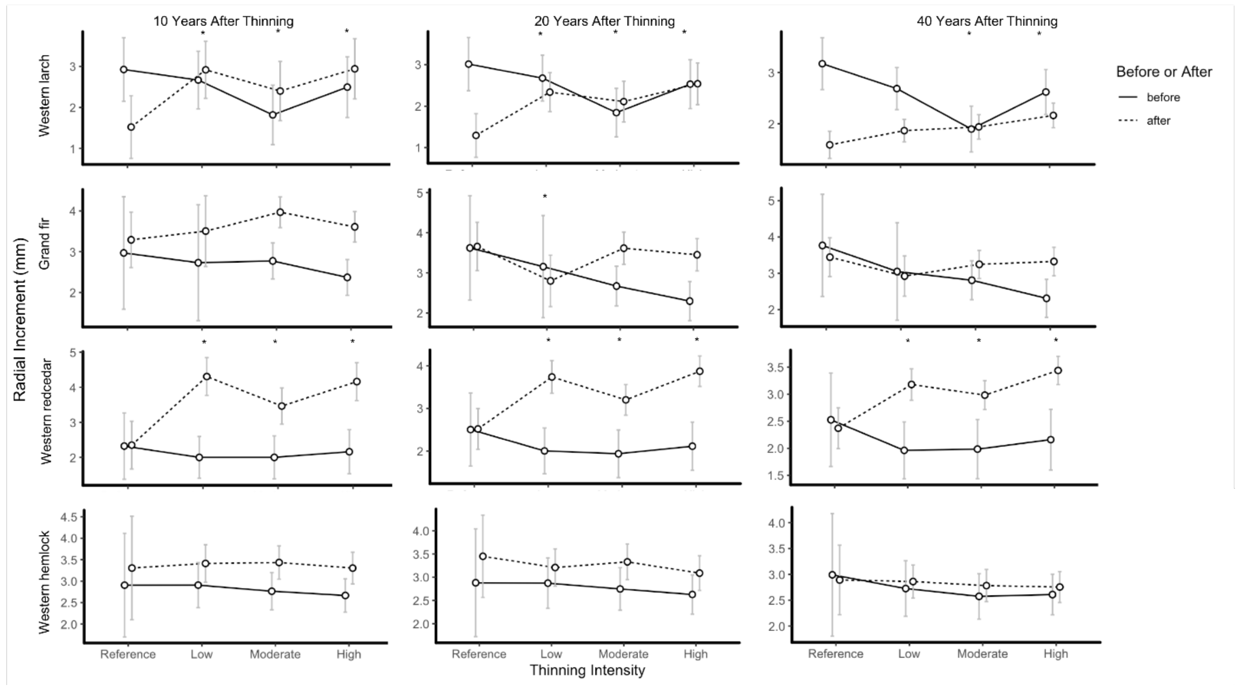

Figure 1—Radial tree stem increment from tree cores showing the increment before treatment (solid line) and after treatment (dotted line) at different time periods after thinning to different intensities. Also shown are before and after growth in untreated reference plot. Asterisks above data points indicate significantly different growth before and after for a given treatment at $p \leq 0.05$.

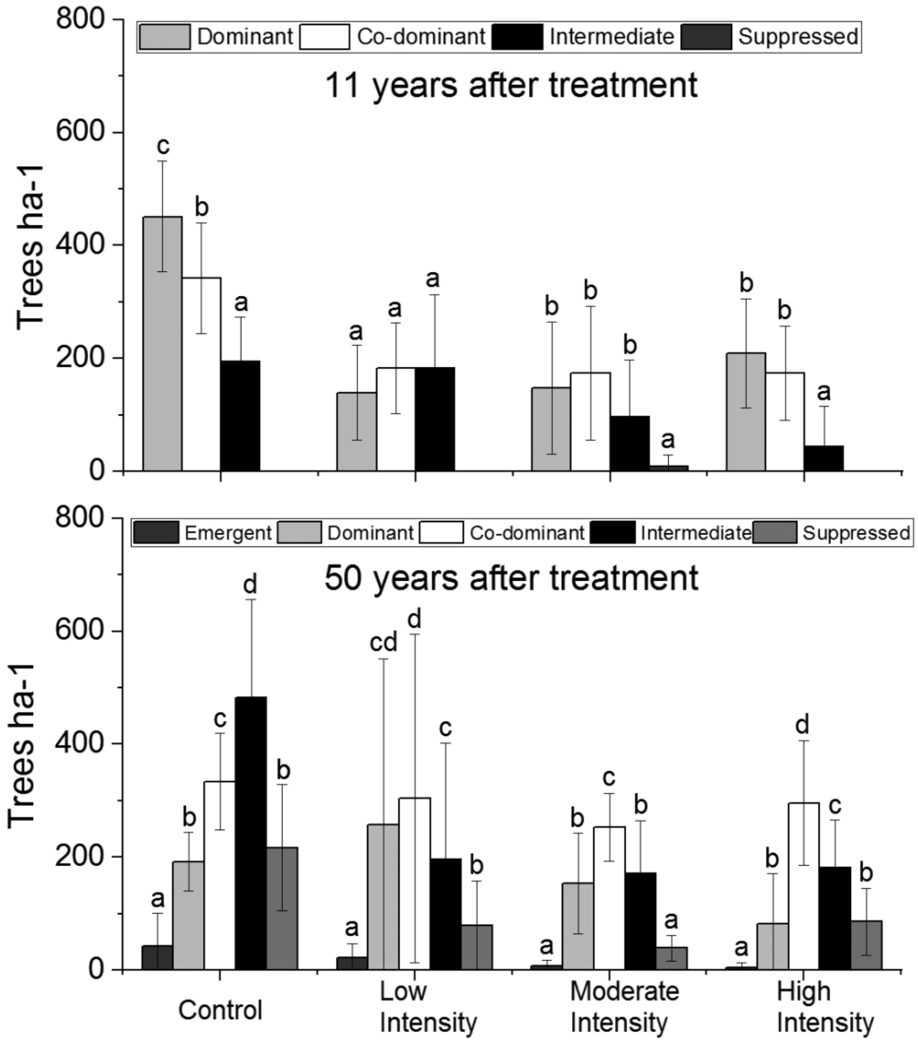

Figure 2—Trees per hectare by stand crown classes for trees only ≥ 11.5 cm (5 in) d.b.h. Data are shown for 11 and 50 years after thinning. For each group, different letters indicate significant differences at $p \leq 0.05$.

Table 1—Total basal area and stem density (trees ac^{-1}) for overstory trees (≥ 5 in d.b.h.), saplings (greater than 1 in d.b.h., but less than 5 in d.b.h.), and seedlings (≤ 1 in d.b.h. and taller than 6 in). Shown are means ± standard errors. Letters indicate significant differences between treatments within a year for each metric.

Treatment in trees per acre	Total basal area (ft^2 ac^{-1})	Overstory density (trees ac^{-1} ≥ 5 in d.b.h.)	Sapling density (trees ac^{-1})	Seedling density (trees ac^{-1})
11 years post-treatment				
Control	135.5 ± 6.0 b	400 ± 19 b	833 ± 49 b	1600 ± 170 a
Low (800)	61.9 ± 10.5 a	204 ± 24 a	200 ± 35 a	2406 ± 152 b
Moderate (400)	67.1 ± 14.8 a	172 ± 16 a	135 ± 19 a	2399 ± 148 b
High (200)	49.2 ± 0.4 a	172 ± 14 a	107 ± 31 a	2485 ± 121 b
50 years post-treatment				
Control	301.4 ± 32.2 b	513 ± 55 c	391 ± 117 b	27 ± 18 a
Low (800)	244.2 ± 17.9 a	347 ± 34 b	400 ± 122 b	256 ± 47 b
Moderate (400)	210.0 ± 8.7 a	253 ± 17 a	255 ± 81 a	283 ± 68 b
High (200)	194.2 ± 13.5 a	263 ± 30 a	463 ± 107 c	253 ± 95 b