United States Department of Agriculture

Forest Management – Research Partnerships:

Proceedings of the 2019 National Silviculture Workshop

Forest Service Northern Research Station General Technical Report NRS-P-193 May 2020

Abstract

Since its inception in 1973, the National Silviculture Workshop (NSW) has brought together forest managers and researchers from across the USDA Forest Service, and more recently our university and other partners, to provide a forum for information sharing and science advancements in silviculture. The 2019 NSW focused specifically on this partnership with the theme "Forest Management-Research Partnerships" in Bemidji, MN. With nearly 300 participants, this proceedings and that of the Journal of Forestry special section (Volume 118, Issue 3), highlight some of the best outcomes of our history of working together, as well as its challenges, and opportunities for the future. The objectives of the workshop included 1) providing a forum to showcase successful partnerships and shared stewardship between forest managers and researchers, 2) enhancing these relationships within the Agency and with our external partners to meet shared goals and objectives, 3) building on the Forest Service strategic objectives for improving the conditions of forests through innovative silviculture and active forest management, and 4) identifying emerging forest management needs to guide future research investment. This report includes of 22 papers (including two from 2017 NSW) and 6 panel-discussion summaries. The report also includes two papers from the 2017 NSW, "Silviculture: The Foundation for Restoration, Resilience, and Climate Adaptation" held in Flagstaff, AZ.

Acknowledgments

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Cover Photo

A field tour during the National Silviculture Workshop at the 70-year-old Level of Growing Stock Experiment on the Cutfoot Experimental Forest. Photo by Nisha van Hees, USDA Forest Service.

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May 21 – May 23, 2019

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A single-blind review process was used in reviewing manuscripts submitted for publication. Each manuscript was peer-reviewed by at least two professionals. Reviews were returned to authors to revise their manuscripts. Upon acceptance by the assigned editor, revised manuscripts were forwarded to the U.S. Forest Service, Northern Research Station for final editing and publishing. The workshop Editorial Committee returned some of the manuscripts to the authors as being more suitable for other outlets.

History of the National Silviculture Workshop

Year	Location	Title
1973	Marquette, MI	Hardwood Management
1974	Sacramento, CA	Silvicultural Work Conference
1976	Eugene, OR	Density of Stocking Control
1977	Flagstaff, AZ	Silvicultural Implications of Section 4 of NFMA
1978	Missoula, MT	Silvicultural Examination, Prescriptions and Related Activities
1979	Charleston, SC	Shelterwood Regeneration Method
1981	Roanoke, VA	Hardwood Management
1983	Eugene, OR	Economics of Silviculture
1985	Rapid City, SD	Success in Silviculture
1987	Sacramento, CA	Silviculture for All Resources
1989	Petersburg, AK	Silviculture Challenges and Opportunities of the 1990s
1990	Wenatchee, WA	Genetics/Silvicultural Workshop
1991	Cedar City, UT	Getting to the Future through Silviculture
1993	Henderson, NC	Silviculture from the Cradle of Forestry to Ecosystem Management
1995	Mescalaro, NM	Forest Health through Silviculture
1997	Warren, PA	Communicating the Role of Silviculture in Management of the National Forests
1999	Kalispell, MT	The Role of Silviculture in the Stand, Forest, Landscape, and Beyond
2001	Hood River, OR	Silviculture Odyssey to Sustaining Terrestrial and Aquatic Ecosystems
2003	Grandby, CO	Silviculture in Special Places
2005	Lake Tahoe, CA	Restoring Fire-Adapted Forested Ecosystems
2007	Ketchikan, AK	Integrated Restoration Efforts for Harvested Forested Ecosystems
2009	Boise, ID	Integrated Management of Carbon Sequestration and Biomass Utilization Opportunities in a Changing Climate
2011	Tallahassee, FL	Collaborative Silviculture for the 21st Century – Cancelled
2013	Charleston, SC	Collaborative Silviculture for the 21st Century – held during the 2013 SAF National Convention
2015	Baton Rouge, LA	Silviculture track – Part of the 2015 SAF National Convention
2017	Flagstaff, AZ	Silviculture: The Foundation for Restoration, Resilience, and Climate Adaptation
2019	Bemidji, MN	Forest Management – Research Partnerships

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INTRODUCTION

The 2019 National Silviculture Workshop: A Focus On Forest Management-Research Partnerships

Lauren S. Pile, Robert L. Deal, Daniel C. Dey, David Gwaze, John M. Kabrick, Brian J. Palik, and Thomas M. Schuler[1]

ABSTRACT.—The 2019 National Silviculture Workshop brought together nearly 300 forestry practitioners and researchers from across the United States and Canada. The theme of this year's biennial Workshop was Forest Management-Research Partnerships.

Over a century ago, Raphael Zon, the founder of the USDA Forest Service's experimental forest network, urged scientists to work with managers to find solutions to "immediate, practical problems" encountered every day in the woods. Following this theme to connect forest managers with scientists, the National Silviculture Workshop (NSW) was established in 1973 to connect emerging forest research with forest management. Since its beginnings, the NSW has worked to advance Zon's vision by providing a forum for sharing silvicultural advances among USDA Forest Service field foresters in the National Forest System (NFS), program staff from State & Private Forestry (S&PF), and research scientists in Research and Development (R&D). In recent years, research scientists from universities, as well as other federal, state, and tribal agencies, have attended and contributed through presentations, panels, posters, workshop papers, and field tours.

The theme for the 2019 workshop was Forest Management-Research Partnerships, recognizing that it is through strong working relationships that forest managers and research scientists come together to identify priority issues, challenges, and solutions in National Forest management. Research direction and priorities are thus informed by managers, and hence are made more relevant and effective at solving practical problems. Research implementation occurs on National Forests, either on management units or experimental forests. This requires good partnerships and true collaborations by both management and research. Problems addressed on National Forests are often of broader interest to managers of state, non-governmental organizations, tribal, and private forest lands. The 2019 NSW provided a critical forum to discuss how we can enhance existing relationships, build new partnerships, and learn from successful collaborations already in place, to improve the condition of forests through innovative silvicultural research and active forest management.

The objectives of the 2019 National Silviculture Workshop (NSW) were to:

- Provide a forum to showcase successful partnerships and shared stewardship between forest managers and researchers.
- Enhance forest management and research relationships within the Forest Service and with external partners to meet shared goals and objectives.

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- Build on the Forest Service strategic objectives to improve the conditions of forests through innovative silviculture and active forest management.
- Identify emerging forest management needs to guide future research investment.

The 3-day NSW included 2 full days of keynote speakers, panel discussions, contributed oral and poster presentations, and a day-long field tour. The Workshop opened on May 21 with welcoming addresses from Forest Service Associate Chief Lenise Lago and Chippewa National Forest Supervisor Darla Lenz. Mike Smith, Tribal Elder from the Leech Lake Band of Ojibwe, welcomed Workshop participants to the Band's ancestral lands.

The NSW included several strategic keynote addresses to highlight partnerships between NFS and R&D, as well as the Forest Service with our university partners. We began the program with an invited joint keynote address from Washington Office (WO) staffs including Eric Davis, the Assistant Director of Integrated Vegetation Management (NFS), and Toral Patel-Weynand, the Director of Sustainable Forest Management Research (R&D). Davis highlighted the need for researchers and managers to work together to make informed management decisions, while Patel-Weynand spoke of a cross-deputy team assembling a national compendium of silvicultural treatments to support scenario planning, shared stewardship, and other landscape planning needs. Linda M. Nagel of Colorado State University and Brian J. Palik of the Northern Research Station delivered a joint keynote on the importance of partnerships between the Forest Service R&D, NFS, and universities. Together, they highlighted the wide breadth of operational scale experiments that "provide opportunities for multigenerational training and education between scientists and graduate students," the National Advanced Silviculture Program (NASP), and importance of maintaining long-term field experiments on experimental forests (EFs). Paul I.V. Strong, Forest Supervisor of the Chequamegon-Nicolet National Forest, shared his insights from his view as a forest supervisor who has worked in both NFS and R&D (Chapter 6). Anthony W. D'Amato, professor at the University of Vermont, highlighted a regional approach for increasing resilience of black ash (*Fraxinus nigra*) wetlands to emerald ash borer (EAB) through research efforts, field studies, and demonstrations by scientists and managers to "determine effective ways for reducing the vulnerability of black ash forest types to EAB." The evening awards ceremony was headlined by Richard Fitzgerald, WO NFS, and Russell Graham (given by proxy), Rocky Mountain Research Station, who provided insights from their over 100 combined years of experience in the field of silviculture research and management in the Forest Service. Together, they highlighted the importance of the National Silviculture Workshop in bringing together NFS silviculturists and research silviculturists since the first meeting held in Marquette, Michigan, in 1973. These broad insights from leaders within the Forest Service and universities provided Workshop attendees with lessons on existing successful partnerships and ideas to enhance relationships in their own regions.

The Program Committee developed six interactive panels to engage attendees in thought-provoking discussions related to forest industry (Chapter 6), NASP (Chapter 8), tribal management (Chapter 7), Experimental Forests (Chapter 8), forest products modernization (6), and a capstone panel to highlight "lessons learned, challenges ahead, and opportunities for enhanced collaboration and alignment between managers and researchers" (Chapter 10). The thoughts and stories shared from the panel discussions were captured and summarized to provide a record of our success, critiques for improvement, and ways to develop or enhance effectively working together as we move forward.

The day 2 field trip showcased long-term and large-scale silvicultural experiments maintained by the Grand Rapids, MN, and Delaware, OH, Forest Service R&D laboratories. These included The Common Sense Study, started in 1927 by Raphael Zon, the Creating Dutch Elm Disease-tolerant Site-Adapted American Elm study, and the Adaptive Silviculture for Climate Change (ASCC) experiment, the largest forest adaptation experiment on the planet. Foresters, scientists, and decisionmakers from agencies, tribes, and organizations across North America viewed and discussed research that has generated solutions to a variety of pressing problems, including how to maintain ecosystem function in the face of emerald ash borer invasion to approaches that provide a range of silvicultural options for adapting northern forests to climate change. This outreach effort demonstrated the power of long-term research for solving the problems facing our forests, an outcome made possible by the long-running partnership among Forest Service R&D, the NFS, S&PF, university collaborators and other stakeholders.

Contributed oral presentations and posters continued to highlight local, regional, and national partnerships in science and management. Concurrent session themes included:

- Silviculture Partnerships
- Forest Management and Planning
- Services, Products, and Getting it Done
- Fire
- Lessons Learned from Long-term Soil Productivity
- Silviculture, Adaptation and Monitoring
- Genetics, Forest Threats and Reintroductions
- Shared Stewardship and Collaborative research
- Partnerships in Restoration

Much of what was shared and contributed by attendees, that made the 2019 NSW a success, is captured in this General Technical Report, along with several special sections of the Journal of Forestry, guest edited by Daniel C. Dey and Thomas M. Schuler (Dey and Schuler 2020). These publications capture much of the presented agenda, but it is often the hallway conversations between sessions and the shared seats on the bus during the field trip that bring us together from around the country, facilitating new forest management-research partnerships and re-igniting old relationships. It is the latter that is a truly important outcome of the NSW helping to ensure that, as Raphael Zon urged, "scientific research must be tempered with common sense."

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FIRE

Regionally Adapted Models for the Rapid Assessment of Vegetation Condition After Wildfire Program in the Interior Northwest and Southwest United States

Craig Baker, Brian Harvey, Saba Saberi, Alicia Reiner, and Max Wahlberg[1]

ABSTRACT.—The Rapid Assessment of Vegetation Condition After Wildfire program (RAVG) provides satellite-based estimates of basal area loss, canopy cover loss, and burn severity following large wildfires on USDA Forest Service lands. The current RAVG models (regression equations) are based on field data collected from burned areas in the Sierra Nevada, northern California, and southern Oregon, and on Landsat imagery from the same period. In collaboration with teams from the University of Washington and the Forest Service Enterprise Team, the Forest Service Geospatial Technology and Applications Center is pursuing a multiyear effort to develop new models adapted to forests in the Pacific Northwest and the Southwest. The UW team is developing the model for the Northwest using data collected on wildfires in interior Oregon and Washington, northern Idaho, and western Montana that occurred during 2016 and 2017. The Enterprise Team is pursuing a similar effort for Arizona and New Mexico based on data from fires that burned in 2017 and 2018. This talk will provide background for the RAVG program and existing models, methods used in the current studies, and preliminary results.

The Rapid Assessment of Vegetation Condition After Wildfire (RAVG) program is a postfire vegetation assessment program conducted by the Forest Service Geospatial Technology and Applications Center. Its purpose is to provide model-based estimates of vegetation condition (burn severity) following large wildfires on forested lands in support of the Forest Service silviculture community.

RAVG models consist of regression equations relating imagery-based burn severity indices—most often the Relative Differenced Normalized Burn Ratio (RdNBR) (Miller and Thode 2007)—to field-based measures: burn severity basal area (BA) mortality, canopy cover (CC) mortality, and the composite burn index (CBI). The models were developed by Forest Service staff in the Pacific Southwest region based on field data collected on fires in the Sierra Nevada, northern California and southern Oregon, and contemporary Landsat imagery (Miller et al. 2009). Although the models are based on data from the specific region just described, they have been applied routinely to forested ecosystems throughout the conterminous United States.

The purpose of this new effort is to generate models tailored to other areas, based on data from those regions, with the goal of incorporating the new models into the RAVG workflow for the respective areas. The regions addressed in this project are the interior northwestern United States ("Northwest"), including eastern Oregon and Washington, northern Idaho, western Montana and northwestern Wyoming, and the southwestern United States ("Southwest"), comprising Arizona and New Mexico. The work is being accomplished through partnerships with the University of Washington's School of Environmental and Forest Sciences (for the Northwest model) and the Forest Service Enterprise Program (the Southwest model).

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The project has three major components:

- Collect field data from burned areas (fires) and nearby unburned areas.
- Calculate burn-related indices from contemporary moderate resolution multispectral imagery.
- Develop models relating the field data to the imagery-derived indices.

Data were collected during the field season of the year following each fire. Fires and plot locations were selected to include forests and woodlands representative of the respective region and to sample the full range of burn severity conditions. The focus was on Forest Service lands, although the Northwest dataset includes two fires on National Park Service lands (Yellowstone and Grand Teton National Parks) with vegetation similar to that found on National Forests in the region. Each field crew sought to sample approximately the same number of plots in each of four categories of burn severity: unburned, low severity (light surface fire), moderate severity (severe surface fire), and high severity (crown fire). Fires that included each severity class were preferentially selected in the Southwest, while fires lacking forest vegetation types were not sampled. In order to increase sampling efficiency and sample size, only fires with reasonable road access were included. Field protocols established minimum distances from roads (100 m) and between plots (400 m). A fraction of the "unburned" plots was located near but outside of the selected fires in areas with vegetation and topographic characteristics similar to those of the burned area plots.

For each circular, 30-m diameter plot, field crews recorded CBI, a sample of canopy cover and individual tree data, and, in the Northwest plots, surface char. The CBI was calculated as a composite score of fire severity ratings by strata (substrate, understory, herb/low shrub, tall shrub, intermediate, and overstory tree) using standardized criteria (Key and Benson 2005). Canopy cover was measured along the north-south and east-west diameter using a densiometer. The Northwest crew took 8 samples on each plot (4 along each transect); the Southwest crew took 17 samples (9 along the North-South transect and 8 along the East-West transect). Species, diameter at breast height, and live/dead state were noted for all trees within the plot. For dead trees, crews noted whether the trees were alive or dead before the fire (e.g., identifying trees killed by insects prior to the fire). In the Northwest, additional data, including tree height and fire effects data (e.g., char height), were collected on the five tallest trees in each quadrant. In the Southwest, similar data were collected on the first five trees encountered working clockwise in each quadrant in order to allow the Forest Vegetation Simulator (FVS) (Dixon 2002) to calibrate allometric equations used in canopy cover and BA calculation.

Field crews in each region collected data from more than 300 plots over the course of two field seasons (see Fig. 1 and Table 1). In the Northwest, data were collected from 84 plots during the summer of 2017 on five fires from 2016 and from 228 plots during the summer of 2018 on nine fires from 2017. Lodgepole pine was the dominant tree species on plots at higher elevations, with subalpine fir as a lesser component. On lower-elevation plots, ponderosa pine and Douglas-fir were dominant; some grand fir were also present. In the Southwest, field crews collected data during the late spring and early summer of 2018 and 2019, with 218 plots on 15 fires from 2017 and 142 plots on 6 fires from 2018. Ponderosa pine was the dominant species across almost all elevations sampled in the Southwest. Several juniper and oak species (generally alligator and Rocky Mountain juniper, and Emory, Gambel and Arizona white oak) were a large component in some southern and lower-elevation areas. The northernmost and highest elevation plots had a mix of Douglas-fir, white fir, subalpine fir, aspen, and limber pine.

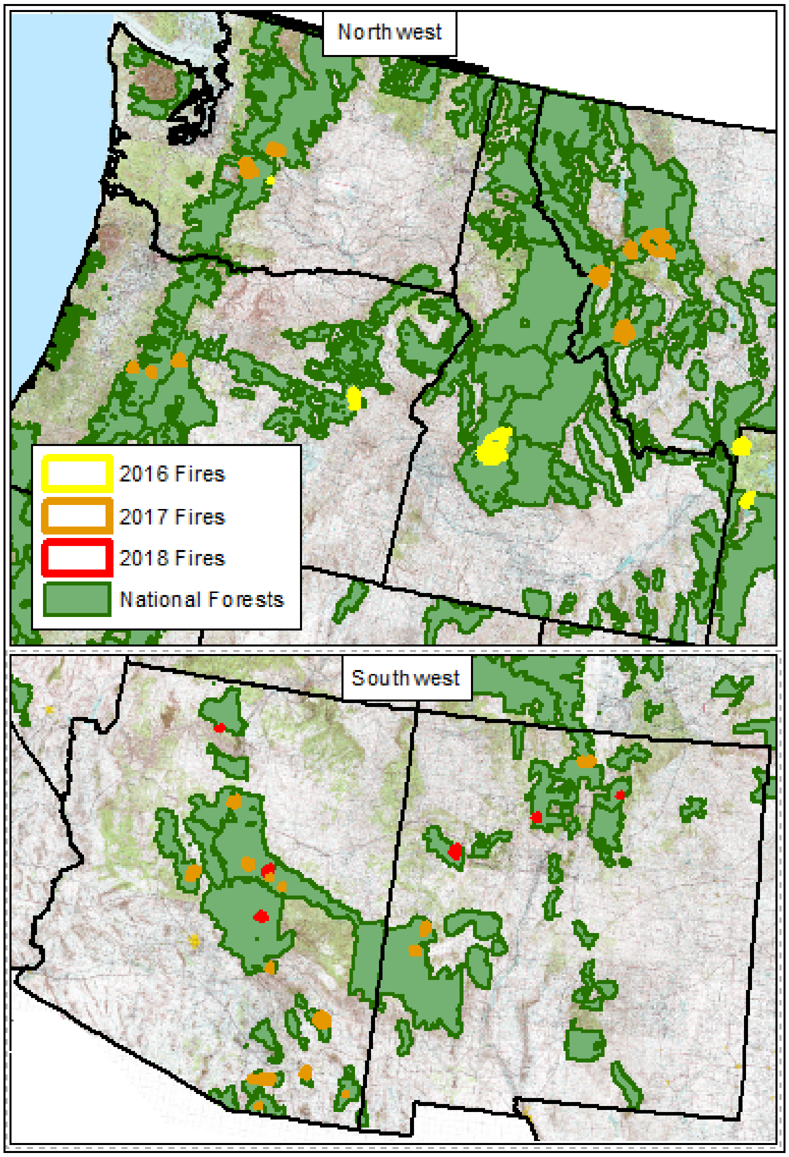

Figure 1.—Locations of sampled fires.

Stand metrics were generated from field data. Prefire BA was estimated from the subset of trees that were alive before the fire. In the Northwest, prefire canopy cover was estimated from regression models built on BA and canopy cover measured on unburned plots and applied to live prefire BA for all plots. In the Southwest, FVS was used to generate estimates of canopy cover from tree species and live BA FVS-generated canopy cover estimates were calibrated by way of adjustment factors available within FVS, which were selected to yield the best match between field-measured and FVS-generated canopy cover. Additional canopy cover data will be assembled using established photo interpretation methods with high resolution pre- and postfire imagery for improved assessment of canopy cover change for the Southwest models.

Burn severity indices were derived from Landsat 8 multispectral satellite imagery. The RdNBR is the primary burn severity index used in the RAVG program. For this project, two other burn severity indices (the differenced NBR (dNBR) and the relative burn ratio (RBR) will also be tested. Consistent with the current RAVG workflow, the indices are calculated from a pair of satellite images—one each pre- and postfire—that are judiciously selected by an analyst so as to reveal fire-related changes and minimize changes due to other factors such as annual or seasonal differences or non-fire disturbances.

Table 1.—Fires sampled and number of plots

Fire year (ignition)	Fire	National Forest (NF) or Park (NP)	State	Plots sampled
		Northwest		
2016	Berry	Grand Teton NP	WY	27
2016	Maple	Yellowstone NP	WY	10
2016	Pioneer	Boise NF	ID	13
2016	Rail	Wallowa-Whitman NF, Malheur NF	OR	23
2016	Rock Creek	Okanogan-Wenatchee NF	WA	11
2017	Jolly Mountain	Okanogan-Wenatchee NF	WA	12
2017	Jones	Willamette NF	OR	27
2017	Liberty	Lolo NF	MT	9
2017	Lolo Peak	Lolo NF	MT	21
2017	Meyers	Beaverhead-Deerlodge NF	MT	24
2017	Milli	Deschutes NF	OR	65
2017	Norse Peak	Okanogan-Wenatchee NF	WA	35
2017	Rebel	Willamette NF	OR	8
2017	Rice Ridge	Lolo NF	MT	27
		Southwest		
2017	33 Springs	Apache-Sitgreaves NF	AZ	14
2017	Baca	Gila NF	NM	24
2017	Bonita	Carson NF	NM	29
2017	Boundary	Coconino NF, Kaibab NF	AZ	14
2017	Flying	Coronado NF	AZ	15
2017	Frye	Coronado NF	AZ	21
2017	Goodwin	Prescott NF	AZ	13
2017	Hondito	Carson NF	NM	7
2017	Kerr	Gila NF	NM	14
2017	Lizard	Coronado NF	AZ	10
2017	Pinal	Tonto NF	AZ	10
2017	Rucker	Coronado NF	AZ	9
2017	Sawmill	Coronado NF	AZ	7
2017	Slim	Apache-Sitgreaves NF	AZ	10
2017	Snake Ridge	Coconino NF	AZ	21
2018	Bears	Tonto NF	AZ	17
2018	Blue Water	Cibola NF	NM	26
2018	Deiner Canyon	Cibola NF	NM	30
2018	Sardinas Canyon	Carson NF	NM	21
2018	Tinder	Coconino NF	AZ	26
2018	Venado	Santa Fe NF	NM	22

Analysis is underway in each region to determine models that best predict percent BA loss, percent CC loss, and CBI as a function of the imagery-derived indices. A variety of model forms will be assessed. In the Northwest, model development is well underway. Additional burn-related metrics are being evaluated to suggest methods to capture burn severity more accurately than with CBI methods. In the Southwest, exploratory analysis is being conducted to increase awareness of data distribution and collinearity among variables, as well as outliers and leverage points. Test error and other model accuracy metrics will be generated within cross-validation procedures (such as k-fold) and used to compare the utility of candidate models. The model with the best test error and accuracy metrics will be formulated using the entire dataset. Thresholds defining low, medium and high CBI categories will be also be identified.

Additional work being considered includes incorporation of other predictor variables (e.g., topographic indices or vegetation type), which also entails determining variable importance rankings (i.e., using Random Forests algorithms). The use of other satellite sensors (i.e., Sentinel-2) and other approaches to scene selection (e.g., seasonal composites) are also options. Follow-on work may include accuracy assessments of new and existing models as well as assessment of the need for additional models tailored to other regions of the United States.

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Evaluating the Applicability of the Shelterwood-Burn Technique for Regenerating the Mixed-Oak Forests of the Allegheny National Forest

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ABSTRACT.—We evaluated the usefulness of the shelterwood-burn technique for regenerating upland mixed-oak (*Quercus* spp.) stands on the Allegheny National Forest of northwestern Pennsylvania. Two mid-spring prescribed fires were conducted in four upland mixed-oak stands that had been partly harvested due to defoliation-mediated mortality and subsequent salvage logging. Overall, the technique performed reasonably well. Before the burns, red maple (*Acer rubrum*) and sweet birch (*Betula lenta*) reproduction dominated the stands in terms of stem density and height. However, two fires conducted 3 years apart killed many of the birch and maple seedlings, creating a seedling pool with a substantial oak component. Additionally, interspecific heights among the seedlings were approximately equal. If these promising trends continue through the final harvest to crown closure of the new stand, then the shelterwood-burn technique will have been shown to be a viable silvicultural method for the Allegheny National Forest.

INTRODUCTION

Throughout the eastern United States, natural resource professionals and the general public highly value upland, mixed-oak (*Quercus* spp.) forests for the multitude of ecological and economic benefits that they supply to society. The forest products sector uses oak extensively; the wood is made into cabinetry, flooring, furniture, construction lumber, pallets, paneling, and specialty items such as whiskey barrels. Oak forests are renowned as wildlife habitat as they provide food and shelter for a variety of species ranging from insects to large mammals (McShea and Healy 2002). Additionally, oak forests offer watershed protection, supply high-quality water resources, and contribute to landscape aesthetics and diversity. Finally, the longevity of the oak trees means they can provide these goods and services for decades. Because of these diverse values, many natural resource managers try to maintain mixed-oak forests on the landscape through sustainable management practices. However, regenerating mixed-oak forests is a daunting task as the regeneration process is slow and vulnerable to numerous problems, especially on intermediate to high-quality sites where competition from mesophytic hardwoods is intense. The Allegheny National Forest (ANF) in northwestern Pennsylvania epitomizes this conundrum of high-value oak and its regeneration challenges. While only about 15 percent of the ANF's 533,000 acres are classified as upland mixed-oak forests, they are prized by the local communities and sustaining them is an objective of current and past forest management plans (Allegheny National Forest 1986, 2007). However, forest managers seeking to do so are confronted with multiple obstacles such as interfering understory vegetation, highly competitive mesophytic hardwood species, and chronic whitetail deer (*Odocoileus virginianus*) browsing. Because the current upland mixed-oak forests exist, in part, due to past fires (Marquis 1975), the ANF became interested in the early 2000s in testing the applicability of the shelterwood-burn technique to overcome some of the oak regeneration obstacles.

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The shelterwood-burn technique originated in the Piedmont region of Virginia in the late 1990s to address red maple (*Acer rubrum*) and yellow-poplar (*Liriodendron tulipifera*) replacing upland mixed-oaks when they were harvested (Brose et al. 1999a, 1999b). It consists of a two-step shelterwood sequence with a hot mid-spring fire applied between the two harvests. The first harvest removes the midstory strata and creates about 50 percent open canopy, thereby allowing ample sunlight to reach the oak seedlings so they can quickly develop their root systems. After 4 to 7 years, the oak seedlings have large root systems and the mesophytic hardwoods are beginning to overtop the oaks. A hot, mid-spring fire occurs during leaf expansion of the understory strata and topkills all of the seedlings and forces the rootstocks to sprout. The oak reproduction experiences less mortality and has accelerated growth relative to the mesophytic seedlings, resulting in an improved competitive position for the oaks relative to the other species. The second harvest usually occurs within 5 years of the prescribed fire.

In late 2000, the ANF approached the Irvine Forestry Sciences Lab of the Northeastern Research Station (now the Northern Research Station) about an administrative study to test whether the shelterwood-burn technique could be used to overcome the competing and interfering vegetation obstacles to sustaining upland mixed-oak forests in the local area. Of particular concern were the responses of keystone oak species (northern red [*Quercus rubra*], black (*Q. velutina*), chestnut (*Q. montana*), and white (*Q. alba*)] and the primary competitors, red maple and sweet birch (*Betula lenta*). Also of concern were how important associate species such as black cherry (*Prunus serotina*), cucumber tree (*Magnolia acuminata*), and serviceberry (*Amalanchier alnifolia*) would respond to the technique, as these had not been extensively examined in prescribed fire studies. The purpose of this paper is to report the results of that administrative study.

METHODS

This study was conducted from 2001 to 2010 in four upland mixed-oak stands located on the Bradford Ranger District of the ANF. Each stand was dominated by northern red oak with lesser amounts of black, chestnut, and white oak. Associate hardwood species included black cherry, cucumber tree, red maple, sweet birch, and yellow-poplar. Stand sizes ranged from 25 to 50 acres and were situated on upland benches so aspect and slope were inconsequential. Oak site index was estimated between 70 and 75 feet based on stand records. All stands were less than fully stocked (basal areas ranged from 60 to 90 square feet per acre) due to gypsy moth (*Lymantria dispar*) defoliations in the late 1980s and early 1990s and subsequent salvage harvesting of some mature oaks. Due to this disturbance, the midstory of each stand was well developed and consisted of mesophytic hardwoods, especially red maple and sweet birch. All stands had been fenced to exclude deer shortly after the salvage harvests. The fences were moderately successful; deer penetrations into the stands were a chronic problem throughout the study. Nevertheless, the understories had an abundance of herbaceous and woody vegetation including hardwood seedlings of the same species as the overstory trees.

Each of the four stands was split into two equally sized treatment blocks and each block was randomly assigned to be a spring burn or an unburned control. In each treatment, SILVAH sampling plots (Marquis et al. 1992) were systematically installed at a density of 1 plot per acre to uniformly cover the area. In summer 2002 and 2003, these plots were inventoried for basal area/density of overstory trees, percent cover of herbaceous vegetation, and density/height of hardwood seedlings less than 1-inch diameter at breast height (d.b.h.) using established procedures (Marquis et al. 1992). Inventory tallies were limited to the major tree species of the ANF. Those were as follows: American beech (*Fagus grandifolia*), black cherry, cucumber tree, northern red oak, other oaks, pin cherry (*Prunus pensylvanica*), red maple, serviceberry, sugar maple (*Acer saccharum*), sweet birch, and yellow-poplar.

Because the forest plan in existence at the time did not have prescribed fire as an acceptable silvicultural activity for mixed-oak forests, the ANF had to conduct an environmental assessment before conducting the burns. This assessment took approximately 3 years to complete, so spring 2004 was the first spring the prescribed fires could have been conducted. However, that spring was quite rainy so the burns were delayed until 2005 when weather conditions were much more favorable for conducting prescribed fires. The burn blocks in two stands were burned on May 6, 2005, and those in the other two stands were burned 3 days later on May 9, 2005. At this time, leaves of the mesophytic hardwood seedlings were approximately 50 percent expanded while the buds on the oak reproduction were only swollen. Weather conditions were measured using a belt weather kit. Recorded conditions for all burns were essentially identical; dry bulb air temperature of 70 to 75 °F, relative humidity between 20 and 30 percent, west winds less than 5 mph, clear skies, and no precipitation for at least 3 previous days. Ten-hour fuel moistures ranged from 10 to 15 percent based on a hand-held wood moisture meter. Observed fire behavior for all fires was as follows: flame lengths of 2 to 4 feet and rates-of-spread between 2 and 5 feet per minute.

All plots were re-inventoried for herbaceous vegetation, overstory trees, and seedlings in summer 2007. A second prescribed fire was conducted in each spring burn treatment block on May 7 and 11, 2008, due to the mesophytic hardwood seedlings' re-emerging dominance over the oak seedlings. At this time, the leaves of the mesophytic hardwood seedlings were approximately 50 percent expanded while the buds on the oak reproduction were swollen. Weather conditions for all burns were as follows: dry bulb air temperature of 55 to 65 °F, relative humidity between 30 and 40 percent, west winds less than 5 mph, 50 percent cloud cover, and no precipitation for at least 3 previous days. Ten-hour fuel moistures ranged from 20 to 25 percent based on a hand-held wood moisture meter. Observed fire behavior for all fires was as follows: flame lengths of 1 to 2 feet; and rates-of-spread between 1 and 3 feet per minute. All plots were re-inventoried for a third time for herbaceous vegetation, overstory trees, and seedlings in summer 2010.

The response variables for this study were density (mean stems/acre), height (mean tallest), and stocking (proportion of plots containing at least one stem) of the seedlings of the major tree species and percent cover of the herbaceous vegetation. The data were analyzed as a randomized complete block with repeated measures via Proc GLMMIX (SAS Institute 2009). Species and prescribed fire treatment (control or spring burn) were the fixed effects in the model while stand was the random block effect. Year of inventory was the repeated measure. To measure the correlation between inventories, we used an autoregressive order 1 covariance structure. Because the response variables for herbaceous cover and stocking were percentages with many large and small values, we used a beta distribution, logit link function, and the Kenward-Rogers denominator degrees of freedom method. We used the Tukey-Kramer least squares mean separation test and an alpha of 0.05 for all multiple comparisons. Residuals were examined to ensure that model assumptions were met.

RESULTS

At the beginning of the study, the four stands were quite similar to each other. Overall, they averaged about 200 trees per acre with an average d.b.h. of 9.5 inches, 94 square feet of basal area (BA), and 60 percent relative density (a measure of stocking). Of these metrics, oaks contributed 30 trees per acre (all in the main canopy) with an average d.b.h. of 19.5 inches, 57 square feet of BA, and 39 percent relative density. Conversely, mesophytic hardwoods tallied nearly 170 trees per acre (primarily in the midstory), with an average d.b.h. of 6.0 inches, 40 square feet of BA, and 20 percent relative density. Dividing each stand into two treatment areas did not result in any differences in overstory metrics among the treatment areas.

In the understory, total seedling estimates averaged slightly more than 37,000 stems per acre with no pretreatment difference between the control and spring burn treatments (Table 1). Red maple seedlings were the most abundant (≈ 11,000 per acre), about 30 percent of all seedlings. Northern red oak seedlings numbered approximately 9,660 per acre followed by black cherry (4,835) and sweet birch (3,185). Seedlings of all other species ranged from 415 (American beech) to 1,500 per acre (pin cherry).

Stocking of the seedlings reflected their abundance, with the most common species being the most widely distributed across plots (Table 2). Black cherry, northern red oak, red maple, and sweet birch occurred on more than 68 percent of the plots. Stocking of all other species ranged from 7 to 32 percent. Herbaceous ground cover ranged from 40- to 50-percent cover regardless of treatment and consisted almost entirely of ferns (bracken [*Pteridium aquilinum*], hay-scented [*Dennstaedtia punctilobula*], and New York [*Thelypteris noveboracensis*]) and various species of grasses.

The seedlings formed three height strata at the beginning of the study with no differences detected among the two treatments (Table 3). Sweet birch and pin cherry were in the first stratum with their tallest stems averaging from 9.7 to 13.2 feet. The second stratum consisted of black cherry and red maple with their tallest stems ranging from 5.1 to 7.2 feet in height. All other species were in the third stratum with their tallest stems ranging from 1.3 (northern red oak) to 3.6 (yellow-poplar) feet. In this stratum, yellow-poplar had the tallest stems and the oaks were the shortest species. The fern layer was generally as tall as or slightly taller than the shortest oak seedlings.

The first prescribed fire reduced overall seedling densities by about one-third, from 38,035 to 25,075 seedlings per acre (Table 1). Most of this reduction came in northern red oak (69 percent), other oaks (57 percent), red maple (48 percent), and sweet birch (43 percent). American beech, yellow-poplar, and miscellaneous hardwood seedling densities increased following the first prescribed fire while densities of all other tree species were relatively unchanged. Seedling densities in the control treatment also declined by 13 percent relative to pretreatment (36,050 to 31,000 stems per acre) and this decrease occurred almost entirely in the oaks. Northern red oak seedling counts dropped from 9,770 to 3,850 stems per acre (61 percent) while other oaks declined from 2,075 to 1,200 stems per acre (42 percent).

The postburn decline in red maple and sweet birch seedling densities affected their distribution among plots as stocking levels dropped from 96 to 79 percent for red maple and 68 to 54 percent for sweet birch (Table 2). Stocking levels also dropped for sugar maple from 7 to 3 percent. Conversely, stocking levels for serviceberry, yellow-poplar, and miscellaneous species increased following the first burn. For all other species stocking did not appreciably change between 2003 and 2007 nor did it change for herbaceous vegetation during the same period.

Table 1.—Densities (mean stems/acre ± 1 standard error) of hardwood seedlings by species, treatment, and year. Pretreatment year is 2003 while 2007 and 2010 are after the first and second burns, respectively. Means followed by different uppercase letters are different within that row while those followed by different lowercase letters are different within that year and treatment.

Species or group	2003	2007	2010
	Control treatment		
American beech	415 ± 50Ae	425 ± 150Af	435 ± 100Ag
Black cherry	4,275 ± 450Ab	5,275 ± 450Bb	5,400 ± 200Bb
Cucumber tree	650 ± 60Ae	760 ± 70Ae	750 ± 70Af
Northern red oak	9,770 ± 850Aa	3,850 ± 350Bc	1,950 ± 400Cd
Other oak	2,075 ± 500Ac	1,200 ± 180Bd	800 ± 200Bf
Pin cherry	575 ± 125Ae	575 ± 100Ae	230 ± 50Bg
Red maple	11,500 ± 750Aa	11,700 ± 400Aa	10,600 ± 350Aa
Sweet birch	3,465 ± 300Ab	3,615 ± 175Ac	3,540 ± 150Ac
Sugar maple	400 ± 125Ae	400 ± 125Ae	400 ± 100Ag
Serviceberry	1,075 ± 80Ad	1,150 ± 75Ad	1,025 ± 60Ae
Yellow-poplar	1,280 ± 50Ad	1,200 ± 150Ad	1,020 ± 200Ae
Miscellaneous	570 ± 75Ae	850 ± 200Be	700 ± 150Bf
Total seedlings	36,050 ± 4000A	31,000 ± 3500AB	26,850 ± 2,500B
	Spring burn treatment		
American beech	600 ± 75Ae	1,425 ± 150Bd	925 ± 100Cf
Black cherry	5,400 ± 500Ab	5,425 ± 450Aa	4,550 ± 200Ba
Cucumber tree	775 ± 75Ae	800 ± 70Ae	650 ± 70Af
Northern red oak	9,550 ± 1000Aa	3,000 ± 350Bb	3,300 ± 400Bb
Other oak	4,800 ± 500Ab	2,075 ± 180Bc	1,950 ± 200Bd
Pin cherry	1,500 ± 100Ad	1,325 ± 100Ad	0 ± 0Bg
Red maple	10,600 ± 700Aa	5,550 ± 400Ba	2,400 ± 350Cc
Sweet birch	2,900 ± 350Ac	1,650 ± 175Bd	1,450 ± 150Be
Sugar maple	225 ± 125Ad	200 ± 25Af	0 ± 0Bg
Serviceberry	850 ± 50Ae	925 ± 75Ae	725 ± 60Af
Yellow-poplar	385 ± 50Af	1,350 ± 150Bd	1,050 ± 200Be
Miscellaneous	450 ± 50Af	1,350 ± 200Bd	1,150 ± 150Be
Total seedlings	38,035 ± 5000A	25,075 ± 3000B	18,150 ± 2,000C

Table 2.—Stocking (mean proportion of plots ± 1 standard error) of hardwood seedlings by species, treatment, and year. Pretreatment year is 2003 while 2007 and 2010 are after the first and second burns, respectively. Means followed by different uppercase letters are different within that row while those followed by different lowercase letters are different within that year and treatment.

Species or group	2003	2007	2010
	Control treatment		
American beech	6 ± 2Ae	4 ± 1Ag	5 ± 1Af
Black cherry	74 ± 8Ab	78 ± 7Ab	84 ± 8Aa
Cucumber tree	29 ± 2Ac	30 ± 2Ad	32 ± 2Ad
Northern red oak	75 ± 7Ab	61 ± 5Bc	48 ± 7Cc
Other oak	25 ± 2Ac	24 ± 2Ae	17 ± 2Be
Pin cherry	10 ± 1Ad	12 ± 1Af	7 ± 1Bf
Red maple	95 ± 4Aa	94 ± 5Aa	96 ± 3Aa
Sweet birch	72 ± 5Ab	69 ± 3Abc	68 ± 5Ab
Sugar maple	5 ± 1Ae	6 ± 1Ag	8 ± 1Af
Serviceberry	30 ± 3Ac	33 ± 3Ad	35 ± 5Ad
Yellow-poplar	5 ± 1Ae	6 ± 1Ag	3 ±1Ag
Miscellaneous	14 ± 2Ad	18 ± 3Af	15 ± 2Ae
	Spring burn treatment		
American beech	8 ± 1Ae	10 ± 1Ae	11 ± 1Ae
Black cherry	74 ± 8Ab	70 ± 9Aa	69 ± 7Aa
Cucumber tree	26 ± 2Ac	36 ± 5Ac	19 ± 1Bd
Northern red oak	74 ± 7Ab	73 ± 6Aa	74 ± 7Aa
Other oak	29 ± 2ABc	24 ± 2Bd	34 ± 2Ac
Pin cherry	10 ± 2Ae	9 ± 1Ae	0 ± 0Bg
Red maple	96 ± 4Aa	79 ± 9Ba	55 ± 5Cb
Sweet birch	68 ± 8Ab	54 ± 5Bb	51 ± 5Bb
Sugar maple	7 ± 1Ae	3 ± 1Bf	0 ± 0Cg
Serviceberry	32 ± 2Ac	50 ± 5Bb	33 ± 3Ac
Yellow-poplar	7 ± 1Ae	11 ± 1Be	6 ± 1Af
Miscellaneous	18 ± 2Ad	34 ± 2Bc	44 ± 5Cb

Table 3.—Heights (mean feet ± 1 standard error) of the tallest hardwood seedling by species, treatment, and year. Pretreatment year is 2003 while 2007 and 2010 are after the first and second burns, respectively. Means followed by different uppercase letters are different within that row while those followed by different lowercase letters are different within that year and treatment.

Species or group	2003	2007	2010
Control treatment			
American beech	2.2 ± 2.8Ac	4.4 ± 2.0Ac	5.0 ± 2.8Acd
Black cherry	5.2 ± 2.0Ab	8.7 ± 2.8Ab	8.4 ± 2.0Abc
Cucumber tree	1.5 ± 2.0Ac	2.0 ± 2.0Ad	3.2 ± 2.2Ad
Northern red oak	1.4 ± 2.0Ac	3.1 ± 2.0Ad	2.8 ± 2.0Ad
Other oak	1.5 ± 2.2Ac	2.4 ± 2.3Ad	2.7 ± 2.0Ad
Pin cherry	9.9 ± 2.3Aa	12.9 ± 2.0Aa	17.2 ± 2.3Ba
Red maple	5.1 ± 2.0Ab	10.4 ± 2.0Ba	11.6 ± 2.3Bb
Sweet birch	10.0 ± 2.3Aa	14.9 ± 2.8ABa	18.0 ± 3.5Ba
Sugar maple	2.4 ± 0.5Ac	2.6 ± 0.5Ad	3.3 ± 0.5Ad
Serviceberry	2.3 ± 1.0Ac	3.3 ± 1.1ABd	4.5 ± 1.5Bd
Yellow-poplar	3.6 ± 2.8Abc	5.6 ± 2.5Ac	3.9 ± 2.0Ad
Miscellaneous	2.3 ± 2.3Ac	8.1 ± 3.2Bb	6.5 ± 2.5ABcd
Spring burn treatment			
American beech	1.8 ± 1.3Ac	2.2 ± 1.2Aa	2.8 ± 1.0Aa
Black cherry	5.7 ± 2.8Abc	3.9 ± 1.4Aa	4.0 ± 2.0Aa
Cucumber tree	1.8 ± 2.0ABc	2.0 ± 0.5Aa	3.2 ± 0.7Ba
Northern red oak	1.3 ± 2.0Ac	2.3 ± 1.3Aa	3.6 ± 1.4Ba
Other oak	1.5 ± 2.0Ac	2.5 ± 1.8ABa	3.3 ± 1.2Ba
Pin cherry	9.7 ± 2.5Ab	2.9 ± 1.0Ba	0.0 ± 0Cb
Red maple	7.2 ± 1.5Ab	4.2 ± 4.0Aa	2.8 ± 3.5Ba
Sweet birch	13.2 ± 2.3Aa	7.0 ± 5.7Ba	3.9 ± 1.5Ca
Sugar maple	1.8 ± 0.2Ac	0.3 ± 0.2Bb	0.0 ± 0Bb
Serviceberry	2.7 ± 1.0Ac	2.6 ± 0.5Ba	2.5 ± 0.6Aa
Yellow-poplar	2.7 ± 1.5Ac	5.6 ± 1.5Aa	2.7 ± 2.0Aa
Miscellaneous	1.5 ± 0.5Ac	2.7 ± 2.0Aa	2.5 ± 1.5Aa

The first spring fire reduced the heights of the tallest seedlings for some species while others had increased height or no change by the third growing season postburn (Table 3). The species with the most height loss were pin cherry, red maple, sweet birch, and sugar maple. Species increasing in height were northern red oak, other oaks, and yellow-poplar while other species did not change in height. Among species, sugar maple was the shortest, 0.3 feet, and all others were taller, ranging from 2.0 feet (cucumber tree) to 7.0 feet (sweet birch). In the control treatment, red maple joined pin cherry and sweet birch in the tallest stratum and yellow-poplar and miscellaneous hardwoods moved into the intermediate stratum.

Three years after the second spring burn, overall seedling densities declined another 28 percent, from 25,075 to 1,8150 seedlings per acre (Table 1). Losses were concentrated in pin cherry and sugar maple (100 percent for each), red maple (57 percent), black cherry (16 percent), and sweet birch (12 percent). Seedling densities for the oaks and other hardwood species were relatively unchanged from the previous inventory. In the control, seedling densities declined another 14 percent, from 31,000 to 26,850 seedlings per acre, with most of this loss occurring with northern red oak (50 percent) and the other oaks (33 percent).

After the second burn, stocking of most hardwood species showed little change from their 2007 levels (Table 2). Three that declined were cucumber tree (36 to 19 percent), red maple (79 to 55 percent), and serviceberry (50 to 33 percent). Conversely, stocking of miscellaneous species increased from 34 to 44 percent. Herbaceous cover remained unchanged from the previous inventory, 50 percent.

Heights among species in the spring burn treatment became quite uniform after the second prescribed fire (Table 3). They ranged from 2.5 feet (serviceberry and miscellaneous species) to 4.0 feet (black cherry and sweet birch) with no differences detected among species. In the control, pin cherry and sweet birch were the tallest at 17.2 and 18.0 feet, respectively, followed by red maple (11.6 feet) and black cherry (8.4 feet). The tallest seedlings of all other species ranged in height from 2.7 feet (other oaks) to 6.5 feet (miscellaneous hardwoods).

DISCUSSION

The upland mixed-oak forests of the ANF epitomize the oak regeneration problem of Pennsylvania and much of the mid-Atlantic region. These forests were born a century ago due to a unique disturbance regime that included multiple harvests, periodic fire, and no deer impact (Marquis et al. 1975). This study intended to test whether that disturbance regime could be recreated by using the shelterwood-burn technique in conjunction with deer fencing. If successful, the ANF would have another tool in its silvicultural toolbox with which to sustainably manage upland mixed-oak forests. Conversely, failure would either eliminate the technique as a viable method or at least expose key caveats important to its successful usage. To date, the results indicate a conditional success; the competitive status of the oak reproduction was improved, but long-term success is not yet assured because of some mitigating circumstances.

Prior to burning, red maple and sweet birch dominated the understory stratum. They made up 35 percent of the seedling population and their seedlings were taller than those of the other species, especially the oaks. This is a common situation in upland mixed-oak forests throughout the region (Albright et al. 2017). Both species can accumulate in the understories of undisturbed oak stands and birch can readily invade during or after regeneration harvests due to its minute wind-blown seeds (Lamson 1990, Walters and Yawney 1990). Harvesting without the concurrent use of prescribed fire exacerbates this situation as demonstrated by the control treatment in this study. At the beginning of the project in 2001, all stands were well on their way to becoming mixed hardwood stands dominated by red maple and sweet birch. Seven years later, this situation had become more pronounced in the unburned blocks as density/stocking of red maple and sweet birch held steady while the heights of their tallest stems doubled. Clearly, harvesting upland mixed-oak stands on the ANF without addressing the aggressive reproduction of red maple and sweet birch will lead to forest type conversion and a loss of the ecologic and economic values contributed by the oaks.

The two spring prescribed fires have stalled, at least temporally, the conversion of the burned portions of these stands to red maple/sweet birch dominance. The burns drastically reorganized the relative composition and dominance of the seedling pool; densities of red maple and sweet birch declined by 77 and 50 percent, respectively. Additionally, their distributions were reduced so they were no longer widespread throughout the burned areas. The two burns eliminated the initial disparity in heights among the hardwood seedlings as the reproduction of all species was between 2.5 and 4.0 feet tall after the second burn. The two fires also evened the relative abundance of the species mix of the regeneration pool. Of the 18,150 seedlings that survived both burns, nearly 30 percent were oak while just 21 percent were red maple and sweet birch.

A large loss of oak seedlings in both treatments occurred throughout the study. In the unburned control, oak seedling densities dropped by 77 percent, from 11,845 to 2,750 stems per acre. In the spring burn treatment, the oak seedling loss was 63 percent, from 14,350 to 5,250 stems per acre. This massive die-off is likely due to a large majority of the seedlings being recent germinants from the fall 2001 bumper acorn crop (Brose 2011, Miller et al. 2017). New oak seedlings are subject to numerous factors that can cause substantial mortality (Brose 2011). In the unburned controls, the oak seedlings likely succumbed to constant dense shade during the growing seasons and periodic browsing by deer. In the prescribed fire blocks, the oak seedlings were just 3 years old at the time of the first burn and had been growing in dense shade their entire lives. They had small roots and such oak seedlings are quite susceptible to being killed by hot spring fires (Miller et al. 2017). Generally, oak reproduction larger than 2 feet tall sprouted postfire, suggesting that they had adequately sized roots to withstand topkilling by fire.

Regarding other hardwood species, reproduction of black cherry, cucumber tree, and serviceberry (three important species with relatively unknown fire ecologies) experienced little mortality, indicating that these species are tolerant of periodic mid-spring prescribed fires. Black cherry is a high-value timber species while all three are important providers of soft mast. Pin cherry and sugar maple seedlings disappeared from the sampling plots after the second burn although they were still present elsewhere in the prescribed fire treatment areas. The loss of pin cherry is surprising given that it is also known as fire cherry (Wendel 1990), a pioneer species that regenerates from buried seed after burning. However, pin cherry is highly desired browse by whitetail deer, and deer incursion into all stands was a chronic problem throughout this study. It is likely that they simply browsed the pin cherry seedlings into oblivion. Also, the salvage cutting and the first prescribed fire may have exhausted the seed bank resulting in few pin cherry germinants after the second burn. The loss of sugar maple was not surprising as this is a species quite sensitive to fire (Godman et al. 1990). American beech, miscellaneous species, and yellow-poplar reproduction increased in densities in the burned areas during the course of the study. For beech, the increase was due to root suckering while the increase in miscellaneous species was driven by proliferation of aspen (*Populus* spp.) and sassafras (*Sassafras albidum*) from root sprouts or buried seed. The increase in yellow-poplar seedlings can be traced to retention of mature trees within the fire treatment blocks that served as seed sources. Finally, fern and grass coverage did not substantially change due to the fire treatments. Apparently, prescribed fire is not a viable approach for controlling these species groups due to their underground rhizomes or soil seedbank longevity (Horsley 1981).

It should be noted that none of these stands had been managed prior to the spring prescribed fires in a manner consistent with the guidelines of the shelterwood-burn technique. In that method, stand stocking is reduced to approximately 50 percent with the cut removing all or nearly all of the midstory stratum (Brose et al. 1999b). Enough overstory trees are removed so that about 50 percent sky is visible. Then 4 to 7 years must pass so that (1) the oak seedlings have sufficient time to develop large enough root systems so their mortality will be minimal; (2) the logging slash can dry and decompose to some degree so that desirable fire intensities can be achieved; (3) leaf litter and other fine fuels can re-accumulate so that the prescribed fire readily spreads; and (4) competing mesophytic hardwood seedlings are beginning to overtop the oak reproduction. In these stands, the midstory was not removed during the harvests and overstory harvesting was based on defoliation-mediated mortality, not creating

50 percent open canopy. Also, the time between the harvests and the first burn was 10 to 15 years. Consequently, the logging slash was quite decomposed likely limiting fire intensities. Additionally, some of the pin cherry, red maple, and sweet birch seedlings had grown large enough to withstand surface fires as well as produce seed. Finally, fence maintenance was lacking; deer intrusion into all the fences was a chronic problem and probably influenced vegetative responses.

In summary, the shelterwood-burn technique appears to be a viable tool for sustaining the upland, mixed-oak forests of the ANF and elsewhere in northern Pennsylvania. The larger oak seedlings readily survive hot, mid-spring prescribed fires and exhibit reasonable height growth postfire. The reproduction of important associate species such as black cherry, cucumber tree, and serviceberry are also strong sprouters postfire. Conversely, sweet birch (the primary undesirable species) is not a strong sprouter, although enough may survive in refugia to facilitate competition problems later in stand development.

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FOREST MANAGEMENT AND PLANNING

Using Historical Reconstructions of Moist Mixed Conifer Forests to Inform Forest Management on the Malheur National Forest

Amanda A. Lindsay and James D. Johnston[1]

ABSTRACT.—The Malheur National Forest works collaboratively with diverse stakeholders to accelerate the pace and scale of forest restoration. Both informal joint fact-finding, empirical research, and multi-party monitoring are used to inform planning and adjust implementation of restoration treatments in an adaptive management framework. Knowledge of historical dynamics is often used to guide restoration on the Malheur because scientists, managers, and stakeholders believe restoring forest structure and composition to the historical range of variability will make forests more resilient to future climate and disturbance regimes. There is a strong shared understanding of the role of frequent, low-intensity fire in fostering resilience of dry, ponderosa pine dominated forests. However, there has been little empirical research describing historical disturbance dynamics in moister landscape settings. USDA Forest Service silviculturists and researchers from Oregon State University investigated historical fire patterns, forest structure, and composition in moist mixed conifer stands on the Malheur National Forest. The findings of this partnership demonstrate that moist mixed conifer forests historically experienced similar fire return intervals, had similar basal area, and in most cases are more departed from historical conditions than dry ponderosa pine forests. Tools were also developed to aid in selection of large-diameter, fire-intolerant species for removal. This research and ongoing fact-finding and dialogue with stakeholders have been used to adapt silvicultural prescriptions over time. A multi-party monitoring program is being implemented to answer stakeholder questions about the effects of restoration treatments, while generating baseline data to answer questions about intermediate and long-term environmental effects.

INTRODUCTION

Congressional legislation including the Healthy Forest Restoration Act of 2003 and the Collaborative Forest Landscape Restoration Program (CFLRP) (16 USC §6501 et seq., 16 USC §7303 et seq) directs the Forest Service to reduce fuels and foster resilient forest conditions (Stephens et al. 2016, USDA Forest Service 2012). The Malheur National Forest (MNF) in the southern Blue Mountains of eastern Oregon (Fig. 1) has met this challenge by working with the Blue Mountains Forest Partners (BMFP) and Harney County Restoration Collaborative (HCRC) to secure $4 million annually under the CFLRP to accomplish accelerated forest restoration treatments within an 800,000-acre area within the MNF boundary (Schultz et al. 2012).

Use of the best available science is critical to maintaining the support of diverse stakeholders for accelerated restoration (Shindler et al. 2004). Informal joint fact-finding with the BMFP and HCRC, empirical research, and multi-party monitoring contribute to an adaptive management cycle in which managers and collaborative stakeholders are learning from restoration treatments and adjusting management practices accordingly.

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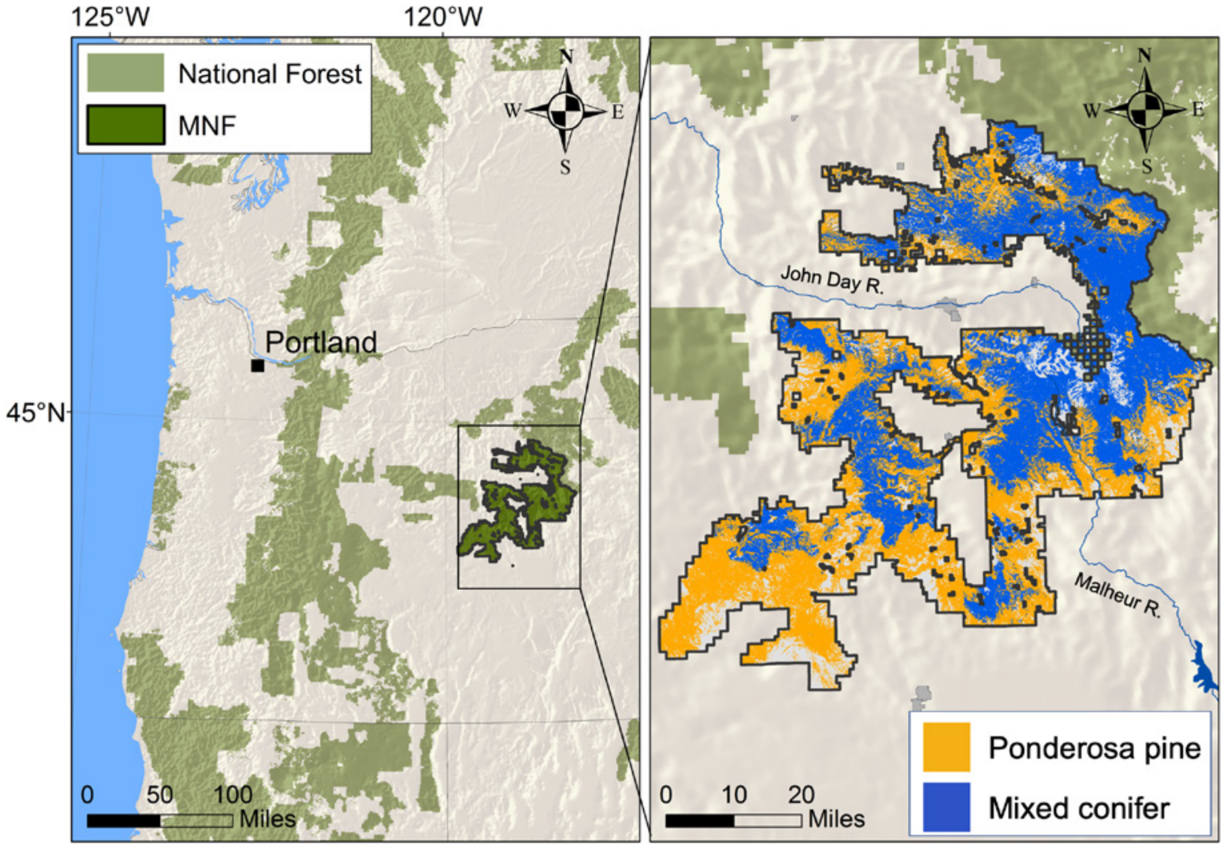

Figure 1.—Ponderosa pine and mixed conifer distributions across the Malheur National Forest in the Blue Mountains of eastern Oregon.

MNF projects generally seek to restore historical structure, composition, and disturbance processes because restoring historical conditions lowers fire risk and promotes resilience to anticipated future climate and disturbance regimes (Franklin and Johnson 2012). There is also strong stakeholder support for returning forests to their natural, presettlement condition (Cannon et al. 2018, Hessburg et al. 2015, Shindler and Mallon 2009, Thompson et al. 2009, Urgenson et al. 2017).

Researchers, managers, and the general public have a strong shared understanding of the role of frequent low-intensity fire in fostering resilience of dry ponderosa pine (*Pinus ponderosa*) dominated forests. They also have strong agreement around the historical structure and composition that frequent fire created and maintained across the landscape (Brown et al. 2004, Stephens et al. 2015). Early collaborative projects on the MNF focused on shared agreement around restorative actions in dry ponderosa pine forests. However, as restoration efforts were accelerated with augmented funding, it was necessary to plan projects within moist mixed conifer forests (Stine et al. 2014, Tiedemann et al. 2000). This forest type is found on deeper ash soils and cooler and moister aspects and is currently dominated by grand fir (*Abies grandis*), with smaller components of Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine, western larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), and western white pine (*Pinus monticola*). Grand fir, Douglas-fir, and Engelmann spruce are less fire tolerant late seral species on the MNF, while ponderosa pine and western larch are highly fire tolerant early seral species.

A critical challenge to restoring historical conditions is being able to identify trees that established before Euro-American settlement disrupted frequent fire that maintained open stands of early seral, fire tolerant species. The Regional Forester's Eastside Forest Plan Amendment 2 (USDA Forest Service 1995), also known as the "Eastside Screens," amended the Forest Land and Resource Management plans of eastern Oregon and Washington NFs to generally prohibit the harvest of live trees greater than or equal to 21 inches diameter at breast height (d.b.h.) Since this amendment, the MNF has shifted from a focus on timber production to a focus on forest restoration with timber removal being a byproduct of restoration activities. To accomplish forest restoration, younger trees that have established since fire suppression often need to be removed, while trees 150 years of age and older need to be conserved to provide old forest structure. However, it became evident over time that many late seral trees that had become established since the beginning of fire suppression often grow rapidly, exceed 21 inches d.b.h., and need to be removed to accomplish restoration goals. Late seral trees contribute to the death of large, old early seral trees by competing for resources and promoting spread of contagious disturbances like fire and insects. They also exacerbate drought stress by transpiring water at proportionately higher rates, providing proportionately higher shade, and casting large amounts of seed when compared to early seral trees.

In response to this management situation, several dendroecological research projects and a multi-party monitoring program have been undertaken to determine:

- To what extent did fire historically shape moister mixed conifer forests?
- What magnitude of change has occurred in moister mixed conifer forests since fire suppression?
- How do managers identify trees to be removed in order to restore historical conditions?
- How are forests responding to treatments over time?

METHODS

Dendroecological Research

Two empirical research studies were conducted to answer the first three questions above. The first study (Johnston et al. 2017) reconstructed historical fire occurrence using fire-scarred trees to characterize historical fire-climate relationships and to determine if climatic influences on fire differed among dry ponderosa pine sites and more productive grand fir sites. The second study (Johnston 2017) used dendro-ecological methods to quantify historical structure and composition in diverse forest types and to describe the magnitude and direction of succession in these forest types in the absence of fire.

To address the shortcomings of diameter-based tree retention guidelines under the eastside screens, the MNF worked with collaborators and researchers to develop a multi-variable system for quickly aging trees in the field based on morphological characteristics that could be incorporated into restoration contracts. Guidelines for identifying old trees published by Van Pelt (2008) are helpful for this purpose and were initially used for projects on the MNF to determine old trees, and allow for the removal of young, late seral trees greater than or equal to 21 inches d.b.h. These guides work well for all species being removed on the MNF, except grand fir, which is the most common species in need of removal for restoration purposes.

Figure 2.—USDA Forest Service managers and members of the BMFP and HCRC discuss the results of thinning treatments on a field trip. Photos by James Johnston, Oregon State University, used with permission.

Multi-Party Monitoring and Adaptive Management

BMFP and HCRC staff and volunteers organize regular (usually once a month during spring-fall) meetings, workshops, and field trips to explore treated areas and develop recommendations for changes to silvicultural prescriptions (Fig. 2). These recommendations are memorialized in technical papers and "zones of agreement" documents that inform National Environmental Policy Act (NEPA) planning.

The BMPF, HCRC, MNF, and Oregon State University have also partnered to create a forest vegetation and fuels monitoring program that is currently monitoring changes to forest structure and composition, surface fuels, and understory vegetation in approximately 500 systematically located plots in 72 random located units of 12 MNF planning areas. Plot based monitoring will allow managers and stakeholders to answer a variety of questions about the effects of treatment, including but not limited to:

- How does treatment affect surface fuel accumulation over time?
- How does treatment affect future fire, drought, and insect disturbance patterns?
- What natural regeneration results from different treatment intensities in different landscape settings?
- What density of trees and what tree species can persist over time in different landscape settings under different climate and disturbance regimes?
- How do "leave" patches and openings respond over time to treatment?

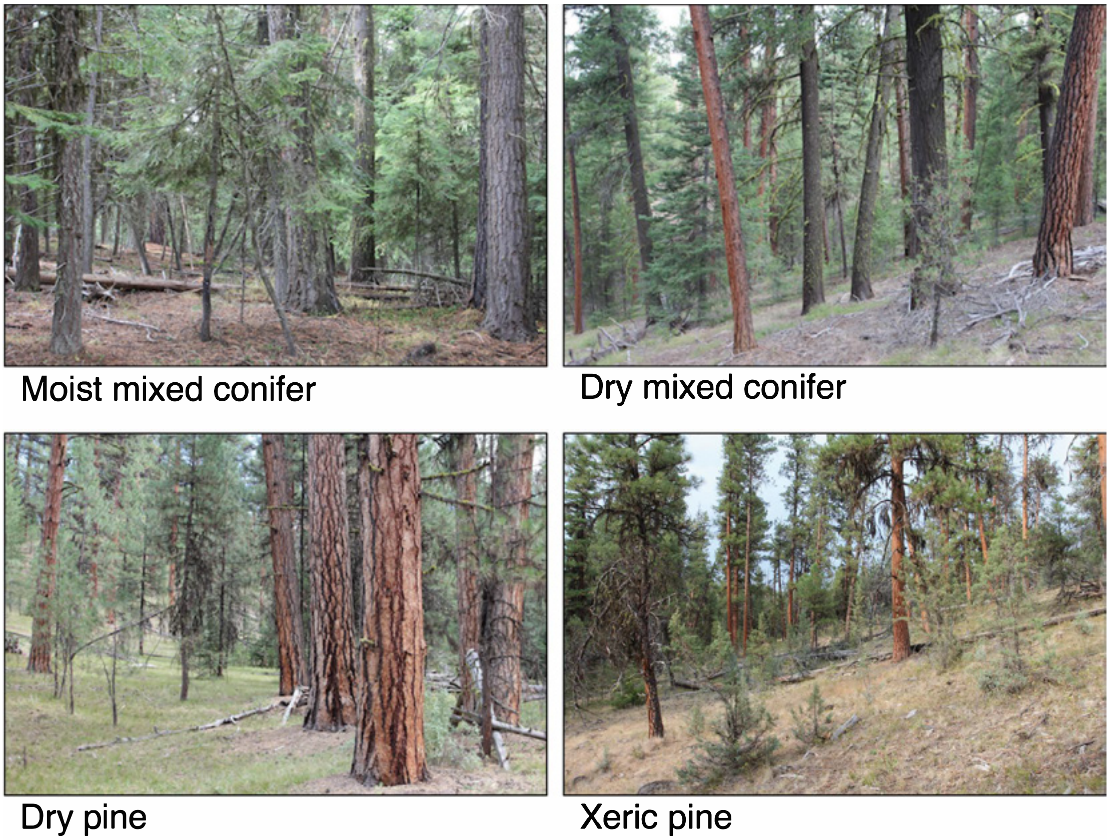

Figure 3.—Examples of different forest types found on the Malheur National Forest. Photos by James Johnston, Oregon State University, used with permission.

RESULTS

Dendroecological Research

Johnston et al. (2017) found that historical (1650–1900) mean fire return intervals (MFRIs) for dry ponderosa pine sites ranged from 10.6 years to 18.4 years, which was not statistically significantly different than MFRIs for moist grand fir sites that ranged from 11.8 years to 21.2 years. The authors also found there was no difference in reconstructed temperature or precipitation in historical fire years across dry ponderosa pine and moist grand fir sites on the MNF. Based on these results, the authors concluded that even though moist grand fir sites are inherently more productive than dry ponderosa pine sites, both forest types were historically fuel-limited systems that burned whenever ignitions coincided with fuel sufficient to carry fire.

Johnston (2017) classified the MNF into four forest types based on historical conditions and stand structures: (1) old-growth pine (stands dominated by pines over 300 years old); (2) transitional pine (stands dominated by younger pine); (3) dry mixed conifer (stands historically dominated by pine with some Douglas-fir, grand fir, and western larch); and (4) moist mixed conifer (stands historically dominated by western larch, Douglas-fir, and grand fir) (Fig. 3). Although the pine types differed from the mixed conifer types with respect to soil water availability, summer vapor pressure deficits, and contemporary tree biomass, this study found that in 1880 there was no statistically significant difference in tree basal area (BA) between these forest types. Although BA in all forest types has increased in the past 150 years, grand fir settings have experienced a far greater change in species composition and forest density than ponderosa pine settings (Figs. 4 and 5).

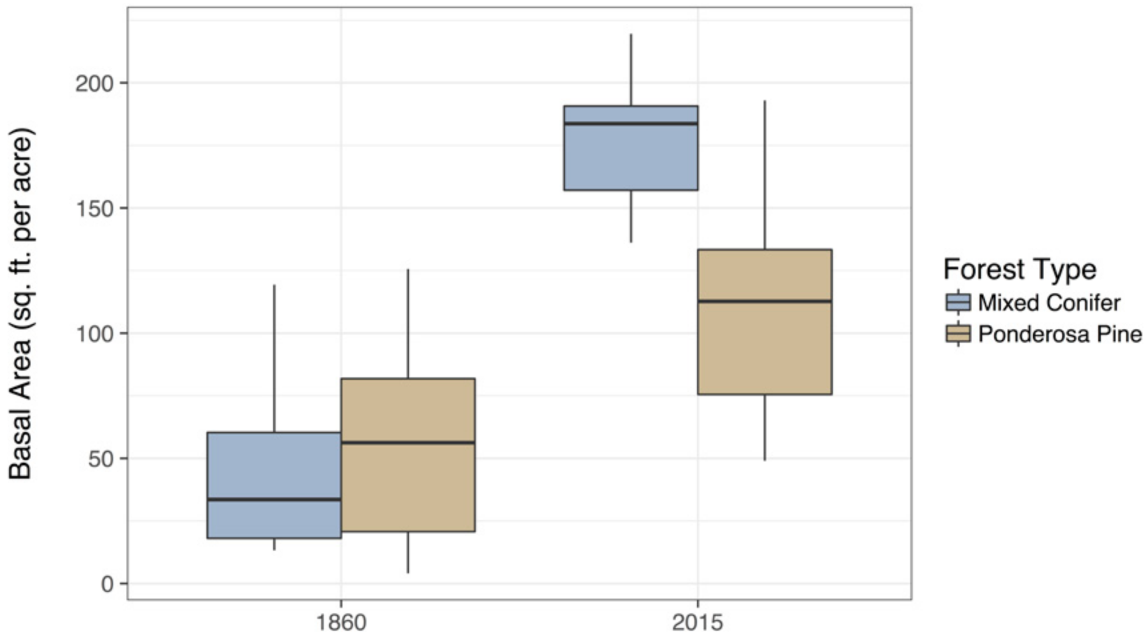

Figure 4.—Difference in basal area between mixed conifer and ponderosa pine in 1860 and 2015.

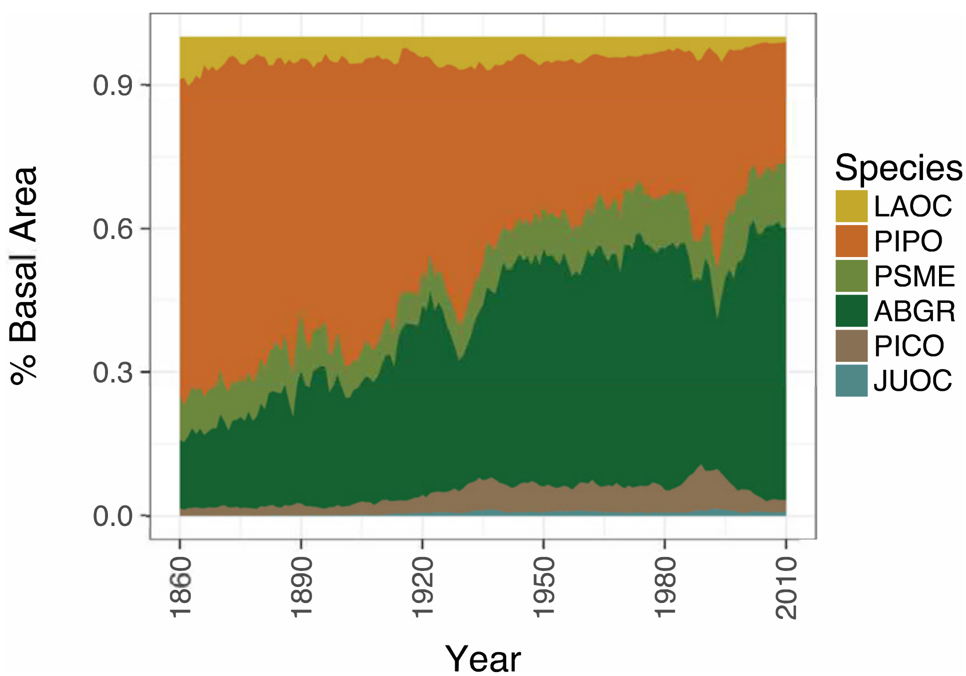

Figure 5.—Change in reconstructed species composition in mixed conifer stands over time. Legend refers to species' Latin names: LAOC= western larch; PIPO = ponderosa pine; PSME = Douglas-fir; ABGR = grand fir; PICO = lodgepole pine; and JUOC = western juniper.

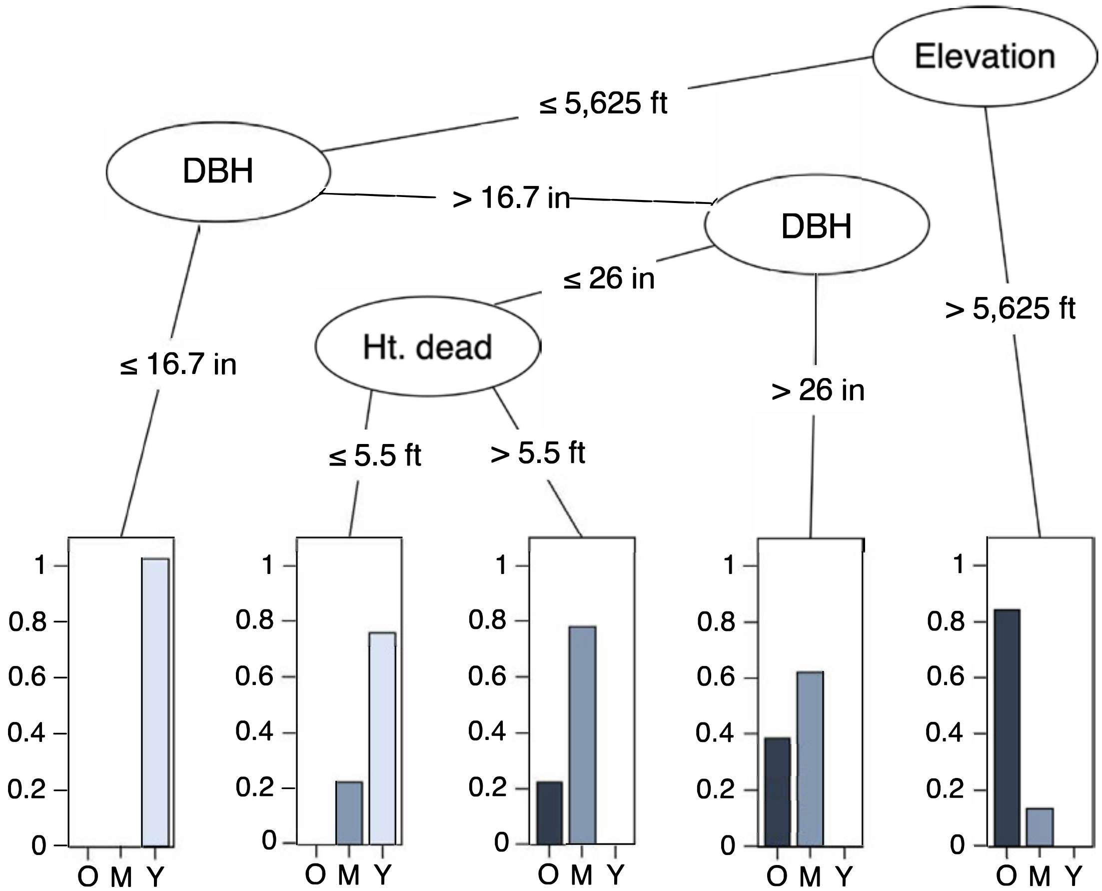

Figure 6.—Example of a conditional inference decision tree to determine the relative age of Douglas-fir based on elevation, d.b.h., and height to dead branches. O = old (older than 175 years old); M = mature (175–125 years old), Y = young (less than 125 years old).

Johnston et al. (2018) found that variables such as elevation, tree height to live foliage, and height to dead branches can be good predictors of grand fir and Douglas-fir age (Fig. 6), the two most common shade tolerant and relatively fire intolerant species targeted for removal by restoration treatments. These variables are also easy to measure in the field and incorporate into silviculture prescriptions. Moist mixed conifer treatments are now being planned using the Van Pelt (2008) guidelines for aging early seral trees and using the variables determined by Johnston et al. (2018) for aging late seral trees. These variables include species, d.b.h., elevation, height to live foliage, and height to lowest dead limb.

Monitoring and Adaptive Management

Initial moist mixed conifer treatments accomplished resilience goals through commercial thinning, noncommercial thinning, and fuel treatments. Commercial thinning prescriptions included a variable density thinning matrix with created openings and leave patches. The goal of variable density thinning was to decrease stand density while maintaining a multi-storied stand after treatment to provide for vertical structure. The specifications for variable density thinning included:

- Thin approximately 55 to 75 percent of each unit by thinning throughout the diameter range to a target of 60 to 140 square feet per acre BA.
- Leave approximately 15 to 35 percent shade tolerant and relatively fire intolerant trees and 65 to 85 percent shade intolerant and fire tolerant trees.

The goals of openings were to (1) regenerate early seral species either through natural regeneration or planting and (2) provide opening sizes that were consistent with historical stand replacement patches created by wildfire. Specifications for openings included:

- Approximately 10 to 20 percent of each treatment unit will be in one or more openings.
- Openings will be 1 to 10 acres in size and will leave 0 to 40 square feet per acre BA of healthy, shade intolerant and fire tolerant trees.

The goals of leave patches were to provide the best available wildlife habitat, protect resources, and maintain forest structure in moist areas. The specifications for leave areas included:

- Approximately 15 to 25 percent of each treatment unit will be left unthinned.
- Patches will be 1 to 10 acres in size.
- Leave patches in areas that would have historically had the potential to be skipped over during a fire event or that provide specific wildlife habitat.

Noncommercial thinning included thinning of small trees to meet preference standards of keeping shade intolerant and fire tolerant species and removing shade tolerant and relatively fire intolerant species. Fuels treatments included piling and burning of piles.

The BMFP and HCRC have undertaken more than 40 field trips, meetings, and workshops to assess restoration treatments over the past 3 years. This work led to the realization that the initial moist mixed conifer treatments undertaken were not adequately shifting species composition from shade tolerant and relatively fire intolerant species to shade intolerant and fire tolerant species, or creating spatial heterogeneity at fine spatial scales. It was evident that both tree markers and equipment operators selecting cut and leave trees tended to create the same target BA at fine spatial scales across the stand resulting in relatively even-spaced residual tree structure despite the variability built into prescriptions.

Moist mixed conifer prescriptions for commercial thinning are now being developed that do not specify BA targets, but instead specify leave tree requirements in which all trees not meeting requirements are removed. Specifications include leaving all old trees, all shade-intolerant and fire-tolerant trees greater than or equal to 21 inches d.b.h., all trees within 30 feet of old grand fir and Douglas-fir, all healthy early seral trees, wildlife trees, and all Douglas-fir within 30 feet of ephemeral draws. Although this leave-tree prescription has not been implemented yet, sample marking conducted within the project area resulted in increased spatial heterogeneity and fewer late seral trees, while still maintaining a similar BA as the targets specified in the initial moist mixed conifer treatments.

DISCUSSION

Results from dendroeclogical studies align with similar studies in the dry forests of central and eastern Oregon and Washington (Hagmann et al. 2014, Merschel et al. 2014, Merschel et al. 2018). Taken together, managers have strong confidence that shifts in stand structure, density, and species composition have occurred across almost all forest types found in eastern Oregon. Fire suppression, historical logging and overgrazing, and a cooler and moister climate were the important drivers of forest change over the past century and a half (Hessburg et al. 2005). Frequent, low-severity fire was historically the dominant disturbance factor across the landscape that tended to equalize forest structure and composition across a wide range of productivity gradients. Current fire patterns have changed from historical conditions: Instead of large, low-severity fires that burned at frequent intervals, the MNF is now experiencing smaller, less frequent, and more severe fires.

Goals of landscape restoration projects on the MNF include shifting the landscape back toward the historical range of variability and improving forest resiliency to disturbance. Accomplishing these goals involves treatments to reduce fuel loadings, reduce tree density, shift species composition from late seral to early seral species, protect old trees and old-growth conditions, and increase spatial heterogeneity at fine and coarse scales. Treatments have been developed over the past 10 years to address this need on moist mixed conifer sites, and these treatments have evolved through an adaptive management process involving USDA Forest Service managers and the BMFP and HCRC.

Mechanical fuel reduction is accomplished by thinning trees, removing ladder fuels, and piling and burning slash generated by thinning. However, after all of these treatments are completed, there is still the need to reduce fine fuels and restore fire cycles on the landscape. The MNF accomplishes this objective through prescribed burning in the spring and fall. Although the MNF has a fairly aggressive prescribed fire program, it has become evident that because of narrow burn windows and a declining workforce and budget, the Forest is not keeping up with the amount of prescribed fire needed to restore fire as a natural process across the landscape. At the current rate of burning, it will take over 150 years to prescribe burn the entire forest once, while Johnston et al. (2017) demonstrated that fire return intervals were much shorter than that.

The BMFP, HCRC, and MNF are working closely with the State of Oregon regulatory agencies to widen the weather parameters during which prescribed burning can occur. Managing wildfire is also being planned during environmental analysis of large landscape projects to increase the amount of burning that can be accomplished each year. Several considerations inform the decision to directly attack and extinguish a wildfire or manage it for restoration purposes. These considerations include weather forecasts, fuel densities and conditions, threats to property and structures, firefighter safety, and adequate holding lines. Restoration projects on the MNF have the long-term goal of restoring large enough blocks of land that managed wildfire can be used to help restore and maintain fire across the landscape at a rate that is closer to historical fire cycles.

CONCLUSIONS

Where restoration of historical conditions is a goal of forest management on national forests, it is critical to understand historical disturbance processes and the composition and structures those processes developed and maintained. Partnerships among managers, researchers, and collaborative groups have helped to inform management prescriptions for moist mixed conifer on the MNF and built understanding and agreement around the need for restoration and the types of treatments in this forest type. Monitoring of the effects of restoration treatments will help to inform the adaptive management process and refine management practices around restoration. All of this work was conducted within the MNF boundary, and although similar studies have been conducted within eastern Oregon and Washington, local information and science is important for developing the social license around site-specific prescriptions in controversial forest types.

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GENETICS, FOREST THREATS, AND REINTRODUCTIONS

A New Look at Some Old Shortleaf Pine Progeny Tests: Lessons for Silvicultural Opportunities Through Partnerships

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ABSTRACT.—Starting in the 1980s, 155 shortleaf pine progeny tests were established by the USDA Forest Service on national forests across the range the species. Originally intended to support the agency's timber management program (post-clearcutting and subsequent reforestation with planting), these progeny tests were largely abandoned as the Forest Service's forest management policies changed. Over the years, some of these shortleaf pine progeny tests were lost to natural disturbances or harvested, but many still remain as more-or-less intact outplantings. Recently, large-scale planting needs to support shortleaf pine restoration on public lands has reignited interest in these established progeny tests, spurring the Southern Region (with the assistance of the Southern Research Station) to take another look at them.

Recently, the Southern Region's Forest Management Unit and the Southern Research Station (SRS) have partnered to reevaluate some shortleaf pine (*Pinus echinata*) progeny tests established in the 1980s and early 1990s in Arkansas and Oklahoma (Hossain et al., in press). Although not established as a research trial, the progeny tests that remain in good condition still retain useful information that can help managers address concerns with this declining species across its natural range. This may be particularly true if new DNA marker technology can shed further light on the genetic nature of these shortleaf pine families, or if sufficient numbers remain to make statistical comparisons of growth and yield performance. If successful, the partnership between the Southern Region and SRS may be expanded regionally to include more progeny tests on other national forests, with emphasis placed on the subregions (e.g., southern Appalachians, Piedmont) that have experienced the most dramatic declines in shortleaf abundance.

To date, staff of the SRS and Ouachita and Ozark–St. Francis National Forests have investigated dozens of these progeny tests and have formally resampled 14 of these tests. Field sampling began in 2018 and will continue into at least the fall of 2019, with limited assessments conducted to date (for example, Hossain et al. 2020; Hossain et al., in press). From this analysis, we can make a few preliminary assessments on the potential of this effort for this paper.

First, although many of these progeny tests were not logged or destroyed by natural disturbances, some had received enough damage from past harvests, fires, ice storms, beetles, and other forest health problems that we chose not to sample them because too few families remained sufficiently intact. For instance, many—if not most—of the pines in these progeny tests had been impacted by multiple glaze events that have struck Arkansas and

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Oklahoma in recent decades, causing physical damage to more than 75 percent of all live trees (Hossain et al., in press). This ice damage was substantial enough to affect the quality (form) of the surviving trees and undoubtedly influenced the height performance of most affected individuals, thereby limiting our ability to use height or forking to assess family performance.

Second, while these progeny tests were established following the tree improvement guidelines available at that time (with establishment records, genetic crosses, and planting maps), there are no subsequent management records from these shortleaf pine progeny tests. Hence, we cannot fully reconstruct the decisions after the closure of the tests, nor have we been able to revisit prior analyses (for example, La Farge 1991; Studyvin and Gwaze 2012). Some of the earliest data collected are available in paper form only, and given the sheer volume of records, they cannot readily be reinterpreted. These limitations further constrain our ability to interpret our present-day results. While we will continue to search for this information and attempt to digitize the data as time and resources permit, we will need to ensure that a similar fate does not befall our work.

Finally, it is clear that there are logistical challenges to re-evaluating these progeny tests so long after the initial effort began, which cannot be corrected. However, we still plan to evaluate this effort, as there are few other options for quick answers to questions about which shortleaf pine families are best suited for deployment on the Ouachita and Ozark–St. Francis National Forests. To avoid such logistical challenges in future efforts, partnerships between national forests and research stations need to be better coordinated from the beginning to ensure that large-scale experiments are properly designed, measured, analyzed, monitored, and archived. After all, some large-scale research must be done on national forests, rather than more controlled locations such as established experimental forests. While experimental forests offer a better degree of treatment control, preservation of ongoing studies, and better certainty for the long-term preservation of documentation and data, and their limited spatial extent mean it is not possible to study family performance in progeny tests across the full range of environmental conditions.

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Restoration of the American Chestnut Will Require More Than a Blight-Resistant Tree

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ABSTRACT.—The American chestnut (*Castanea dentata*) was a keystone species that was decimated by nonnative diseases, most notably a fungus (*Cryphonectria parasitica*) that causes chestnut blight disease, during the early 20th century in eastern North America. Breeding for a blight-resistant tree began over 100 years ago, and a backcross breeding approach that incorporated blight-resistant genes from Chinese chestnut (*C. mollissima*) was initiated in the 1980s. Field trials to test pure American chestnuts and hybrid trees from different breeding generations were established from 2009 to 2017. These research plantings were established as a collaborative effort among the USDA Forest Service's National Forest System (Eastern and Southern Regions) and Research and Development (Southern Research Station, Northern Research Station) branches, a state agency (Connecticut Agricultural Experiment Station), state universities (The University of Tennessee, The University of Vermont), and a nonprofit organization (The American Chestnut Foundation). The goals of this paper were to: (1) summarize the present status of chestnut restoration research plantings established on the NFS using the most advanced breeding material currently available, and (2) summarize NFS field managers' insights on potential obstacles and contributions affecting future restoration efforts.

In the Southern Region, 13 research plantings were established on three national forests (Cherokee, Nantahala, and Jefferson) from 2009 to 2015 to test hybrid seedlings from the most advanced generation (i.e., BC_3F_3) (Clark et al. 2012). Ten plantings were in relatively open sites treated with low residual basal area (BA) shelterwood-with-reserve regeneration harvests and three plantings were in high residual BA stands treated with a midstory removal (Loftis 1990). Survival ranged from 41 to 61 percent for the oldest (age 10) plantings in the shelterwood harvests, where trees averaged 10–16 feet in height after eight growing seasons. Limitations to successful establishment were root rot disease caused by *Phytophthora cinnamomi*, browsing of terminal buds by whitetail deer (*Odocoileus virginianus*), shading by competitors, and chestnut blight disease (Clark et al. 2016). The BC_3F_3 seedlings had higher levels of blight resistance compared to American chestnut seedlings, but were less resistant than Chinese chestnut seedlings (Clark et al. 2019).

In the Eastern Region, 40 research plantings were established on four national forests (Wayne, Allegheny, Monongahela, and Green Mountain) from 2009 to 2017 in a variety of management conditions, but most plantings were in relatively low residual BA regeneration harvests. Four-year old plantings on the Wayne and Allegheny had 29 to 85 percent survival and low blight incidence (less than10 percent). Mortality was attributed to poor drainage and deer browsing. Direct-seeding resulted in substantially lower survival (50 percent) than planting bare-root seedlings (92 percent) after 2 years. Six-year-old plantings on the

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Monongahela had 25 to 53 percent survival, and mortality was primarily related to soil compaction, suspected root rot, and chestnut blight; BC_3F_3 seedlings had blight resistance more similar to Chinese chestnut than American chestnut seedlings (Thomas Van-Gundy et al. 2017). In the Green Mountain planting, 7-year-old pure American chestnut trees had 70 to 90 percent survival, and mortality was affected by shading for trees planted under full canopy conditions and affected by blight for trees planted in open canopy conditions. On a separate planting on the Green Mountain, 5-year-old BC_3F_3 seedlings had 85 percent survival, with mortality related to poor germination and vole damage, as these trees were from direct-seeded nuts.

Feedback from 16 NFS managers in the Eastern and Southern Regions, at the district, forest, and regional level, was received on both potential challenges and assistance to chestnut restoration, and on the cohesion of chestnut restoration with existing policy, plans, and capacity. Major perceived challenges were: (1) uncertain blight resistance levels from external breeding programs (Steiner et al. 2017); (2) mortality from root rot; (3) lack of silvicultural knowledge to implement prescriptions; (4) animal damage (e.g., deer and rabbit [*Sylvilagus floridanus*]) browsing, bear [*Ursus americanus*] nut consumption); and (5) coordinating harvests with availability of planting material. The ability to prioritize chestnut restoration while also conforming to National Environmental Policy Act processes were generally not viewed as obstacles. Some forest plans and decision memos already include chestnut planting and were met with little opposition. Public sentiment for chestnut restoration using hybrid seedlings is generally favorable, although there was some concern that more widespread chestnut restoration might be opposed if concurrent with increased timber harvests. The planting of genetically modified (GM) chestnuts will probably be opposed by some private citizens or nonprofit organizations even if the GM tree is federally approved for release. Managers preferred that chestnut restoration be implemented as part of existing plans of work and not mandated. Adequate funding for planting establishment and associated maintenance (e.g., deer protection, herbicide release) and monitoring of plantings would be required, and there was concern that this might detract from existing underfunded programs of work. Strong partnerships with nongovernmental organizations or volunteer groups already exist, and they could assist with planting implementation and monitoring. The use of Knutson-Vandenberg funds (USDA Forest Service 2019a), traditional contracting, and newly delegated stewardship contracting (USDA Forest Service 2019b) could be utilized where appropriate.

Development of a blight-resistant tree is only part of the solution for restoring this once dominant and ecologically important species. Information gleaned from silvicultural research and collaborative partnerships will improve the efficiency of future restoration; however, challenges from native animals and insects and nonnative pests are not easily mitigated. Important future research questions include: (1) determining differences in cross-site genetic tests; (2) examining the relationships between site quality and silvicultural treatment; and (3) relating seedling quality and stock type to tree competitive abilities over time. Dependent variables should include shoot winter injury, leaf phenology, growth form, and competitive ability, in addition to the more commonly measured variables of survival, growth, and blight resistance. Substantial long-term investments in chestnut restoration have already been made (Clark et al. 2014). Success will require both maintaining existing and developing new partnerships among organizations and agencies in order to maximize existing infrastructural capacities, as resources are limited for long-term research and restoration programs.

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LESSONS LEARNED FROM LONG-TERM SOIL PRODUCTIVITY STUDY

Long-Term Soil Productivity Study: 25-Year Vegetation Response to Varying Degrees of Disturbance in Aspen-Dominated Forest Spanning the Upper Lake States

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ABSTRACT.—Installations of the Long-Term Soil Productivity Study were established in northern Minnesota and Michigan at the Chippewa, Ottawa, and Huron-Manistee National Forests (NFs) in the early 1990s and have since provided a wealth of data for assessing the response of aspen-dominated forest ecosystems to varying levels of organic matter removal and soil compaction. An assessment of 25-year standing woody biomass indicates that neither whole-tree harvest nor whole-tree harvest combined with forest floor removal reduced forest productivity on silt-loam soils compared with conventional, stem-only harvest; however, moderate and heavy compaction did negatively impact aspen biomass and stem densities. In contrast, whole-tree harvest reduced standing biomass of aspen and all species combined on sandy soils at the Huron NF while compaction had no discernable impact. Neither treatment factor affected vegetation response at the Ottawa NF (clay soils), but reduced sample size at this site may have increased variability. Over all, the response of standing biomass and forest structure to organic matter removal and compaction treatments demonstrate that the sustainability of practices such as whole-tree harvesting and associated potential for soil impacts varies with site conditions, even when stands are dominated by the same species (e.g., *Populus tremuloides*).

INTRODUCTION

Scientists established the Long-Term Soil Productivity (LTSP) program in 1989 in part to provide data for assessing whether forest management practices degraded productivity as mandated in the 1976 National Forest Management Act (NFMA) (Powers 2006). While the basic questions underlying the LTSP Study were developed over 30 years ago, they remain no less relevant today. Increasing concern related to climate change has renewed interest in sourcing renewable, bioenergy feedstocks from forests (Becker et al. 2009, Berger et al. 2013, Janowiak and Webster 2010, Millar et al. 2007) and may lead to more frequent harvests and greater likelihood of residue removal in some regions. Additionally, changing climatic conditions have potential to influence the length of winter and associated frozen-soil logging season where soils tend to be wet, fine-textured, and prone to compaction (Rittenhouse and Rissman 2015, Wolf et al. 2008). Together, these factors have potential to reduce forest site quality through a reduction in nutrients and increased physical impacts to soils.

Compared to presettlement conditions, quaking aspen (*Populus tremuloides*) has become more dominant across the Upper Lakes States region, having regenerated successfully after extensive harvesting and associated fires that occurred during the late 19th and early 20th

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centuries (Friedman and Reich 2005, Schulte et al. 2007). Quaking aspen is now one of the most abundant tree species across this landscape and has become economically important, particularly in Minnesota. Both quaking aspen and big-toothed aspen (*P. grandidentata*) are shade intolerant, pioneer species that respond favorably to disturbance through the production of prolific root suckers (Frey et al. 2003, Graham et al. 1963). Perhaps for this reason, they are widely characterized as resilient and managed accordingly, typically with a coppice system (Burns et al. 1990, Graham et al. 1963, Stone 2001).

The effects of whole-tree harvest on tree regeneration and forest productivity have been studied across temperate and boreal forests of North America and Europe, but little consensus about the sustainability of such practices exists because results vary depending on forest type, site quality, time since disturbance, and land-use history (Thiffault et al. 2011). On nutrient-poor soils, particularly where harvests have already occurred one or more times, whole-tree harvest can reduce soil nutrient availability and tree growth (Helmisaari et al. 2011, Morris et al. 2014, Walmsley et al. 2009). Importantly, negative impacts may take 10–20 (or more) years after harvest to emerge (Mason et al. 2012, Thiffault et al. 2011). In forests with greater nutrient availability, the practice of removing harvest residues may not negatively impact nutrient availability in the soil organic layer (Smolander et al. 2010) or subsequent vegetative growth (Muñoz Delgado et al. 2019, Roxby and Howard 2013). In a broad analysis of vegetative response across the entire LTSP network, 10-year results suggested no negative impact of biomass removal on vegetative growth (Powers et al. 2005). In the present study, we assessed the 25-year impact of organic matter removal and compaction on tree density and standing biomass at 3 LTSP sites dominated by aspen species in the Upper Lake States region.

STUDY AREAS

We present results based on data collected from three USDA Forest Service installations of the LTSP Study distributed across the Laurentian Mixed Forest Province. Sites included the Chippewa, Ottawa, and Huron National Forests in Minnesota and Michigan. Aspen (*Populus tremuloides* and *P. grandidentata*) dominated all forest stands prior to harvest, but sites differed in soil texture, ranging from clayey to sandy (Table 1). Consistent with the original intent of the LTSP Study, we compared responses across site types that vary in quality for the dominant tree species, aspen (Powers 2006, Stone 2001).

Table 1.—Site characteristics

	Harvest year	Location	Site index[a]	Soil texture	Dominant tree species prior to harvest
Chippewa NF	1993	Minnesota 18’47’N, 94 31’W	23	silt loam	Trembling aspen (*P. tremuloides*), red maple (*Acer rubrum*), sugar maple (*A. saccharum*), basswood (*Tilia americana*), northern red oak (*Q. rubra*), eastern white pine (*Pinus strobus*)
Huron NF	1994	Michigan 44 38’N, 83 31’W	19	sand	Trembling aspen, big-tooth aspen (*P. grandidentata*), red maple, black cherry (*P. serotina*), northern red oak, white pine (*P. strobus*)
Ottawa NF	1992	Michigan 46 37’N, 89 12’W	17-18	clay	Trembling aspen, balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), red maple

[a]Aspen, base age 50 (Lundgren and Dolid 1970).

METHODS

Experimental Design and Field Sampling

This study assesses the impacts of two main factors on forest productivity, organic matter removal and soil compaction. The three organic matter removal treatments included: (1) stem-only harvest (SOH), the removal of all shrubs and merchantable stems and retention of harvest residues (nonmerchantable tops and branches) onsite; (2) whole-tree harvest (WTH), the removal of all aboveground portions of trees and shrubs; and (3) whole-tree harvest plus forest floor removal (FFR), the removal of all aboveground biomass. Compaction levels included: no additional compaction, representing operational conditions during a typical winter harvest (C0); moderate compaction (C1); and heavy compaction (C2). Both factors were fully crossed using a factorial design and replicated three times at the Chippewa and Huron NF sites. Replication at the Ottawa NF differed slightly, in part because of recent impacts from beaver. The Ottawa NF installation does not have the SOH/C2 treatment but includes five replicates of the WTH/C0 treatment, two replicates of SOH/C1, two replicates of FFR/C2, and three replicates of the remaining treatment combinations. Treatments were applied to 0.25 ha stands consisting of a 40 m × 40 m plot surrounded by a 5 m buffer. Overstory vegetation was sampled 25 years post-harvest in nine 1.78 m radius (10 m^2) circular subplots per stand. In these plots, the diameter and species for all woody stems with height greater than 15 cm were recorded. The analyses presented here only include data for overstory trees with diameter at breast height (d.b.h.; 1.37 m) greater than 10 cm. Harvest operations and treatment implementation are described in greater detail by Stone (2001).

Analysis

Aboveground biomass for all observed stems (d.b.h. >10 cm) was estimated using species-specific allometric equations (Jenkins et al. 2004). More detailed information about the equations used for species observed in this study are available in Curzon et al. (2017).

The influence of organic matter removal and compaction on tree standing biomass (all species) and on aspen standing biomass (all quaking and big-toothed aspen stems) was tested with mixed-effects ANOVA using the SAS MIXED procedure and the following statistical model: $Y_{ijk} = OMR + CPT + OMR*CPT + e_{ijk} + e'_{ijk}$ where OMR is the level of organic matter removal, CPT is the compaction level, and Y_{ijk} is aboveground woody biomass or stem density at the *i*th level of OMR, the *j*th level of CPT, and the *k*th level of plot. Plot was included as a random effect while OMR and CPT were treated as fixed effects. Type III sums of squares were used to account for the unbalanced design at the Ottawa NF. Each site was analyzed separately. Residuals were inspected visually to ensure assumptions for ANOVA had been met. Tukey-adjusted multiple comparisons were used to distinguish between treatment pairs where warranted.

RESULTS

The 25-year response of overstory trees at both the Chippewa NF and Huron NF suggests treatments have had a long-term impact on productivity, but results vary between the two sites. On silt-loam textured soils at the Chippewa National Forest, the no additional compaction treatment resulted in the greatest productivity in terms of aspen biomass while C1 and C2 reduced productivity by 46 percent and 73 percent, respectively (Fig. 2). Likewise, compaction decreased the density of aspen stems (C0 > C1, C2; Fig. 1). Reductions in mean stem density and standing biomass for all tree species, combined, were also observed (C1 and C2 reduced standing biomass by 18 percent and 33 percent, respectively), but differences were not statistically significant (Table 2; Figs. 1 and 2). Responses to the three organic matter removal treatments did not differ, nor was there an interaction between compaction and harvest treatment for any of the response variables assessed (Table 2).

In contrast to responses at the Chippewa NF, the removal of harvest residues associated with WTH negatively impacted total tree biomass (reduction of 39 percent) as well as aspen biomass, specifically (47 percent reduction) at the Huron NF. The additional removal of the forest floor (FFR) had a negligible impact on productivity relative to WTH at this site, and compaction did not impact either stem density or standing biomass (Figs. 1 and 2). No effects of organic matter removal or compaction on 25-year standing biomass or stem densities were observed at the Ottawa NF.

Table 2.—ANOVA results. Statistically significant effects ($p<0.05$) are shown in bold text

			Tree biomass		Aspen biomass		Stem density (all tree species)		Stem density (aspen)	
	Source	df	F	P-value	F	P-value	F	P-value	F	P-value
Chippewa NF	OMR	2	1.95	0.17	2.89	0.08	0.66	0.52	1.91	0.17
	CPT	2	3.21	0.06	**13.1**	**0.0004**	**10.2**	**0.001**	**21.85**	**< 0.0001**
	OMR*CPT	4	0.46	0.76	1.11	0.38	0.23	0.92	0.63	0.64
Huron NF	OMR	2	**3.77**	**0.04**	**4.12**	**0.03**	2.87	0.08	3.08	0.07
	CPT	2	1.17	0.33	1.35	0.28	1.84	0.18	1.74	0.20
	OMR*CPT	4	1.01	0.43	0.78	0.55	0.82	0.53	0.64	0.64
Ottawa NF	OMR	2	2.8	0.09	2.36	0.12	3.38	0.06	2.79	0.09
	CPT	2	0.24	0.78	0.26	0.77	0.41	0.66	0.48	0.62
	OMR*CPT	4	0.51	0.68	0.56	0.65	0.75	0.53	0.81	0.51

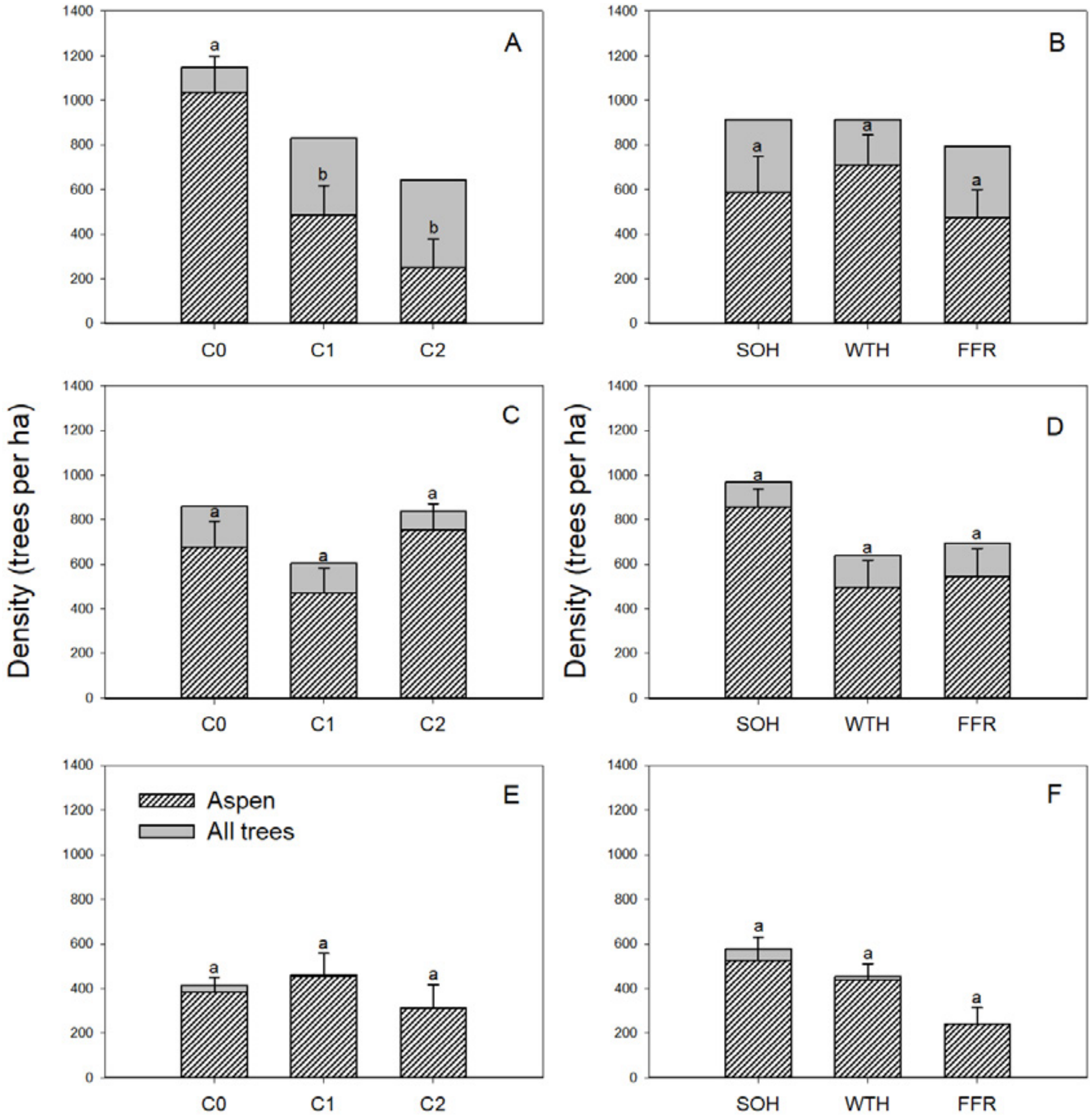

Figure 1.— Stem density for trees (d.b.h. >10 cm) in response to compaction (panels A, C, and E) and organic matter removal (B, D, F) 25 years post-harvest at Chippewa NF (A, B), Huron NF (C, D), and Ottawa NF (E, F). Grey bars show density for all tree species combined while the hashed portion of each bar indicates aspen (*P. tremuloides* and *P. grandidentata*, combined). Lowercase letters indicate significant differences in aspen density between factor levels ($p<0.05$). At Huron NF, mean stem density for all species also differed significantly between OMR factors (SOH > WTH, FFR; $p<0.05$). Abbreviations are as follows: CO, minimal compaction; C1, moderate compaction; C2, heavy compaction; SOH, stem-only harvest; WTH, whole-tree harvest; and FFR, forest floor removal.

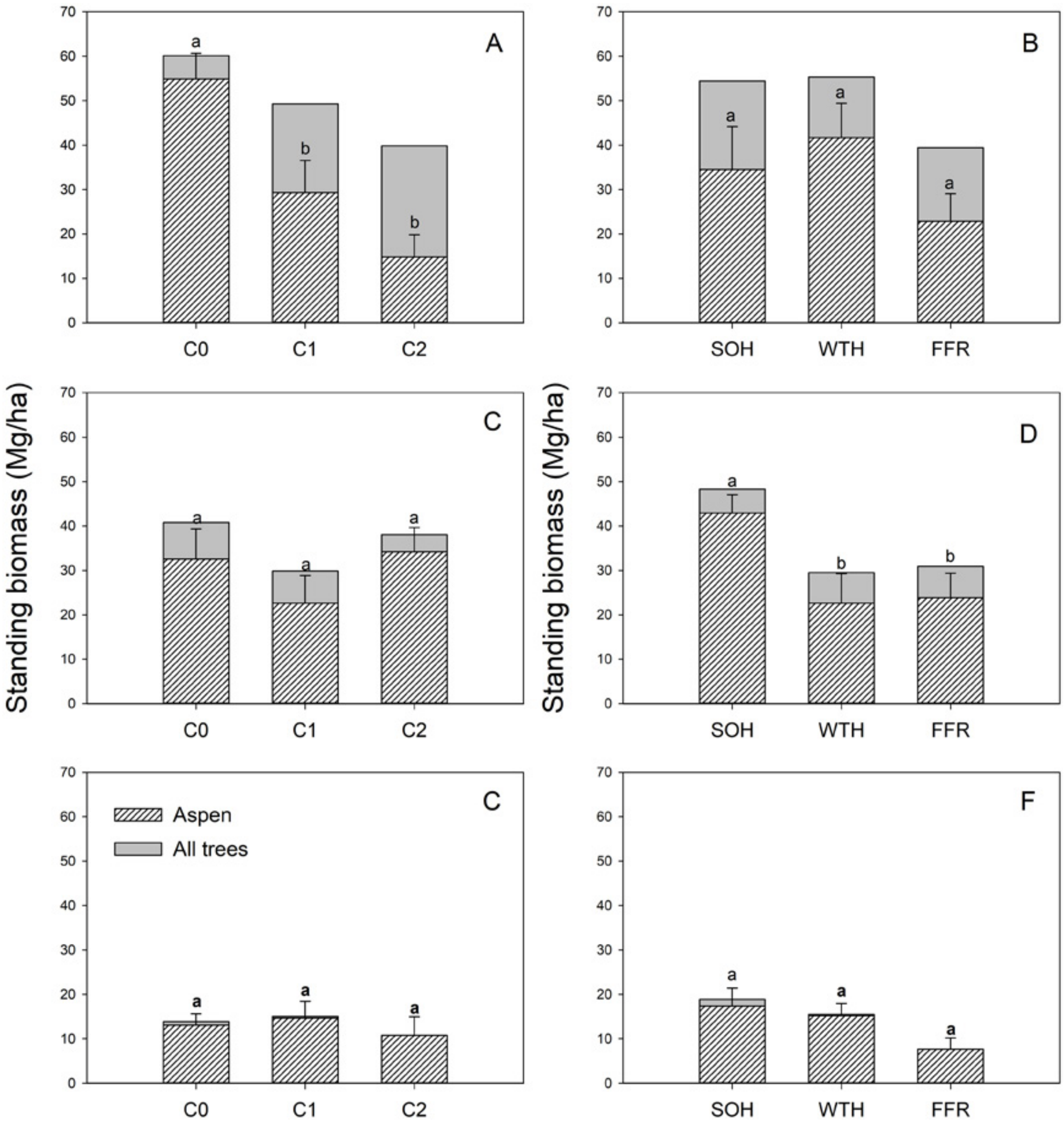

Figure 2.—Live standing biomass for trees (d.b.h. >10 cm) in response to compaction (panels A, C, and E) and organic matter removal (B, D, F) 25 years post-harvest at Chippewa NF (A, B), Huron NF (C, D), and Ottawa NF (E, F). Grey bars show density for all tree species combined while the hashed portion of each bar indicates aspen (*P. tremuloides* and *P. grandidentata*, combined). Lowercase letters indicate significant differences between factor levels for aspen biomass ($p<0.05$). Standing biomass for all tree species combined did not differ significantly among factors at any of the sites (see Table 1). Abbreviations are as follows: CO, minimal compaction; C1, moderate compaction; C2, heavy compaction; SOH, stem-only harvest; WTH, whole-tree harvest; and FFR, forest floor removal.

DISCUSSION

Following enactment of the National Forest Management Act (NFMA) of 1976, a series of discussions led to the definition of productivity (for the purposes of monitoring and enforcing compliance with the NFMA) as maintaining the carrying capacity of a given site for vegetative growth. Departures from baseline productivity exceeding 15 percent were deemed substantive (Powers 2006). The combination of stem-only harvest and no additional compaction (SOH/C0) in this study serves as an operational control for comparison with other treatments. Using those numbers as a baseline, our results demonstrate that excessive compaction on silt loam soils at the Chippewa NF undoubtedly decreased carrying capacity for the dominant species, quaking aspen. Reductions in mean standing biomass for all species combined also exceeded the 15 percent threshold, but results were not considered statistically significant ($p = 0.06$, Table 3). The removal of harvest residues with whole-tree harvest at the Huron NF, relevant to ongoing conversations about bioenergy feedstocks, also reduced productivity quantified in terms of standing biomass based on 25-year results.

Early results from the Chippewa, Ottawa, and Huron National Forests reported 4–5 years post-harvest suggested that a greater degree of disturbance impacted vegetation response relative to conventional practices, though many responses were not statistically significant. Initial observations indicated compaction at the Huron NF might have had a positive effect on mean aspen sapling height and biomass. These trends, reported following the fourth (Stone et al. 1999) and fifth growing seasons (Stone 2001), have diminished over time and are no longer apparent when analyzing only the 25-year data. Early observations from the fifth growing season at the Ottawa NF showed increased aspen sucker density in response to FFR compared to SOH as did greater levels of compaction (C1, C2 > C0) (Stone 2001), but neither factor continued to impact stem densities after 25 years. On the other hand, initial observations of reduced stem densities in response to greater compaction observed at the Chippewa NF (C0 > C1 > C2; Stone 2001) persisted to 25 years post-harvest (C0 > C1, C2; Fig. 1), and initial, non-significant observations of potentially reduced sapling biomass at the Huron NF (Stone et al. 1999) have become more pronounced (Fig. 2).

Analyses of data collected in earlier sampling periods also suggest changes occurring to the composition and diversity of regenerating forests across all three sites. Results based on 15-year data suggest that shrub biomass is greater in those plots at the Chippewa NF treated with heavy compaction, particularly when combined with forest floor removal, but that shrub species took time to occupy the sites rather than dominating immediately after disturbance (Curzon et al. 2014). Responses assessed 15 years post-harvest also indicate that severity of disturbance created by combining forest floor removal and heavy compaction reduced recovery of woody community composition (all shrub and tree species) relative to conventional harvest (Curzon et al. 2016). Whole-tree harvest has been shown to influence species composition and diversity in other forest types as well, suggesting this is an important factor to consider even if overall productivity is maintained (Muñoz Delgado et al. 2019).

Overall, our results indicate precautions should be taken to protect finer-textured soils (such as those at the Chippewa NF) and support other studies that discourage whole-tree harvesting on sandy soils that are less nutrient rich and have lower water-holding capacity (Flinn et al. 1980, Janowiak and Webster 2010, Thiffault et al. 2011, Vangansbeke et al. 2015). The LTSP research program was designed to follow forest stands through an entire rotation, so comparing responses to standing biomass prior to harvest at these sites will not be possible for some time. Even after 25 years, our results might still be considered preliminary, and while they are relevant to current management, they also highlight the value of designing experiments for the purpose of collecting long-term data.

Table 3.—Median (IQR) d.b.h. (cm) for each tree species by treatment at the Chippewa, Huron-Manistee, and Ottawa National Forests. Abbreviations are as follows: ABBA, *Abies balsamea*; ACRU, *Acer rubrum*; ACSA, *Acer saccharum*; BEPA, *Betula alleghaniensis*; FRPE, *Franxinus pennsylvanica*; POBA, *Populus balsmifera*; POGR, *P. grandidentata*; POTR, *P. tremuloides*; PIRE, *Pinus resinosa*; PIST, *Pinus strobus*; PRPE, *Prunus pensylvanica*; PRSE, *Prunus serotina*; QUAL, *Quercus alba*; QUMA, *Q. macrocarpa*; QURU, *Q. rubra*.

		Treatment								
Site	**Species**	**SOH/C0**	**SOH/C1**	**SOH/C2**	**WTH/C0**	**WTH/C1**	**WTH/C2**	**FFR/C0**	**FFR/C1**	**FFR/C2**
Chippewa NF	ACRU	n/a	11.4 (11.4, 11.4)	n/a	n/a	13.7 (13.7, 13.7)	n/a	n/a	n/a	n/a
	ACSA	n/a	n/a	n/a	n/a	10.5 (10.5, 10.5)	10.5 (10.5, 10.5)	n/a	n/a	n/a
	BEPA	10.35 (10.2, 10.5)	11.9 (11.05, 16.05)	12.5 (10.7, 15.5)	10.5 (10.5, 10.5)	11.8 (11, 13.6)	15.7 (12.7, 18.5)	11.9 (11.3, 12.5)	11.5 (10.5, 12.7)	12.7 (11.1, 14.2)
	FRPE	12.6 (12.6, 12.6)	13 (13, 13)	13.2 (13.2, 13.2)	n/a	n/a	n/a	n/a	11.5 (11.5, 11.5)	n/a
	POGR	22.9 (19.4, 26.4)	n/a	n/a	n/a	17.4 (14.95, 20.3)	n/a	16 (15.6, 17.8)	n/a	n/a
	POTR	13.2 (11.7, 15.15)	13.5 (11.7, 16.2)	12.85 (11.05, 16.15)	13.4 (11.6, 15.8)	13.1 (11.7, 16.2)	14.65 (12.2, 16.5)	12.2 (11, 13.7)	13.2 (11.2, 14.6)	12.8 (11.8, 13.9)
	POBA	n/a	17.5 (17.5, 17.5)	21.7 (15.8, 27.6)	n/a	n/a	n/a	n/a	n/a	13.1 (12.7, 13.9)
	PRPE	n/a	14.2 (14.2, 14.2)	n/a	n/a	n/a	10.3 (10.1, 10.5)	n/a	n/a	11.3 (11.3, 11.3)
	QUMA	10.3 (10.3, 10.3)	10.8 (10.2, 12)	11.65 (10.8, 12.5)	n/a	n/a	11.4 (10.6, 13)	n/a	10.3 (10.3, 10.3)	10.6 (10.6, 10.6)
	QURU	n/a	12.4 (12.4, 12.4)	n/a	n/a	n/a	n/a	n/a	17.6 (14, 17.7)	n/a
	Salix spp.	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	10.7 (10.1, 11.3)
	TIAM	11.45 (11.2, 11.9)	10.85 (10.3, 12.4)	n/a	16.5 (12.5, 17.8)	12.7 (12.7, 12.7)	13.75 (11.3, 15.4)	11.05 (10.9, 11.8)	11 (10.9, 11.2)	11.2 (10.5, 11.7)
Huron-Manistee NF	ACRU	10.55 (10.3, 11.9)	12.6 (10.2, 12.7)	n/a	10.35 (10.15, 10.75)	11.2 (10.55, 14.7)	10.2 (10.2, 10.2)	11.35 (11.2, 11.5)	n/a	10.5 (10.3, 10.7)
	PIRE	n/a	n/a	n/a	13.3 (11.5, 15.1)	n/a	n/a	12.25 (11.05, 13.65)	n/a	n/a
	PIST	12 (11.4, 15.3)	n/a	n/a	11.7 (10.8, 12.7)	10.2 (10.2, 10.2)	n/a	12.8 (11.8, 14.8)	11.1 (11, 12.1)	n/a
	POGR	13.2 (12, 15.25)	13.05 (11.1, 15.5)	12.5 (11.2, 15.6)	14 (11.7, 15.6)	15.3 (14.2, 19.2)	13 (11.8, 16)	12.3 (11.5, 15)	12.7 (10.7, 14.7)	12.15 (10.85, 14.1)
	POTR	12.75 (11, 13.85)	11.1 (10.6, 11.3)	10.65 (10.2, 11.8)	11.3 (10.6, 12.6)	11 (10.5, 12)	11.1 (10.7, 12)	10.75 (10.5, 11)	10.85 (10.5, 12)	10.55 (10.15, 11.1)
	PRSE	11.8 (11.6, 12)	n/a	11.8 (11.5, 12.1)	10.5 (10.5, 10.5)	12.2 (12.2, 12.2)	11 (11, 11)	12.5 (12.5, 12.5)	13 (13, 13)	n/a
	QUAL	n/a	n/a	n/a	n/a	11.8 (11.8, 11.8)	n/a	n/a	11.4 (10.3, 11.6)	n/a
	QURU	12.6 (12.6, 12.6)	10.7 (10.5, 11.6)	10.7 (10.2, 12.5)	11.8 (11.4, 13.1)	12.6 (11, 14.3)	10.7 (10.2, 11.3)	10.95 (10.8, 11.1)	12.4 (11.9, 13.1)	10.8 (10.3, 14.1)
Ottawa NF	ABBA	10.75 (10.6, 10.8)	14.8 (14.8, 14.8)	11.15 (11, 11.3)	10.5 (10.3, 12.4)	10.4 (10.4, 10.4)	n/a	n/a	n/a	n/a
	PIST	n/a	n/a	10.4 (10.4, 10.4)	n/a	n/a	n/a	n/a	n/a	n/a
	POTR	11.1 (10.6, 12.2)	11.4 (10.5, 12.95)	n/a	11.3 (10.6, 12.9)	11.15 (10.5, 12.1)	12 (10.9, 13)	11.4 (10.5, 12.8)	11.25 (10.65, 11.6)	11.2 (10.7, 11.8)

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The North American Long-Term Soil Productivity Study: Collaborations to Understand Forest Responses to Land Management

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ABSTRACT.—The Long-Term Soil Productivity (LTSP) Study is one of the most successful and extensive collaborative science efforts undertaken by the USDA Forest Service. It was launched through a back-of-the-bus conversation about problems arising from the National Forest Management Act of 1976 and rose as a grassroots effort to determine how soil compaction and organic matter removal are linked to both tree and stand productivity. It has sparked collaborations at all levels of the agency and with universities, non-profits, and other research organizations, nationally and internationally, with the common goal of sustaining forest productivity in perpetuity while continuing to provide ecosystem services after timber harvesting.

BACKGROUND

The National Forest Management Act of 1976 (NFMA) mandated that national forests be managed without impairment of the productivity of the land (USDA Forest Service 1993). This included a call for the USDA Forest Service to conduct the research, monitoring, and assessment to ensure sustained yield in perpetuity while protecting all resource values. Furthermore, one key section of the resulting framework was that the Forest Service was required to monitor the effects of forest management prescriptions. The need for monitoring presented a problem because the monitoring work had not been completed on a comprehensive level. Monitoring the effects of forest management was the topic of discussion in 1989 during a field tour on which the Forest Service National Soils Program Leader for the National Forest System arm of the Forest Service remarked to scientists from the Research branch that the national soils program needed help. This grassroots effort started the North American Long-Term Soil Productivity (LTSP) Study (Powers 2006; Powers et al. 2005, 2014) and it predated many other national and international efforts at sustainable forestry or green certification by more than a decade.

Once the Forest Service, with help from the Office of General Council, defined *land productivity, carrying capacity,* and *significant change* (Powers et al. 2014), the decision was made that a productivity decline of 15 percent or greater would have to occur to be measureable under operational conditions (USDA Forest Service 1987). But how do you monitor these changes? The Watershed and Air Management division of the National Forest System (NFS) took the lead with the philosophy that:

- Management practices create soil disturbance.
- Soil disturbance affects soil and site processes.
- Soil and site processes control forest productivity.

At this same time soil quality standards were being developed across national forests, but there were no clear baselines or agreement on what constituted enough soil disturbance to result in a decline in forest productivity. During the development stages of LTSP an extensive literature

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review revealed that forest productive capacity declined when there were soil organic matter losses or a decrease in soil porosity (compaction). Both compaction and organic matter loss can be managed through silvicultural prescriptions and forest management, but it was unclear where to draw the lines.

In 1988, a study plan for a national, coordinated research project to determine the long-term effects of soil disturbance on fundamental (including both understory and overstory growth and diversity) forest productivity was sent to Forest Service research silviculturists and soil scientists and their counterparts in Regional Offices, as well as scientists at universities and other research organizations. The study plan was the most widely reviewed of its kind in the history of the Forest Service (Powers et al. 2014)! Finally, in 1989 the study plan was presented to the joint Deputy Chiefs for NFS and Research and Development (R&D) and was approved. Installation costs were covered from excess timber sale receipts administered through the Washington Office and Forest Service Regional Offices.

THE COLLABORATIONS BEGIN

At each installation, the initial collaborations involved the principal investigator from many of the Research Stations and the Regional and Forest Soil Program managers and silviculturists from the participating Forest Service Region. National oversight was provided by four members of the Washington Office representing timber and soil interests—two from R&D and two from NFS. This oversight committee, Regions, and R&D scientists helped identify soil and forest types to help focus the LTSP experiment and encouraged cooperation among participating National Forests and Ranger Districts. Once sites were chosen, the collaborations extended to local foresters, soil scientists, hydrologists, and timber sale administrators. It also extended to universities and other research organizations because this study resulted in well defined treatments that could be used for large- and small-scale studies. In addition, many researchers wanted to work on these study sites because they were installed on national forests and could be counted on to be maintained for longer than a few years.

Because LTSP focused on commercial forest types, NFS personnel were essential to the success of this endeavor. Study sites were selected based on the presence of soil that supported productive, mature forests typifying those under management. Once sites were identified by NFS, pretreatment data were collected (e.g., soil bulk density, forest floor depth, downed wood, understory biomass, overstory height, and diameter). Plots were laid out and treatments were implemented following a standard template of three levels of organic matter removal (bole only, whole tree harvesting, and whole tree harvesting plus forest floor removal) and three levels of compaction (none, moderate, and severe). Plots size was 1 acre (0.4 ha).

Harvest operations were administered by NFS. Often trees were directionally felled to reduce the impacts on soils. In general, the plots were harvested, treatments installed, and trees planted. Many of the sites also used herbicide on one-half of each plot to measure tree growth only and the other half was allowed to regenerate with a natural understory to measure overstory and understory growth. Responses were measured as dry matter production over time (net primary productivity).

There were no historical guidelines for how to go about installing a replicated study of such large scope. Therefore, the oversight and regional committees agreed that Experimental Forests would be the sites of the pilot installations. Experimental Forests in the Southern, Pacific Southwest, North Central, and Intermountain Research Stations were selected. The benefit of using Experimental Forests is that they are under the jurisdiction of the Research Stations, so treatments could be easily installed, have high visibility, and have a close rapport with Ranger District and NFS personnel. Experimental forests also have lodging available, thereby reducing the cost of travel.

SOME ADMINISTRATIVE HURDLES

As might be expected with a large-scale field experiment, each researcher at each experimental forest had to deal with a few hurdles. However, the collaborative effort and support from R&D, NFS, industry, and universities helped overcome these hurdles. For example, NFS had to deal with logistical issues related to how to harvest trees while limiting logging equipment to buffer areas or how to effectively compact the soil over a large 1-acre plot. Many researchers also depended on university collaborators to help with graduate students or laboratory space. Furthermore, our industry collaborators were able to include harvest and site preparation practices that were new and innovative.

THE COLLABORATION EXPANDS

It wasn't long after the first four study sites were installed that our colleagues in Canada began installing similar study sites in British Columbia and Ontario. The installation at the Priest River Experimental Forest is a replicate for two study sites in British Columbia, and data and samples are shared with Canadian research colleagues. Furthermore, there are international LTSP installations in China and Australia (Smaill et al. 2008). The grassroots LTSP effort that was started by a small cadre of motivated researchers and forest managers has now expanded into a major network. It is an extraordinary example of collaboration between research and management arms of the Forest Service that has expanded to include colleagues and partners from various land management agencies, industry, and universities and is a model for how an elegant experimental design can draw in partners. The collective experiences gained from the first few installations set a research trajectory that bridges affiliations and political borders.

HAS LTSP IMPROVED LAND MANAGEMENT?

Forest development is a slow process and so making sense of the data has also been slow. However, in 2006 many of the researchers produced a special issue in the journal Forest Ecology and Management that summarized the first decade of data from 26 installations in the United States and Canada. In these papers the group noted several key responses to the treatments:

- Complete removal of the surface organic matter resulted in a decline in soil C concentration to a depth of 20 cm and reduced nutrient availability after 10 years (Powers et al. 2006), but this was not detected at the 5-year measurements (Sanchez et al. 2006). Furthermore, removal of the surface organic matter had a greater impact on CO2 efflux than clearcut harvesting (Fleming et al. 2006a).
- Biomass removals during harvest operations had no influence on forest growth through 10 years (Powers et al. 2005).
- The amount of compaction that could be achieved was dependent on the initial bulk density; sites with a high initial bulk density could not be compacted as much as those with a low initial bulk density (Page-Dumroese et al. 2006).
- Soil density recovery was slow in soils with a frigid temperature regime and at depths up to 30 cm (Page-Dumroese et al. 2006).
- Microbial biomass, respiration, and fungal phospholipid fatty acids declined after harvesting in a Mediterranean-type climate (Busse et al. 2006).

- In the southeast, a bulk density increase of less than 10 percent resulted in a significant reduction of loblolly pine (Pinus taeda L.) growth (Carter et al. 2006).
- Soil compaction combined with intact forest floors generally benefited conifer survival and growth, regardless of climate or species. In addition, compaction with forest floor removal generally increased survival but had limited effects on individual tree growth (Fleming et al. 2006b).

In addition, Cline et al. (2006) notes that there were five key findings after the first decade that have a direct impact on forest management and soil quality: (1) surface organic matter is the link between most management systems and sustainable site productivity; (2) nutrient deficiencies can be corrected; (3) soil texture is the key variable that affects surface and mineral soil organic matter and site productivity; (4) tree residues left on-site enhance soil organic matter; and (5) productive, healthy forests provide many ecosystem services. Page-Dumroese (2010) published a list of publications (over 200) associated with the LTSP sites that highlight the benefits of this study to management and research.

Since 2010, several more studies have been published. For example, in a summary of 45 of the LTSP installations in North America, Ponder et al. (2012) indicated few consistent effects from both organic matter removal and compaction. Furthermore, combining the loss of surface organic matter with severe compaction resulted in lesser gains in planted tree biomass production. In California, the 12 LTSP installations there had a 15 percent increase in planted tree biomass on a plot-scale basis, which was attributed to improved seedling survival and reduced competing vegetation on plots with understory vegetation control (Zhang et al. 2017). Longer-term measurements from the LTSP network show that in aspen (*Populus tremuloides*) stands in the Lake States region, forest floor removal resulted in soil carbon (C) and calcium reductions over a 20-year period, which may have resulted in reductions in aspen growth that were not noted during previous measurements (Slesak et al. 2017). Consistent changes in microbial populations on harvested sites indicate that there was an expansion of desiccation- and heat-tolerant organisms and a decline in ectomycorrhizae on plots with organic matter removed from sites that were 11 to 17 years old (Wilhelm et al. 2017). These results make it clear that early results may not dictate the trajectory of stand growth for an entire rotation, results across numerous sites may be variable, and the later expression of site changes may have significant impacts on potential site productivity.

ORGANIC MATTER REMOVAL

For many years, land managers have known about the importance of coarse wood for many ecosystem services (e.g., infiltration, water quality, biodiversity; Rochelle 2008). The LTSP program has shed additional light on the importance of also maintaining the forest floor throughout harvest operations across many ecosystems. Removal of surface organic matter had a statistically significant impact on soil C concentrations after one decade (Powers et al. 2005) and this 10-year finding is different from the work in North Carolina where there were no declines in soil C among the treatments after 5 years (Sanchez et al. 2006). Other studies have shown that retaining surface organic matter can also reduce soil temperature and evaporative moisture loss (Li et al. 2003, Powers et al. 1998).

LTSP has shown that maintenance of surface organic horizons is important for nutrient and carbon cycling, but also to maintain tree growth. However, the relationship between surface organic horizons and tree growth is different on some sites. For example, Alban et al. (1994) showed that aspen responded to organic matter removal by generating a high density of root suckers after the first year, but by the third year, most of these had died from increased competing vegetation. Scott et al. (2004) found that bole volumes at year 5 in Mississippi were 40 percent lower on plots with all the surface organic matter removed as compared to those where it was retained; after 10 years the difference was only 29 percent. On these plots, declines in productivity were associated with the reduced availability of soil P (Scott et al. 2004). In California, after 5 years there were no differences in tree biomass, periodic annual increment, or competing vegetation on any of the organic matter removal plots. Vegetation control, however, was the single most important factor affecting tree biomass after 20 years (Zhang et al. 2017). The LTSP results illustrate the value of long-term studies spread across numerous forest and soil types; early or site results may or may not forecast long-term trends or results from other sites.

COMPACTION

When compacting the plots, we set out to have study plots with a clear difference between the moderate and severe compaction level, but the end result was a small difference between these two levels across many soils and sites (Page-Dumroese et al. 2006). This is because some soils already had a high bulk density (1.4 Mg m^{-3} or greater) and could not be readily compacted beyond this level. Compaction was carried out when the plots were at or near field capacity. Therefore, once macropores are compressed, further compaction was difficult because the micropores were filled with water. Soils with the lowest recovery rates are in Idaho, Michigan (clay soils), and Minnesota—all sites with a frigid soil temperature regime. This means that the freeze-thaw cycle in cool temperate or boreal life zones is not particularly effective at remediating compaction below 10 cm (Page-Dumroese et al. 2006).

On the North Carolina sites, soil bulk density on fine loamy soils increased by 0.34–0.54 Mg m^{-3}, which resulted in reduced root aeration and impaired tree growth (Sanchez et al. 2006). In California, soil moisture storage on clay soils was substantially reduced by compaction and reduced tree growth (Powers et al. 2006). Effects of soil compaction are generally related to soil texture with the greatest reductions in tree growth occurring on fine-textured soils; clayey soils had the greatest volume loss, loamy soils (including volcanic ash-cap soils) had intermediate growth reductions, and sandy soils generally had growth increases due to compaction. The increased growth on sandy soils is associated with an increase in available water storage in micropores (Powers et al. 2006).

SOIL MONITORING

In forestry, there is a strong link between science and policy and the science must be translated into tools for a wide audience. When NFMA was signed it, along with several other Acts (e.g., NEPA, Clean Water Act; Cline et al. 2006), they set forth three points that supported the need for a long-term soil monitoring program. The first was that land management should not produce substantial and permanent impairment of site productivity. Second, trees should only be harvested where soil, slope, or watershed conditions would not be irreversibly damaged. Third, tree cutting should protect soils, watershed, fish, wildlife, recreation, and esthetic resources, and the regeneration of trees. From language in NFMA, the Forest Service was the first land management agency to develop soil quality standards, but they were not perfect! Blanket soil quality standards were used in nearly every Forest Service Region and little validation had been done to determine if they were adequately assessing changes in long-term productivity (Page-Dumroese et al. 2000). The soil quality standards usually reflected best professional judgment rather than documented evidence and were intended as early warning signs rather than absolute limits (Powers et al. 1998). As the LTSP Study was being developed, soil quality standards were also being tested in several lawsuits. Therefore, when the request for a coordinated LTSP effort to determine how soil organic matter loss and compaction altered productivity came to R&D, it was the perfect opportunity to test soil quality indicators and validate the standards.

One tangible product of the LTSP study that helps land managers was the development of a reliable, cost effective, statistically valid, and easy-to-use soil monitoring protocol. This protocol leveraged the findings of LTSP in the United States and Canada, work done developing uniform and unambiguous definitions for soil disturbance categories that relate to stand productivity and hydrologic function (Curran et al. 2007), and the pioneering efforts in the Pacific Northwest Region to develop visual disturbance classes (Howes et al. 1983). The Forest Soil Disturbance Monitoring Protocol (FSDMP) was developed as a multifaceted tool that uses visual disturbance classes and a standard method for collecting data (Page-Dumroese et al. 2009). One advantage of a consistent tool is that all disciplines or the public can use it and get similar results. The FSDMP considers soil resilience coupled with the degree, duration, distribution, and location of disturbance. It provides useful indicators of a change in soil disturbance level that can be linked to LTSP findings or more local validation data. Several authors (Burger and Kelting 1999, Heninger et al. 1997, Kneeshaw et al. 2000, Powers et al. 1998) have identified attributes of indicators for sustainable forest management and soil monitoring, and many of these were incorporated into the FSDMP. The FSDMP is scientifically sound, operationally feasible, socially responsible, and credible, and uses a common language and standard method. This makes the results easy to interpret and to link to silviculture prescriptions so that best management practices can be developed for current and new harvest technologies.

WHERE DO WE GO FROM HERE?

The LTSP collaborative effort has proven that a grassroots effort led by a small group of motivated forest managers and researchers could expand into a major network. It stands as an exceptional example of research and management collaborations for shared stewardship of vegetation, soil, and water resources of the Forest Service at all levels of the agency and this research is internationally recognized. Our accomplishments bridge affiliations and political boundaries, have influenced other programs in the United States and abroad, and have resulted in tangible benefits to national forest management and the public.

After 20 years, the LTSP results suggest that forest site productivity in North America is generally highly resistant and resilient to a one-time clearcut harvesting, compaction, and organic matter removal disturbance. Overall, results of planted seedlings and soil properties have shown consistent results from biomass and organic matter removals. This large network of sites has improved our knowledge of both continental and local-scale fundamentals of sustaining forest growth and soil health and has informed regional-to-local guidelines regarding forest harvesting and biomass removal (or retention) levels.

We still have some unanswered questions including: (1) Will soil properties return to predisturbance levels within a rotation? (2) How will soil compaction and organic matter removal, applied as a pulse disturbance and/or with intermediate thinning, affect total biomass yield at the end of a rotation? (3) How do we maintain these study sites into the future in the face of limited budgets? These questions are essentially the same ones asked by Powers et al. (2014). Our network continues because Forest Service, universities, and international partners have skin in the game and will collect core data as best they can, when they can. But longer-term funding and a new cadre of Forest Service managers and researchers are still needed to ensure that each site is intact to reach rotation age.

The LTSP Study sites continue to evaluate how management activities, specifically timber harvesting, compaction, and organic matter removal, influence ecosystem function across diverse sites. As such, they are particularly valuable for determining local impacts on soil physical, chemical, and biological properties. Our initial hypothesis that impacts would be universal has not played out and points out the value of repeated sampling to demonstrate decadal scale processes. We have informed policy decisions and land management to ensure sustained forest productivity, biodiversity, and clean, consistent water supplies. Continued measurement of these sites will lead to understanding how future environmental stressors (e.g., climate change, additional harvesting) might alter both aboveground and belowground productivity.

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SERVICES, PRODUCTS, AND GETTING IT DONE

The Business Aspects of Silviculture in the Delivery of Forest Products: A Panel Discussion

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ABSTRACT.—Use of designation by prescription (DxP) as a valid method to designate National Forest System timber for harvest is a significant change to the way the USDA Forest Service prepares and sells timber. Prior to the use of DxP, the Forest Service often used the expensive and time-consuming practice of the Forest Service marking individual trees to leave or cut with paint to ensure retention of the most desirable trees needed to meet management objectives. With DxP, a Forest Service silviculturist prepares a prescription describing the desired characteristics of the trees and stand to be retained following harvesting (i.e., desired end results). Using the prescription as a guide, the timber sale purchaser or stewardship contractor selects the trees to cut. Eliminating the need to mark trees in advance of cutting reduces sale preparation time and costs. Sale administration responsibilities and costs can increase, however, due to a lack of paint marks that aid the Forest Service's ability to quickly determine whether the correct trees were cut. Perspectives on the use of DxP, to date, and criteria for success are discussed by the panel.

INTRODUCTION

In the Agricultural Act of 2014, P.L. 113-79, Title VIII, Subtitle D, section 8303 (2014 Farm Bill), Congress authorized a significant change in USDA Forest Service business practices. The 2014 Farm Bill, among other things, specifically amended paragraph 14g of the National Forest Management Act of 1976 (16 U.S.C. 472a(g) (NFMA), to authorize the use of designation by prescription (DxP) as a valid method of designating timber to be harvested. The changes in the 2014 Farm Bill allow a prescriptive approach to describing desired stand conditions in a timber sale without needing to individually designate trees by marking them with paint to leave or cut. When DxP is used, a silvicultural prescription, prepared by a Forest Service silviculturist, specifies desired stand conditions. The timber sale purchaser or stewardship contractor has discretion, consistent with the prescription guidelines, to select the trees to cut. The 2014 Farm Bill authorized the Forest Service to supervise a purchaser's or contractor's choices during sale administration or later (16 U.S.C. 472a(g)(3)).

DxP may simplify sale preparation and reduce Forest Service sale layout costs for marking and may result in improved operational efficiency for some timber operators by providing more flexibility to choose which trees to select for removal based on the identified prescription, which is incorporated into contract special provisions. (Marking costs average approximately $70/acre according to cost studies conducted on the Four Forest Restoration Initiative [personal communication, Richard Fleishman, Coconino National Forest, May 2018].) But DxP may not always be the most appropriate tool. For example, some operators may not have the ability or technology to implement complex silvicultural prescriptions. This may

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prevent those operators from bidding, or it may increase their operational costs. Additionally, determining compliance with a prescription can be more time consuming for Forest Service sale administrators, who are unable to quickly look for the presence or absence of Forest Service paint marks on stumps. Further, the risk when trees are individually marked with paint prior to cutting and less discretion is given to a purchaser or contractor to choose which trees to cut, the risk that harvesting will meet desired conditions is lessened. Conversely, as the complexity of the prescription increases the risk of not meeting the prescription increases when using DxP due to more difficult on-the-ground interpretation.

DESIGNATION BY PRESCRIPTION BACKGROUND AND DEFINITIONS

Prior to the 2014 Farm Bill amendments, paragraph 14(g) of NFMA stated, "Designating, marking when necessary, and supervision of harvesting of trees, portions of trees or forest products shall be conducted by persons employed by the Secretary of Agriculture." As such, timber marking had to be conducted by Forest Service employees or by contractors who did not have a personal interest in the purchase or harvest of the timber and were not employed directly or indirectly by the purchaser of the timber.

Beginning as a pilot program in FY1999, the Stewardship Contracting Authority, 16 U.S.C. 6591c(d)(5), exempted stewardship contracts and agreements from paragraph 14(g) of NFMA. Under the exemption, persons other than those employed by the Secretary of Agriculture may designate trees to leave, or to be cut and removed, to meet restoration objectives. After enactment of the stewardship authority, the exemption prompted the Forest Service to adopt special DxP contract provisions for limited use on thinning sales in 2004. Under procedures developed by the FS, timber sale purchasers and stewardship contractors were often required to mark leave trees for FS approval prior to cutting.

Section 8303 of the 2014 Farm Bill, entitled "Extension of Stewardship Contracts Authority Regarding Use of Designation by Prescription to All Thinning Sales Under National Forest Management Act of 1976," amended paragraph 14(g) of NFMA as follows:

> (1) IN GENERAL
>
> Designation, including marking when necessary, designation by description, or designation by prescription, and supervision of harvesting of trees, portions of trees, or forest products shall be conducted by persons employed by the Secretary of Agriculture.
>
> (2) REQUIREMENT Persons employed by the Secretary of Agriculture under paragraph (1)—
>
> (A) shall have no personal interest in the purchase or harvest of the products; and
>
> (B) shall not be directly or indirectly in the employment of the purchaser of the products.
>
> (3) METHODS OF DESIGNATION
>
> Designation by prescription and designation by description shall be considered valid methods for designation and may be supervised by use of postharvest cruise, sample weight scaling, or other methods determined by the Secretary of Agriculture to be appropriate.

Despite the reference to "thinning sales," the title of section 8303 does not have the force and effect of law. Consequently, section 8303 does not limit the use of DxP solely to thinning sales and is therefore applicable to all timber sales and stewardship contracts, and a broad range of silvicultural treatments. Under section 8303, preparation of the prescription, and supervision of the harvesting activities, must be performed by persons employed by the Secretary of Agriculture. Selection of which trees to cut, consistent with the prescription, may be left to the discretion of the timber sale purchaser or stewardship contractor.

Designation by description (DxD) and paint marking had been standard methods of designating timber in contracts for decades, but when the 2014 Farm Bill clearly authorized DxP as a valid method of designating National Forest System timber for harvest, the Forest Service significantly increased its use of DxP. New DxP contract provisions and implementation direction was issued in FSM 2440 in 2015. Implementation procedures and guidelines continue to evolve as use and experience with DxP increases. Recognizing efficiencies in sale layout, the Forest Service encouraged increased use of DxP in the Forest Products Modernization initiative through an internal letter from the Chief to the field in February 2018. The Forest Service is considering a policy that will allow timber sale purchasers and stewardship contractors to mark timber in advance of cutting, if they so choose, but the policy will not require them to do so.

In some DxP units, the Forest Service may choose to mark certain trees to be cut or left that don't fit into the general parameters of the prescription. For example, important wildlife trees might be marked to leave (called DxP with Reserve Tree Marking), while individual trees that the Forest Service specifically wants removed might be marked to cut. Because the trees harvested will differ from those that are measured when a DxP unit is cruised, Forest Service policy states that DxP is only authorized for use on timber sales and stewardship contracts where the volume for payment is measured by postharvest scaling.

Designation Definitions

Designation by Description (DxD). Trees are designated to be cut by describing measurable characteristics of individual trees and/or their juxtaposition to each other. Examples of descriptions include spacing, species, diameter, damage class, or a combination of two of these factors. Determining whether the correct trees are cut is done at the individual tree level. When trees are designated by the description, it is possible to look at individual stumps to determine if a tree was authorized to be cut or not.

Designation by Prescription (DxP). Trees are designated by describing the desired condition of the residual stand following harvest. The purchaser has discretion within the guidelines of the prescription, as described in the contract provisions, in selecting which trees to cut and which trees to leave. Determining whether the correct trees are cut or left is done at the cutting unit level. Examples include verifying whether a certain residual BA was left in the unit or measuring crown closure throughout the stand. Simple examples of criteria used in a DxP prescription include "leave 50 to 70 sq. ft. of basal area" in a southern yellow pine stand, or "leave two crowns touching" throughout an even-aged mixed conifer stand.

Designation by Marking. Trees are "marked" when individually designated with paint marks above and below stump height. Trees can be marked to cut or leave as distinguished by the color of paint used.

DISCUSSION ON APPLICATION OF DxP

This paper offers four perspectives on the use of DxP: three are from different FS Regions and one is from private industry. The perspectives focus on the successes and lessons learned when DxP is used to designate timber for harvesting.

Region 8—Jeff High

DxP on the Ouachita National Forest is used for a specific purpose: to deal with overstocked pine plantations. Historically, the Forest Service delayed entry into these stands until the trees were large enough to be marked at a sufficient spacing to facilitate mechanical logging equipment access. This delay has resulted in a backlog of overstocked stands with increased tree mortality that are susceptible to insect damage (e.g., stand-replacing southern pine beetle outbreaks). Using DxP, pine plantations can now be thinned at a younger age before serious forest health issues arise. For example, with DxP, the operator can plan access of machinery and vary tree to tree spacing to achieve both basal area prescription and logging equipment access. Timber markers would have difficulty doing this without significant logging experience and extensive layout considerations. The net result on a marked sale is that in sale administration, many of the marked "leave trees" must be marked to cut so the unit can be logged. In a "cut tree mark", the situation is much more restrictive for loggers in young stands. Because of reduced time to mark timber, DxP also facilitates the ability to strategically package sales at a faster pace.

The Ouachita National Forest uses DxP because it is a more efficient method when prescriptions are relatively simple and have less than three selection criteria. Based on my experience, including what I have learned from purchasers and DxP training sessions attended by purchasers, DxP allows purchasers to realize efficiencies through harvest planning in advance that considers access and logging corridors and landing areas. DxP techniques result in more stand density variability with less uniform spacing and higher quality residual trees when compared to a typically marked stand. In the South, forest industry has 30 or more years of experience using methods like DxP and commonly used the designation method to thin pine plantations to a specified residual basal area without any tree marking.

My discussions with purchasers and the bids received for DxP sales indicate purchasers are very receptive to using DxP. The results that purchasers have achieved, which I have seen, are exceptional. DxP can result in better residual stands and less logging damage than stands marked with paint. DxP timber sales in Region 8 are attractive to purchasers, garner more bids, and generate higher bid premiums because the purchaser can be more efficient than in marked sales. This also results in fewer no-bid sales.

Efficiencies gained in using DxP during the presale phases of a sale may increase sale administration due to more complex timber sale administration phases. DxP sales, however, are always scaled sales so there is no need to tally additional timber for activities such as equipment access, damaged timber review, landings, and temporary roads. The purchaser has the freedom to plan the harvest without additional Forest Service personnel marking additional trees thus obtaining the desired outcome in an efficient manner. The only extra work in using DxP is that the quality of prescription implementation must be done as a part of Sale Administration by checking the quality of trees left and the residual basal area. This results in more time being spent in a DxP sale by the sale administrator and possibly more frequent visits than in stands marked by Forest Service personnel.

DxP is not the best choice in some areas. Complicated prescriptions can cause problems for both the Forest Service and the purchaser. For instance, if the prescription stated that all shortleaf pine trees must be retained as leave trees in a stand mixed with shortleaf and loblolly pines, DxP may not work well since it is difficult to differentiate shortleaf pine from loblolly pine easily while operating a feller-buncher. Also, to be efficient in young pine plantations, the purchaser must have high production rates. A complicated prescription would take away the efficiency and may not even be implementable. Selection criteria needs to be fairly straight forward for it to be efficient for the cutting machine operator. If it is not efficient for both the operator and the Forest Service, it is not going to work. Paint can be used in a DxP prescription to identify locations of leave islands and openings, for trees of particularly high value or for trees that are difficult for the cutting machine operator to identify. The prescription must be clear and operationally feasible for the loggers so that they can make correct tree selections efficiently. That creates a win-win scenario for both parties.

Region 3—Jim Youtz

All Forests in Region 3 have either recently revised forest plans or are in the process of finalizing revisions. In Region 3, regionally desired conditions are described by forest type. For frequent fire forests of ponderosa pine, and dry mixed conifers, uneven-age management is emphasized consistent with the natural fire regime and desired objectives. The design understanding needed by practitioners is that DxP should be used only for simple prescriptions for low value material not requiring some level of precision in tree selection. The Region has some experience, however, in using DxP with certain uneven-age management prescriptions, like group selection cutting. With group selection, variable density and free thinning in the matrix is used, while the regeneration groups are generally designated with paint or flagging. This type of prescription is amenable for DxP.

Another new approach currently being used by the Region is the digital prescription guide. Silviculturists use tablet computers with geo-referenced aerial photos to digitally designate areas for treatment within a stand. For example, areas for group selection, including skips and gaps, are designated on the tablet. Technically they are writing a prescription on the tablet as they walk the stand. The digitally mapped prescription then is sent to the contractor as a shapefile to be used with a tablet in the cab of the harvesting equipment. This shapefile gives the exact location where the group openings, skips, and gaps should be. Early implementation shows good results. Digital prescription guides reduce a complex prescription to an operationally simple approach.

Forest Service foresters are much more willing to try this approach when they have large ongoing landscape scale projects, especially those done with stewardship contracts, because they can develop and issue one task order at a time. Often the contract implementation is started with a task order that uses leave tree timber marking. Once that task order is implemented by the contractor, it provides a demonstration template, representing a specific treatment prescription. The demonstration provides a good reference of the desired prescription to be implemented on DxP task orders with similar prescriptions. Forest Service foresters are hesitant to try DxP timber designation on small project areas where the contractor is unknown because there is no time to work intensely with the purchaser or contractor to ensure that the contractor has the ability, knowledge, and expertise necessary to meet the prescription, with an appropriate level of oversight by Forest Service administrators. DxP has not been tried out yet in single tree selection stands. This may be tried in the future, but that would depend on having an experienced operator with an established working relationship.

The big lesson learned from the Region's experience is that silviculturists need to work with the sale administrators to ensure that both are on the same page and the result is as expected. Another lesson learned is the operators' concern with some inefficiency. Operators indicated DxP slowed their operations because the free-thinning in the matrix required examining trees' canopies and making judgment calls. They felt confident about making those calls, but it slowed down productivity. This parameter might get more efficient over time with experience or might stay as an inherent issue of using DxP timber designation in uneven-aged silvicultural applications.

To sum up, DxP is still an ongoing learning process. It can be implemented in complex situations under some circumstances but doesn't work with all contractors and all prescriptions, especially where complex conditions such as dwarf mistletoe and other disease situations require more careful and time-consuming tree selection processes. Some purchasers do not like this process and the responsibility for making those decisions, so they do not bid on timber sales utilizing them. Many purchasers, however, are willing to bid on sales with DxP contract provisions.

Bell Lumber and Pole Company—Jim Parma

Bell Lumber and Pole Company (BLP) has been emphasizing DxP for the last 10 years, and it is good to see it is being used in proper stands and proper prescriptions. BLP is a 110-year-old family owned company and the largest producer of utility poles in North America. BLP has experience with thinning pine not only in the Lake States but also in the South, in Region 8, and some experience with Douglas fir and western red cedar in the West. The first thinning of pine stands is a good time to use DxP, but it also can be used in more than just that. Using DxP is about trust and partnership. The trust only can be gained from the experience of implementing the prescription on the ground. Experience and confidence will show DxP can be tried out on other than first thinning sites, such as basal area thinning or matrix free thinning.

In industry, DxP can help reduce costs. When DxP is implemented, a logger can get equipment to the trees that need to be cut without damaging or cutting the leave trees. In a typical timber sale, the purchaser must contact FS and they must mark any trees that are in the way and approve it. With DxP, the logger can simply cut appropriate trees and designate other leave trees without wasting time. That helps improve efficiency.

Industry people are looking at what trees to leave with the perspective of what trees will make a better product, as well as being interested in the long-term sustainability of forest resources.

Region 6, Siuslaw National Forest—Guenther Castillon

Using DxP can leverage and improve the silvicultural process in the Forest Service. Almost all timber sales in the Siuslaw National Forest are done by DxP. Some of the myths and challenges about DxP are discussed here.

Myths

One of the myths about DxP is that it only works on simple, less complex prescriptions. There are many complex interactions going on in the forests, but the only three things manipulated with prescriptions, generally, are density, species, and structure. Manipulating these characteristics can be simple and clear enough for the loggers, but communicating how to accomplish DxP contract provisions tend to be presented as complicated. Silviculturists, as well as the interdisciplinary team that may have developed the design criteria, should consider that it is not possible to meet all aspects of desired composition and structure. They should be aware of what can be done and what nature has to offer and adapt the prescriptions accordingly. Nature is inherently variable, so if a single prescription is done across the whole unit, it does not mean the result will be uniform across the whole unit. Why not use natural variability rather than create it? There is no such thing as a perfect treatment.

If the treatment is too complex for the purchaser, it is too complex for the cruiser as well. If the prescription is seen as too complex, it implies a problem with the prescription. In DxP, there should be a clear purpose and objectives that are implementable and verifiable. The complexity can be removed by the way of sale layout and by marking the critically important trees. Clear thinking and clear communication can remove most of the complexity through understanding of the objectives and expectations across time and the landscape. Differentiation should be done between what should be achieved by removing certain trees and the associated decision points in selecting those trees. In most cases, there are no complexity issues.

The other myth of DxP is about accountability, i.e., that it cannot be assured using DxP. Accountability cannot always be assured with tree marking either: Paint on trees doesn't always guarantee accountability, although it can increase accountability. Accountability can be reached by clear agreements and clear expectations and communication and supporting each other with the common goal. The purchaser needs wood, the forester needs treatments—helping each other will benefit both by holding each other accountable through sale administration. In the end, DxP can be objectively verifiable if it is thoughtfully designed, written, and communicated through appropriate contract provisions.

Sale layout with DxP is cheaper when compared with tree marking. This creates another myth that it will solve fiscal and efficiency challenges for Forest Service management. Poor understanding of what the actual cost and time savings are and the reality of implementing DxP can worsen the situation and can lead to poor decisionmaking. Appropriate sale layout, cruising, and sale administration are still needed. Costs can be reduced because tree marking is not needed. With DxP, more costs may occur through more field visits at the right time (during and after the implementation, not before).

Challenges

Silviculturists should not put all the prescription development information into the final DxP document presented. It is not the place. That document should be clear and concise with decision points for selecting trees, and it should be presented in clear understandable language. "Simple" language doesn't mean ending up with a "simple" prescription or missing opportunities. In application, the more complex silvicultural prescription is reduced to a marking guide/tree designation guide that is inserted into the timber sale special contract provision that should be more readily interpretable or understandable by both the sale administrator and purchaser.

Both timber sellers and timber purchasers need to invest time and energy in making the process successful by establishing a relationship (which should be done regardless of the designation method). Silviculturists need to improve on clear thinking and clear communication: Consider the landscape perspective by not trying to achieve everything at one time. Silviculturists need to be more realistic with stand-level tactical implementation and gain a greater understanding of other resource disciplines.

Once identified challenges are addressed, the Forest Service can realize the true benefits of DxP in cost efficiencies through better trained, more versatile employees, more fulfilling work process with greater learning potential, clearer thinking, simpler silvicultural process, useful monitoring data, and more adaptive and efficient planning process.

SUMMARY

Using DxP on Forest Service timber sales has been an important business change for the agency. All panelists agree that DxP works best when prescriptions are well designed and communicated, and generally, when prescriptions are not too complex and are limited to about three selection criteria. Forest Service personnel using DxP need to focus on the residual stand and not as much on the individual trees being removed, i.e., concentrate on the overall density, species, and structure of the resulting stand, and not so much on individual trees being left in the exact correct spot. Techniques are available, however, to handle more complex prescriptions (DxP with Reserve Tree Marking, and digital prescription guide). If there are individual trees that are specifically important for biodiversity or other reasons, Forest Service personnel can mark them as reserve trees. Also, digital prescription guides may be used for complex prescriptions, where a tablet is used in the cab of the logging equipment to assist in what type of harvesting should occur in each area.

DxP does not work with all contractors and all prescriptions. Complex conditions such as dwarf mistletoe, other disease situations, and salvage logging after a fire (where live crown ratios are considered) require more careful and time-consuming tree selection processes. Prescriptions that utilize characteristics of individual trees rather than stand characteristics may be more suitable for individual tree marking. Additionally, prescriptions that depend on individual tree characteristics may be more difficult to implement and administer.

DxP can reduce sale layout costs because tree marking is not needed. With DxP, however, sale administration may increase through more field visits during and after implementation, and operator costs may increase if tree selection decisions increase harvesting time. Additionally, the assurance of meeting desired conditions may be lessened when paint is not used. Foresters may be hesitant to try DxP timber designation on small project areas and when the contractor's expertise and performance history is unknown. Development of a good working relationship is important.

DxP can help timber sale purchasers and stewardship contractors achieve better efficiency in harvesting and thinning operations because the operators don't have to give the Forest Service notification around factors specific to the silvicultural prescription and their operator-specific considerations such as cutting trees for skid trails and landings. Trees are not individually designated for cutting or leaving. Operators are free to make any adjustments they want as long as they meet the prescription criteria.

A DxP prescription must be written clearly and must include specific desired end results that are measurable and understandable by both Forest Service sale administration personnel and timber sale purchasers or stewardship contractors. Silviculturists should ensure prescriptions are clear, well-communicated, and tailored to the appropriate desired end result for the landscape to be harvested. Silviculturists need to consider operational feasibility and stand-level tactical implementation when developing silviculture prescriptions.

Use of DxP continues to be an ongoing learning process. Using DxP is about trust and partnership. The trust only can be gained from the experience of implementing the prescription on the ground. Experience and confidence will show that DxP can be implemented on a variety of stand conditions and sites.

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Forest Industry Sector: A Panel Discussion

Robert L. Deal and Olga Romanova[1]

ABSTRACT.—This panel discussion focused broadly on the forest industry sector and how forest management and research on public lands is important to the forest industry sector. Panel members provided different perspectives from the forest industry sector and highlighted some key market topics for the forest industry. The panel addressed opportunities and challenges that the USDA Forest Service will face to increase the pace and scale of forest restoration while providing forest products for the forest industry sector. The panel discussed four themes including: (1) forest market updates and wood product innovations; (2) private landowner perspectives; (3) forest industry perspectives on the forestry sector; and (4) partnerships between the Forest Service and wood products industry and private forests including the use of various contracting mechanisms such as stewardship contracts and Good Neighbor Authority. The panel included four members who addressed the four subthemes. This moderated 1-hour panel began with each panelist providing a 5-minute introduction followed by a series of questions about the forest industry sector, forest products, and forest services that come from Forest Service and private and publicly managed lands. Overall, this panel provided different perspectives on the connection among forest management, research, and the forest industry sector.

FOREST INDUSTRY SECTOR PANELISTS

Brian Brashaw: Program Manager for the Forest Products Marketing Unit (FPMU) at the USDA Forest Service's Forest Products Laboratory (FPL) in Madison, Wisconsin. FPMU's mission is to work collaboratively and strategically with Forest Service and external partners to advance high-value, high-volume markets for forest products. Utilization and marketing emphasis areas include lumber, engineered wood materials, mass timber, wood energy, biochemicals and biofuels, and cellulosic nanomaterials.

Paul DeLong: Senior Vice President for the American Tree Farm System & Conservation at the American Forest Foundation (AFF). He leads a team of conservationists working with partners to administer the 20-million-acre Tree Farm Program and implement projects on family-owned forest lands designed to protect drinking water supplies, at-risk wildlife, and sustainably produced wood across the country. Prior to joining the AFF team in 2016, Paul was for 13 years Wisconsin's Chief State Forester and Administrator of the Wisconsin Department of Natural Resources' Division of Forestry, part of his 24-year investment serving the people of Wisconsin.

Rick Horton: Director of Forest Policy for Minnesota Forest Industries (MFI), a trade organization representing the major timber consuming mills in Minnesota. He advises and informs MFI members of policies, guidelines, and actions that will have an impact on timber supply and forest management activities. Horton is a Wildlife Society certified wildlife biologist with a master's degree from the University of Wisconsin-Madison. He has focused on forest wildlife management throughout most of his 25-year career, including a significant amount of Forest Service NEPA document analysis and engagement.

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Karl Welch: Timber Program Manager for the Chequamegon-Nicolet National Forest (CNNF). Prior to 2019, Welch also served as the CNNF Timber Sale Contracting Officer. His duties include short- and medium-term budget and implementation planning for the forest as well as direct oversight of timber sale preparation, appraisal, and contract development. Welch has planned, prepared, executed, and administered traditional timber sale contracts, stewardship contracts, stewardship agreements, and Good Neighbor Authority agreements with the State of Wisconsin, with combined volumes in excess of 1 billion board feet. Prior to working on the CNNF, Welch has worked for National Forests in Idaho and Alaska as well for the Itasca County Land Department in Minnesota.

PANEL SUMMARY COMMENTS

Paul DeLong (PD): Private Forest Landowner Perspectives

The influence of private landowners in forest landscapes can be shown through the example of the AFF, which supports American family-owned forests. Nationwide, a quarter of a billion acres are owned by over 11 million individuals and families with private landowners constituting the largest forest land ownership category. The daunting challenge is how to sustain this large chunk of forest land for present and future generations. First of all, it should be done through partnerships. In the last decade, AFF undertook an initiative looking at how it could achieve priority conservation outcomes in specific places. Twenty million acres of forests managed sustainably on a third-party certification occurs throughout the country, with a goal of achieving landowners' objectives and doing so in a sustainable manner. AFF recognizes the important challenges facing both forests and society. For example, in the western United States, public land dominates, but family owned private land plays a critical role in protecting water quality. Protecting water supplies requires working across private and public lands together. This is an example of shared stewardship. Maintaining healthy forest conditions on the landscape are important for providing community resilience and reducing threats to forests. In the southern United States, in a landscape dominated by private land, the scale of the biodiversity conservation effort is inspiring. There are many challenges with the prospect of building trust and in the ability of private landowners to be recognized as good land stewards, but this recognition is critical in order to achieve the outcomes everyone can benefit from.

What happens to our ability to manage forests when there are no markets for wood products? Inability to achieve a return on managed land and inability to invest in forest treatments lead to untreated forests, increased wildfire hazard, and increased risk of death and property damage. Where markets exist, incredible amounts of conservation occur; where absent (or limited), it becomes a greater challenge that puts forests at risks and conservation efforts are made more challenging. To sustain forests, there needs to be markets for forest products so that these forests can be managed using sound principles of good silviculture.

Rick Horton (RH): Forest Industry Perspectives

Everybody wants something from the forest: timber, clean water, wildlife habitat, healthy soils, protection of their communities from fires—and all of it takes industry to help accomplish. Grants and partnerships allow us to do things on a small scale, but to do it at the large scale, there has to be an economic driver, which industry provides. This represents a unique partnership between public agencies who have the mandate to manage lands for all the public interests and the industry who gets it done but exists in the competitive economic world. The industry cannot do it just from the goodness of their heart; workers have to be paid, materials purchased, and facilities maintained. There is a lot of forest products competition from the global to local scale, among countries, among companies, and even within big companies.

Industry is concerned about mills completely shutting down due to the loss of the markets, which leads to the loss of jobs. The main causes of the mills' business dwindling are decreases in wood availability and high energy costs. But what can be controlled to sustain the industry?

- First and foremost is having a sustainable and reliable supply of wood. A long-term, reliable supply of wood plays a key role in the decision to invest.
- The other thing is the quality of the wood. Here in Minnesota, for example, people have been chasing old aspen for the last 20–25 years. Now there is a whole generation of foresters that thinks that aspen should be managed on a 75–80 year rotation, but it should not. A better rotation length is 50 years. There is a need to change that and start putting some quality wood on the market instead of old, decadent stuff that is no longer any good.
- Thinning operations produce a lot of small-sized products, which are difficult to use for the industry.
- Another major concern is transportation cost. Foresters need to know where their mills are located, know where their procurement zones are, and understand that transportation is a big cost to the mills. They should put emphasis on production in the forests that are close to the mills, and those forests that are far away can be utilized for experimentation and other options.
- While designing timber harvesting prescriptions, foresters should think about efficiency onsite: Is the site an efficient landing area for the operators, can equipment be placed and used there, can equipment be transported, etc.? Every constraint put on operation leads to loss of efficiency.
- Everything should be done to keep the local industry thriving. It is a lot easier to keep a mill open than to restart a closed one or bring in a new one.
- Forest Service staff should tour the local mills, meet with their managers, get to know the local industry and what their needs are, and work with them to help manage the things that the Forest Service wants from the forest.

Brian Brashaw (BB): Forest Products Research Perspectives

The FPL focuses on a couple of core principles. First, healthy, sustainable forests need a healthy and competitive industry. Second, the industry needs markets for all of the parts of harvested materials (there are gaps in the market right now). These markets exist both locally and globally. To support these core principles, the FPL focuses on research and demonstration projects and technical assistance. For example, about $9 million was recently granted through the National Wood Envision Program to spur market development in areas of wood products and wood energy.

Paper and pulp are still incredibly important. Currently, mills are diversifying by looking for new product applications. Although the paper market is decreasing, packaging, tissue, and toilet paper markets are increasing, and there is diversification in specialty paper. Some of the pulpwood in the southern United States goes through the Panama Canal and starts filling markets in Japan or Korea or other Asian countries, as it is cheaper to get low-cost fiber out of the southeastern United States and barge it across the ocean rather than get it out of Pacific Northwest region.

The lumber market is driven by housing and the United States is still below the 60 years average in housing starts. In the lumber market, about $5 billion in softwood lumber is coming on sales from the United States with even some lumber exports to Canada, as it is cheaper to ship pine to Canada than their local spruce/pine/fir. The hardwood industry has changed: For example, there has been a loss of furniture manufacturing to China over the last couple of decades.

Another important market to cover is the wood energy market. Although in the U.S. midwest region, solar and wind are now prevailing alternative energy sources, wood-based energy is the only energy source that helps us manage our lands. In this particular market, success depends on location. In the U.S. southern region, exports of 15 million tons of wood pellets go to Europe, primarily the United Kingdom, where wood energy is policy driven and creates an opportunity. However, in the U.S. midwest region, wood pellets are only for the domestic market, as it would be too expensive to deliver them to the coast and export them overseas.

Karl Welch: Forest Service's Forest Products Perspective

The existence of a robust industry makes forest management much easier. The relationship between the wood products industry, private businesses, and public land management are symbiotic. Recognizing the benefits of this relationship helps to get things done; if there is a need for a product, there is an opportunity to sell and budget to manage and implement what needs to be done. A bright future for wood products and forest management are codependent on the health and stability of each other. There is a need for both a viable industry and well managed public and private lands. It is essential to communicate achievable forest goals to the forest products industry and to ensure that a reliable supply and even flow of fiber can be available to the industry from national forests. No one is interested in one-time sale projects and waiting for another one in the next decade; that won't work for either the land or for the industry. We all benefit from a healthy forest and multiple-use objectives and that should be taken into account for the long-term goals.

Question: What is the best opportunity for family forest landowners and the Forest Service to work together to develop the forest product sector? What's the biggest challenge?

PD: Greatest opportunity is related to looking at a broad picture of the cross-boundary nature of this work and understanding what is required to have a robust forest products industry. Part of it is predictability of supply. For the part of the national forest management side, it is the maintaining of a robust program of active vegetation management.

The work that has been done concentrated a lot on the tools and techniques to increase the engagement of private landowners because the majority of wood harvested in this country comes from their lands. We need to get the landowners interested and have their own ethics and confidence in making decisions about how they can achieve their objectives. Often, managing timber can be daunting and of concern for obvious reasons. That is why it is crucial to help landowners become confident in their decisions to achieve the outcomes they care about, be it the creation of wildlife habitat, or timber, or something else. Their concern relates to questions about the market being there in the future. If the market has been lost, it is hard to bring it back.

Another challenge for landowners is figuring out how much it is going to cost them if they want to create a wildlife habitat or reach some other goal. The win-win situation is when they break even or earn a profit by creating the forests they want that produce the desired benefits. That requires the relationships where the Forest Service, other public and private land managers, and industry are all working together to deliver that desired outcome. A challenge is trying to synchronize that work. Part of overcoming that challenge is policy work on the state and federal level. Another part is sending signals of what resources (states' investments in the system) are available to help private owners. Where states work collectively, there are more robust market opportunities—and a more robust industry as a result.

Question: Why are folks so excited about building with wood right now?

BB: It is common to build homes out of wood; however, new products are coming up for nonresidential use. Now, wood is being used where it was never used before, such as multi-family high-rise residential housing and industrial, commercial, and retail applications. Mass timber (cross-laminated lumber, like "plywood on steroids") creates really durable products. With architects designing with mass-wood products as a material of choice, it has become a preferred building material for high tech companies like Google, Amazon, and Facebook. Mass timber helps them meet their sustainability goals for carbon sequestration and it is fast to build with such material. In addition, people enjoy working in offices and living in residential housing made of mass timbers. There are seven mass-wood companies currently operating in the United States, with three more in construction (and there are six in Canada). It is about 1 billion board feet of purchased lumber that starts filling this market and it's developing. Mass wood mostly uses low structural grade softwood 2 x 6 or 2 x 8 inch boards, and there are many opportunities for research on how to move that size down. Hardwoods have potential in the future for that as well. Overall, there is a huge opportunity for growth in this area.

Question: How is industry (paper, lumber, composites) being more innovative to remain competitive in today's marketplace?

RH: Most of the industry has their own research programs. Industry is looking at ways to increase efficiency, increase safety, be more innovative, be able to adapt and change quickly, and utilize every available species. If there's an abundance of the relatively cheap raw materials, there is a good opportunity to make investments to find ways to use that material. An example from Minnesota is the production of cellulosic fiber: The pulp gets shipped from the mill to another facility, which turns it to the equivalent of cotton, so that now trees can be used to make clothing. It is very innovative. Another example is Louisiana Pacific's siding mill that produces rot- and insect-resistant siding out of aspen with a 30- to 50-year warranty. Mills are looking at equipment that can rapidly (in less than a day) change from one product to another—like switching from siding to OSB and vice-versa to adapt quickly to changing prices on the market. Mass timber (as previously mentioned), and also mill residues, are being used for energy production. Underutilized species can be turned in something else, such as biochar, as a way to sequester carbon and address soil health issues.

Innovations are one thing, but the biggest thing for the industry to remain competitive is the supply of wood. If the industry has wood, it will find a way to use it.

Question: How do the new authorities and partnerships create opportunities for increasing forest management and restoration?

KW: Authorities and partnerships are a collection of tools that are made available through legislation and legislative tools for funding, etc. Sometimes, policies have been developed by people who did not have on-the-ground experience on the impacts of these policies and their effects on forest management. When such tools come out, there is an "opportunity cost" to learn how to use a tool, to get it in place, and to develop experience to implement it. The cost is generally commensurate with the size of the desired outcome. Thus, it is better to start small, and even if the tool did not initially work as planned, keep trying to utilize it.

Incentivizing traditional opponents of forest management and having them come to the table and be part of the process can reduce appeals, reduce litigation associated with environmental planning, and eventually achieve greater outcomes. Having diversity in the stakeholders brings value through more creative thoughts and discussion that can be leveraged to greater outcomes. Having that discussion and figuring out how to tweak that tool to make it more efficient helps to get over those "opportunity costs." Also, without a commitment to those tools, improvement is unlikely as land management is a long-term prospect. There may not be tangible outcomes right away, but they should materialize with time, especially on the landscape level. There are many tools and opportunities that should be used strategically as a team effort to reach the desired outcomes. Partnerships that can be granted through the regulation or legislation are available. The first and foremost step in going into a partnership is the mutual agreement and overlap of desired outcomes. Partnerships need to stay focused on the highest priority outcomes without adding additional objectives that may be desired by only one party. Also, staying focused on mutual goals will allow the partnership to leverage additional resources.

Question from audience: We've seen the fallout of the industry from genetics tree-improvement programs. What's the hook now? How can industry be engaged in long-term projects important for managing resources?

RH: Today, industry is dedicated to the future health of the forest and it has its own research projects. Talk to individual companies. I can help to get in with the right people. It is a good question to have because it is connected with the long-term survival of the forest and the industry.

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Silviculture in a Complex Management Environment: A Forest Supervisor's Perspective

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ABSTRACT.—Managing vegetation with silviculture on national forests in the 21st century will be far more complex than at any time in the hundred plus years of the agency's history. Silviculture will take place in an environment of great uncertainty. A changing climate, unprecedented rates of change to biological communities from invasive species and pests, the likelihood of continued capacity limitations to treat acreage, changes in land use and forest management on surrounding lands, and business models of timber companies will challenge managers and silvicultural practitioners to make tradeoff choices and determine optimization outcomes that will have far reaching and long-lasting effects. Practicing silviculture with humble confidence will become even more imperative. Four attributes essential to facing these practical realities are given to highlight the kinds of dilemmas managers will face and how silviculturists can best contribute to informed decisionmaking.

A PERSPECTIVE ON OUR HISTORY

USDA Forest Service silviculturists, as well as many others in tribal, local government, university, and private sector agencies and businesses, have a long, deservedly proud, and important history in the now hundred plus years of managing national forests and other forested lands in the United States. The science and practical implementation of silviculture helped restore and reforest not just what are now national forest lands, but also profoundly influenced the management of tribal, state, county, town, industrial, and non-industrial private lands. Those private lands now play an increasingly important role in the accumulation of broad social benefits and values that go beyond the desires and values of individual landowners.

Silviculture has afforded the means for managing national forests so that they can provide the many social and economic benefits of wood fiber in its many forms with reasonable assurance that those same forests can sustain the removal of trees and provide the same suite of benefits again and again. Think how different this is from the great logging era when extraction of wood fiber was maximized to great detriment of other values and without thought of stewardship or long-term sustainability. This idea of sustainable forestry may sound simple and almost a given, but consider what it is we are doing—inserting ourselves into complex biotic communities we call forests that are still reassembling after the most recent glacial presence, climatic fluctuations, loss of megafauna and other species that had been there for thousands of years, and multiple incursions of humans after the last glacial period. Then, recently we disturbed these forests again, significantly, a hundred or so years ago when their trees became the raw material that helped build cities and towns of America and in the process disturbing them greatly and shocking them from the canopy to the soil and then allowing them to recover to some semblance of their original productivity, vigor, and future resilience. Today through silviculture, we are planning to disturb these forests to a lesser degree but again and again in the same places. At least we hope that is what is occurring. And theoretically, we are doing this with "humble confidence."

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The management of national forests has been based on ever-evolving paradigms of sustainable forestry and ecosystem management influenced by science, social trends, popular opinion, and politics. The business model of national forest management is therefore almost unexplainable if one considers the millions if not billions of decisions made every day from places in the woods, laboratories, offices, and halls of Congress. One constant theme throughout, nonetheless, is that decisions are made and implemented, thereby setting in motion a multitude of trajectories on millions of acres of land, trajectories which influence each other and natural processes, and in turn are influenced by the forces, large and small, of Nature and of humans. In my simple way of thinking, "*It is impossible to describe exactly and precisely what is going on out there and why.*"

Managers want to know what is occurring and the public expects it. There are many important and sometimes conflicting values we want from public lands, and perhaps most importantly the ecosystems services needed to support human society. Yet, predicting the future condition of forest vegetation remains challenging despite decades of research into reasonably undisturbed and significantly human-altered systems, and similar decades of management, measurement, experiments, and observation.

Despite these uncertainties, we manage. We observe, measure, record, analyze, plan, model, predict, implement, monitor, evaluate consequences, project scenarios, make choices to change or stay the course, and keep managing. Our fundamental principle is that many lands in the National Forest System should be actively managed to account for ecological disturbance factors that no longer occur in form, intensity, or periodicity and to optimize social, economic, and ecological benefits to be derived from these public lands with raw material in the form of wood fiber as one of the important outcomes. Silviculture continues to be the gas in the engine of implementation on these acres with commercial timber sales as the vehicle to make it happen, those sales being a most fortunate business arrangement on many acres, the desired management subsidized to a degree by the demand for wood-based products and a set of laws and policies that allow us to sell these products.

Political, social, and ecological factors have directed national forest managers to either manage lightly or not at all in other places like federally designated Wildernesses, Wilderness Study Areas, Research Natural Areas, old-growth designated areas, and similar places. There, the forces of both humans and nature occur, as none are large enough nor can they be bounded effectively to keep out the effects of what is occurring everywhere else. In these places we do far less observing, monitoring, evaluating, predictive modeling, scenario projecting, and evaluating of consequences of management actions, and the like, perhaps naively and to the detriment of our ability to manage actively elsewhere. Our foundational principle has largely been to let these places be with the idea that perhaps nature will show us what happens in the absence of human management, and in turn we can learn how to manage the other areas and national forests as a whole more successfully.

At our best, research and management silviculturists have responded to these challenges with "humble confidence"—managing actively or lightly, always recognizing the complexity of the ecological, social, political, and economic systems that converge around our work, applying what we've learned with keen eyes and ears for change, and adapting our understanding as we continue to learn.

It can be a bit unnerving to think about our forests in North America as constantly reassembling and recovering, and our past, current, and future actions, designed to restore and sustain, as adding another disturbance factor into them. We know not to what end the forests are evolving, but we know that the complex interrelationships of soil, water, air, sunshine, shade, plants, and animals are what comprise the forest at any one time, and that there are thresholds and tolerances determining if the future is a community that might still be called a northern hardwood forest or a spruce-fir forest or something else.

While silviculture has always been an evolving and adaptive practice, I wonder if and I fear that the pace of adaptation in our "humble confidence" may now not be rapid enough. As author and renowned conservationist Aldo Leopold wrote in his essay, *Arizona and New Mexico: Thinking Like a Mountain* (Leopold 1949), "We all strive for safety, prosperity, comfort, long life, and dullness." I think in two words he meant we all strive for certainty and stability. How wonderful it would be for the science and practice of silviculture to be occurring in a relatively stable world, one where we had time to learn, try, adapt, and find the ideal set of practices for all forest types and conditions where commercial timber sales and other stewardship activities are to occur. With forestry as a long-term proposition, one in which we will not likely have careers or lives long enough to see the fruits of our labors, we would benefit greatly from a century or two at least of such stability and certainty to really see if what we are doing is working. At best, we see the first few strides out of the gate of what we do, the middle hurdles of those who came before us, and the last strides to the finish line of what those who began long ago, such as the Civilian Conservation Corps workers planting trees or early foresters tending regenerating aspen or hardwood forests.

THE PRESENT AND FUTURE PROJECTIONS

We are living in far more interesting times than Sir Austen Chamberlain was referring to 75 years ago when he said in a now famous speech: "May you live in interesting times. There is no doubt that the curse has fallen on us. We move from one crisis to another. We suffer one disturbance and shock after another" (The Yorkshire Post 1936). This is our fate as land managers and scientists in the times we are living in. We live in a world of less certainty, other than the high probability of change in pace and intensity and form, that will challenge our established science and practices.

What will this future look like and what roles will research and practicing silviculturists have in it? The "Northern Forest Futures" project (from the Forest Service's Northern Research Station) uses predictive modeling and scenario projections as "a window on tomorrow's forests, revealing how today's trends and choices can change the future landscape of the Northeast and Midwest. Using the latest inventory data and scientific projections, the Northern Forest Futures Project helps visualize what's here today and what to expect tomorrow. Ultimately, this project informs decisionmaking about the sustainable management of public and private forests in the northern United States" (Shifley and Moser 2016). A scenario projection results when certain assumptions about such factors as harvest rates, climate, land-use change, and others are fed into a model of future forest conditions. Similar bodies of work in the South and West provide a glimpse through the window to the future in those parts of the country.

The Northern Forest Futures Project provides predictions for a number of factors. For forest productivity, of particular relevance to silviculturists, key findings include:

- Forest area by age class is concentrated in the 40– to 80–year age category, resulting in a lack of structural forest diversity that would take decades to alter.
- Under all projections for northern forests:
    - The growth-to-removals ratio would be <1.0 (indicating an unsustainable situation over the long term) from 2035 to 2055; by 2060, the ratio would increase to 1.2 if harvesting rates observed in the recent past (2003 to 2008) continue into the future.

  - o The trend of steadily increasing live wood volume that characterized northern forests in the past century would level off from 2010 to 2050; after 2050, volume is projected to decrease if harvesting increases to satisfy demand for bioenergy.
  - o The area of the maple-beech-birch forest-type group would increase and the area of nearly all other forest-type groups would decrease; projections are mixed for the white-red-jack pine forest-type group.
- For the North as a whole, projected forest removals resulting from land-use changes are likely to average about 13 percent of total removals, with the remainder resulting from harvesting; in populous eastern States—including Massachusetts, Maryland, New Jersey, and Rhode Island—removals resulting from land-use changes would be >50 percent in some decades.

Other factors addressed by the Northern Forest Futures Project are of relevance and importance to national forest land managers and to silviculturists who support the work because of the Forest Service's multiple use–multiple values mission. Predicted futures for biodiversity, ecosystem health, soil and water conservation, and the global carbon cycle indicate trends of change and threats to current values of forests and to their long-term sustainability. While some projections offer less concerning trends and conditions, there are a number of threats to forests already occurring and likely to increase and expand.

- Present-day and likely future challenges to forest ecosystem health, diversity, and resilience are unprecedented.
- Existing forest threats already causing major changes to forests are likely to increase with the potential to decimate a variety of tree species in urban and rural areas.
- Decline-disease complexes, such as oak decline, are causing negative ecological and economic effects and are expected to continue.
- Invasive plants will continue to affect habitat loss, ecosystem degradation, and decreasing species diversity.
- Deforestation and fragmentation will contribute to worsening forest health conditions, which provide increased opportunities for invasions to spread.
- The ability of forests in the Midwest and Northeast to store carbon is likely to decrease.

THE FUTURE ROLE OF SILVICULTURE

This moment—the National Silviculture Workshop—and this place, Bemidji, Minnesota, are right for pondering imminent changes on the horizon. For anyone managing a national forest in Wisconsin, the approach of emerald ash borer (EAB) is a case study in managing under 21st century uncertainty. EAB has worked its way from lower Michigan around Lake Michigan and up and around the part of northern Wisconsin where most public forest lands and the greatest abundance of upland ash and black ash forested wetlands occur. What we do or don't do in the next 5 years will not only determine the fate of the majority of black ash lowlands in Wisconsin, but it is likely the final place EAB will invade before it sets course for the last great stronghold of ash in the East and Upper Midwest here in northern Minnesota. While EAB has been and remains on the radar screen of major forest health issues, it is likely not the last one. We need to be better prepared for rapid and unpredictable invasions of insects and diseases that threaten the viability of forests and their many values; we must be ready to project scenarios and make informed decisions that are understood as experiments.

Silviculturists must practice their craft with even more humble confidence. Silviculture is a science and practice of probabilities and consequences versus likely certainty. The prescribed trajectory for a treatment decision has a high probability of not being consummated. That thinned or regenerating or maturing forest stand is likely to be overbrowsed by those big and small who would eat leaves, bark, and twigs; subject to severe drought and episodic rain; exposed to variable winters with more freeze-thaw cycles; and enduring higher heat and perhaps colder cold. Water tables may rise and fall beyond normal variability. Species expected to be part of the future stand may disappear suddenly. Soils may have altered functions as nonnative earthworms dine their way deeper into forests.

Silviculturists may create thresholds and scenario options but it is imperative for those who succeed them to understand trigger points and options for when prescriptions and desired future conditions need to be changed. Research scientists already are and need to continue and accelerate science around uncertainty and scenario projections.

Silviculturists must be strident advocates and practitioners of integration of values and treatments. Silviculturists must play an increasing and adaptive role in the future of forests and forest management. They can neither go it alone nor can they represent a singular or narrow position or value set. Silviculture must be woven into the complex problems for current and future forests that go beyond prescribing treatments for forest stands that support commercial timber harvests. Forests always have and always will provide values beyond commercially valuable wood fiber. There will not be enough land to parse out to singular or dominant outcomes and values. Designing forests that can accommodate and provide increasingly overlapping value sets will be necessary. Silviculturists play a difficult and special role in land management for not only do they need to integrate for land outcome values; they also need to interface successfully with business practices of commercial timber operations, which also change to respond to other values including an increasingly difficult financial bottom line.

Silviculturists must be increasingly innovative and forward thinking with the ability and motivation to develop options for unforeseen circumstances for managers and decisionmakers. A classic example is the lack of capacity to implement prescribed ideal silviculture regimens on national forests due to shortages of funding and staffing. Stands projected for treatment every 15 years may end up on a 25–30 year regimen. The reality for silviculturists is like that for doctors. You may have less time for meeting with and treating your patients. Identifying in advance what can be done under a different treatment model will be invaluable to managers.

Research and practicing silviculturists need to spend less time and focus on planning and consequence evaluations and more on monitoring, evaluation, and predictive modeling and scenario projections. The world has changed in national forest planning under the 2012 planning rule. We are expected to keep constant attention on the relevance of the national forest Land and Resource Management Plans versus comprehensively redoing the Forest Plans every 15 years. Monitoring and evaluating must expand and be better designed on not just what the on the ground results are, but to constant evaluation of the assumptions used to do modeling and scenarios and predictions of results.

Silviculturist cannot do this alone, but they need to be an advocate for management as an experiment with a willingness to be wrong and to adapt. For too long, management direction, prescriptions, and desired outcomes have been looked at as social contracts or promises. In a world of rapid and sometimes unpredictable change and uncertainty in the places we manage, the outcomes from that management is what we hope for, but with less certainty from both the ability to reach that outcome, and from the possible need to change management direction because outcomes and conditions planned for in other areas are no longer possible or from shifts in knowledge, desired outcomes, or local conditions. Our research experimental forests will increase in importance, but not all needed silvicultural experimentation can occur there. Adjustments to both management and research design need to be made so that important science findings occur more where national forests are being managed and increase in both number and rate.

Ultimately, achieving these future roles will require research and practicing silviculturists to become forest druids—lore keepers, forest health professionals, and effective and influential advisors to those who are delegated and authorized to make informed decisions. Silviculturists have the same challenges as human health professionals who have to adapt to a different holistic approach to medicine. The skills to summarize, synthesize, effectively communicate not just in words on paper or verbally—but to communicate inherently complex concepts and to help explain probability and scenarios with tradeoffs, consequences, and complex interactive effects—will be key. These skills generally are not taught in forestry schools and trends in higher education suggest that these skills may not be taught in the future. This important skill must be learned and honed on the job. Those who can span management and science and communicate effectively will be the primary influencers of the future.

The land we have the privilege of stewarding has always needed adaptive management. Now those of us who steward need to be adaptive as well, to evolve professionally as quickly as the imminent changes around us.

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Integrating Ecosystem Services Into Sustainable Forest Management of Public Lands

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ABSTRACT.—Ecosystem services are recognized as a way of framing and describing the broad suite of benefits that people receive from forests. The USDA Forest Service has been exploring use of an ecosystem services framework to describe forest values provided by public lands and to attract and build partnerships with stakeholders to implement projects. In addition to describing ecosystem services provided by forest landscapes, this framework examines the potential tradeoffs among services associated with proposed management activities, while attracting and building partnerships with stakeholders who benefit from particular services these forests provide. Projects that describe objectives and outcomes using an ecosystem services framework could provide an important forest management tool. So, the Forest Service has recently sought place-based applications of the ecosystem services framework to national forest management to better illustrate the concept for policymakers, managers, and forest stakeholders. This paper describes how project scale guidelines can be designed to address commonly recognized products such as timber and water, as well as critical regulating, supporting, and cultural services. We present results from national programs to forest plan assessments to project-scale applications that enhance the provision of ecosystem services and sustainable forest management at broad to local scales.

INTRODUCTION

Ecosystem services have emerged as a way of framing and describing the broad suite of benefits that people receive from nature and the value of these services are now recognized from global to local scales (Costanza et al. 1997, Daily 1997, Farley and Costanza 2010, Kroeger and Casey 2007). The Millennium Ecosystem Assessment (MEA 2005) developed a classification for these services and defined them as provisioning, regulating, cultural, and supporting services. Provisioning services are familiar commodities such as food, fresh water, timber, and fiber for direct human use. Regulating services provide benefits such as flood and disease control, water purification, climate stabilization, and crop pollination. Cultural services include recreational, spiritual, aesthetic, and educational values. Supporting services are the underlying processes that maintain the conditions for life on Earth and include nutrient cycling, soil formation, and primary production.

Forests provide an abundance of ecosystem services. For instance, they have high conservation value for a number of threatened and endangered species, for mitigating pollution, and for flood control. Forests can be managed for the long-term sustainability of wood products, wildlife, and other ecosystem services (Deal et al. 2014). Forests also play a major role in the global carbon cycle through the ability of trees to withdraw or sequester carbon, and forests serve as a terrestrial carbon sink during most stages of forest development (FAO 205, Oliver 2001, Oliver and Deal 2007). Forest carbon is a particularly important ecosystem service to monitor and manage because there is interest in both maintaining current forest carbon stocks and increasing carbon sequestration as a mitigation strategy for reducing atmospheric CO_2

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(FAO 2005, Oliver and Meznik 2005). Forests can serve as carbon sinks in the standing timber, in wood products, and in avoided emissions when wood is used as a substitute for more fossil fuel-consuming structural products such as steel, concrete, and brick (Campbell et al. 2009, Lippke et al. 2004, Mitchell et al. 2009).

Not only can forest products play an important role in carbon sequestration, they have long had a critical role in ensuring that forests function as a vital part of the economy. Hence, sustainable forest management is also crucial. Sustainable forest management is the practice of meeting our current forest resource needs and values without compromising the use of forests by future generations (Deal 2018). Not surprisingly, then, natural resource legislation directs federal land management agencies to include ecosystem services in federal decisionmaking and forest plan revisions (OMB 2015, USDA FS 2012). As an example, the Forest Service's 2012 Forest Planning Rule requires the agency to include ecosystem services in assessments and forest plan revisions (USDA FS 2012). Likewise, a 2015 Presidential memorandum asserts that by incorporating ecosystem services into federal agency planning and decisionmaking, government institutions will be able "to more effectively address challenges facing the Nation and ensure ecosystems are healthy for this and future generations" (OMB 2015, p. 12).

There is now a need to integrate national policy and programs both for the evaluation of ecosystem services into the national forest planning process and for local project implementation. In particular, forest managers and planners want to demonstrate how an ecosystem services framework can be used in national forest assessments and forest plans revisions, and to address ecosystem services in local projects. To support their efforts, the Forest Service has been evaluating the use of an ecosystem services framework to describe forest values provided by federal lands and to attract and build partnerships with stakeholders and nongovernment organizations to implement projects (Smith et al. 2011). An ecosystem services framework based on sustainable forest management principles could easily be incorporated into stand level silvicultural prescriptions and may be a highly effective way to demonstrate the provision of important ecosystem services included in forest assessments and plans. Forest management plans and stand silvicultural prescriptions could include both common ecosystem services provided such as sustainable timber supply, wildlife habitat, or reduced wildfire risk, and some services that are undervalued or not typically included in forest management plans or stand silvicultural prescriptions such as special forest products, cultural values, and recreation use.

These services are often overlooked or undervalued in typical management plans but including them in a silvicultural prescription would be an innovative way to both address the protection of some key ecosystem services identified in forest assessments and develop management plans that could enhance or preserve these services. Identifying these key services in the desired future condition would be a suitable starting point from which silviculturists could develop specific management plans to ensure these services will be maintained into the future. In this paper, I identify opportunities and needs to integrate ecosystem services into national Forest Service policy and operations and summarize current efforts to address this potential. I further describe how Forest Service national forest plans can use an ecosystem services framework to both meet the requirements of the Forest Service planning rule (USDA FS 2012) and help the agency identify and clarify relationships between the conditions of forest ecosystems and the quality of services they provide. Finally, I provide some examples of how ecosystem services frameworks have been integrated into sustainable forest management at the project scale and how this framework helped the agency meet its mission at the national, forest, and local levels.

ECOSYSTEM SERVICES INTO NATIONAL FOREST SERVICE POLICY AND OPERATIONS

With national forests and grasslands covering over 188 million acres on 155 national forests and grasslands (USDA FS 2008), the Forest Service manages about one-fifth of the forested area in the United States. The Multiple Use Sustained Yield Act (MUSYA 1960), the National Forest Management Act of 1976 (USDA FS 1976), and the National Environmental Policy Act (NEPA 1969) are some of the primary laws and regulations (Table 1) that specified how the Forest Service manages these lands. More recently, the Obama Administration started directing the Forest Service and other federal agencies to incorporate ecosystem services into their decisionmaking processes. A crucial step in operationalizing the new policies regarding ecosystem services into management of Forest Service lands nationwide was the establishment of the 2012 land management planning rule (USDA FS 2012).

Table 1.—Natural resource legislation and response to legislation by the Forest Service (FS) and Bureau of Land Management (BLM).

Natural resource legislation	Intent of legislation	Response by FS and BLM to legislation
Multiple Use Sustained Yield Act (1960)	Promote sustainable management of natural resources to meet the growing needs of an increasing population and expanding economy.	FS and BLM directed to manage timber, range, water, recreation, and wildlife with equal importance.
National Environmental Policy Act (1969)	Encourage harmony between people and the environment, enrich the understanding of the ecological systems and natural resources important to the Nation, and establish a Council on Environmental Quality.	Any federal, state, or local project that involves federal funding, work performed by the federal government, or permits issued by a federal agency must take a multidisciplinary approach to decisionmaking, including consideration of alternatives.
Federal Land Policy and Management Act (1976) National Forest Management Act (1976)	Establish policy of inventory and planning in accordance with the Multiple Use Sustainable Yield Act.	FS and BLM develop land management plans in collaboration with the public to determine appropriate multiple uses, develop strategies for resource management and protection, and establish systems for inventory and monitoring to evaluate the status of resources and management effectiveness.
National Forest System Land Management Planning Rule (2012)	Regulation developed by the FS to implement planning required by the National Forest Management Act.	Rule explicitly requires FS managers to address ecosystem services in planning to ensure that forests have the capacity to provide people and communities with a range of social, economic, and ecological benefits for the present and into the future. Staff across the agency develop and apply tools to address ecosystem services in land management efforts.

Regionally, the agency had already taken some steps in the direction of ecosystem service-driven management policies. For example, prior to adoption of the 2012 planning rule, some Forest Service researchers, National Forest System planners, and managers developed an ecosystem services framework on the Deschutes National Forest in central Oregon (Smith et al. 2011). This effort included (1) describing the ecosystem services provided by the forest; (2) investigating how an ecosystem services framework could support an integrated management approach across program areas to sustain ecological functions and processes; (3) assessing the potential tradeoffs among different ecosystem services following specific management actions; (4) using the ecosystem services framework to identify partners and stakeholders to collaboratively plan and implement projects with stakeholder and cooperators; and (5) developing tools and models for managers to assess the potential tradeoffs among ecosystem services following management plans. This effort led to the development of a project-level management plan based on ecosystem services (Smith et al. 2011). Although this framework has not been directly used in assessments and forest plan revisions, it has been used to evaluate smaller scale projects in the Forest Service's Pacific Northwest Region (Marsh and Drink planning areas) described in following sections. This report also enabled managers to explore how an ecosystem services framework can be applied operationally to guide stewardship of national forests and to support restoration of functions and processes characteristic of healthy and resilient forest ecosystems.

The 2012 rule explicitly required the Forest Service to include ecosystem services in the assessment phase of forest planning as mandated by the National Forest Management Act (USDA FS 1976). In this new rule, the term "ecosystem services" was frequently mentioned with "multiple use," a reference to the MUSYA. MUSYA called for national forests and grasslands to be managed for "outdoor recreation, range, timber, watershed, wildlife, and fish purposes" and further defined multiple use as "management of all the various renewable surface resources of the national forests." Although there was substantial overlap between provisioning services and multiple uses as defined by the MUSYA, the addition of ecosystem services in the 2012 planning rule expanded the concept of multiple use through the inclusion of supporting, regulating, and cultural services. For example, the 2012 rule underscored the importance of cultural heritage values and specifically mentions services important for maintaining cultural use, special forest products, and services of particular value for Native American tribes (USDA FS 2012). The 2012 planning rule also expanded public participation in the planning process in several important ways. Specifically, the planning rule states that plans will guide the management of Forest Service land so that they have the capacity to provide people and communities with ecosystem services and multiple uses that offer a range of social, economic, and ecological benefits for the present and into the future (USDA FS 2012).

In 2015, a new Presidential memorandum further required that federal agencies promote consideration of ecosystem services in planning, investments, and regulations (OMB 2015), something that the Forest Service has worked on extensively. However, the Forest Service has struggled to describe, quantify, and value all of the potential ecosystem services that public forestlands provide. To address this challenge, the Planning Rule Final Directives (USDA FS 2015) that guided implementation of the 2012 planning rule directed that forest plan revisions focus on "key" ecosystem services. These key services are important in the broader landscape outside of the plan area and are likely to be influenced by the land management plan (USDA FS 2015). The inclusion of key ecosystem services allows some flexibility and specific focus for individual national forests. Most forest plan assessments include 10–15 key ecosystem services that may vary from common provisioning services (timber, water, fish and wildlife habitat) to highly specific regulating or cultural values (special forest products, endangered species habitats, scenic views, carbon sequestration or flood control, among others).

Another critical effort for incorporating ecosystem services into Forest Service national policy and operations developed from the National Ecosystem Services Strategy Team (NESST). NESST was chartered by the Forest Service leadership (NESST 2013) to collaboratively develop national strategy and policy around ecosystem services and integrate them into Forest Service programs and operations. In particular, there was a need to develop a common understanding of ecosystem services in order to explain the relevance of an ecosystem services framework for the agency and to provide better communication across agency Deputy Areas by formalizing information sharing and reporting mechanisms. Major NESST objectives included articulating and demonstrating the relevance of an ecosystem services framework across the agency; developing formal policy and informal guidance to support an ecosystem services framework for federal, state, private, and tribal forest lands; building capacity and infrastructure across Forest Service Deputy Areas to manage forests for the enhancement of ecosystem service benefits; designing inventory methodologies and data management solutions to improve reporting and evaluating ecosystem service benefits; and fostering two-way communication inside and outside the Forest Service regarding how an ecosystem services framework can better support management objectives and improve outcomes (Deal et al. 2017).

Nationally, the application of ecosystem services has occurred across all types of lands (public and private) and across different Deputy Areas of the Forest Service (the National Forest System, Research and Development, and State and Private Forestry). Some examples of such efforts include the adoption of the 2012 Planning Rule in forest assessments and for developing new tools to assess ecosystem services provision such as i-Tree (Nowak 2008). However, there is now a need to move from national programs and policy to regional and local scales to assess how an ecosystem services framework can be used in national forest assessments and forest plans, and to implement and evaluate ecosystem system services into projects. The following section describes how forest plans can use this framework to (1) meet planning rule requirements; (2) help the agency identify and communicate why particular management actions are needed; and (3) clarify relationships between the conditions of forest ecosystems and the quality of services they provide.

APPLYING ECOSYSTEM SERVICES AT FOREST AND PROJECT SCALES

Ecosystem services can add particular value at the forest- and project-scale levels of decisionmaking and implementation. Place-based application of the ecosystem service framework highlights the connections between public benefits and ecosystem condition and addresses management challenges by considering the range of services that are affected by projects and the potential tradeoffs that result from particular actions. After all, the project scale is where forest management is applied. To highlight these opportunities, I will assess the use of the ecosystem services framework with three examples of projects in the Pacific Northwest Region.

The Marsh Project

The Marsh planning area on the Deschutes National Forest (Oregon) is a 30,000-acre watershed just south of Crescent Lake that encompasses the Big Marsh and Refrigerator Creek Drainages. The ecology of the area is extremely complex with high biological diversity. The Crescent Ranger District engaged in intensive planning in Big Marsh, one of the most expansive high elevation wetland/marsh complexes in the continental United States. The marsh supports the largest Oregon spotted frog (*Rana pretiosa*) population in the state and

Figure 1.—The Marsh Project planning area is the headwaters of the Deschutes River in central Oregon. It provides dispersed recreation for mountain bikers and canoers as well as habitat for many wildlife species including beaver, river otter, elk, marten, Oregon spotted frog, migratory birds, and rare graminoids. Photo by Carina Rosterolla, USDA Forest Service.

provides habitat for two rare graminoids, *Scirpus subterminalis* and *Carex lasiocarpa*. Other major resource considerations include matsutake mushroom (*Tricholoma matsutake*) habitat (a commercially harvested and culturally significant species), two late successional reserves (LSRs), threatened and endangered species like the great grey (*Strix nebulosa)* and northern spotted owls (*Strix occidentalis caurina*), wild and scenic river values, riparian reserves, big game and fish habitat, and dispersed recreation including mountain biking and canoeing (Fig. 1).

Due to the complexity and uniqueness of this watershed, the Forest Service incorporated an ecosystem services framework into the project analysis as a way to communicate the goods and services supported by sustaining a functioning, resilient landscape. The ecosystem services framework provided a platform for integrating forest management and restoration actions with public benefits such as clean water, cultural values, and wildlife habitat. Although this project-level assessment was not directly related to forest plan revision, it reflects the intent of the 2012 planning rule to support forest restoration and conservation, watershed protection, and wildlife conservation, as well as the sustainable provision of benefits, services, resources, and uses of Forest Service lands, including sustainable recreation (USDA FS 2012). In order to identify the key values associated with the ecological, economic, and social benefits or services of this landscape, Forest Service staff designed workshops with The Nature Conservancy to engage stakeholders, constituents and subject-matter experts in discussions. Public engagement includes dialogue regarding where active management and restoration were needed to sustain ecological function and reduce risks to those values. Once the key ecosystem services were identified, the challenge was to ensure they were clearly linked to the project purpose and need as defined by the National Environmental Policy Act. Metrics were

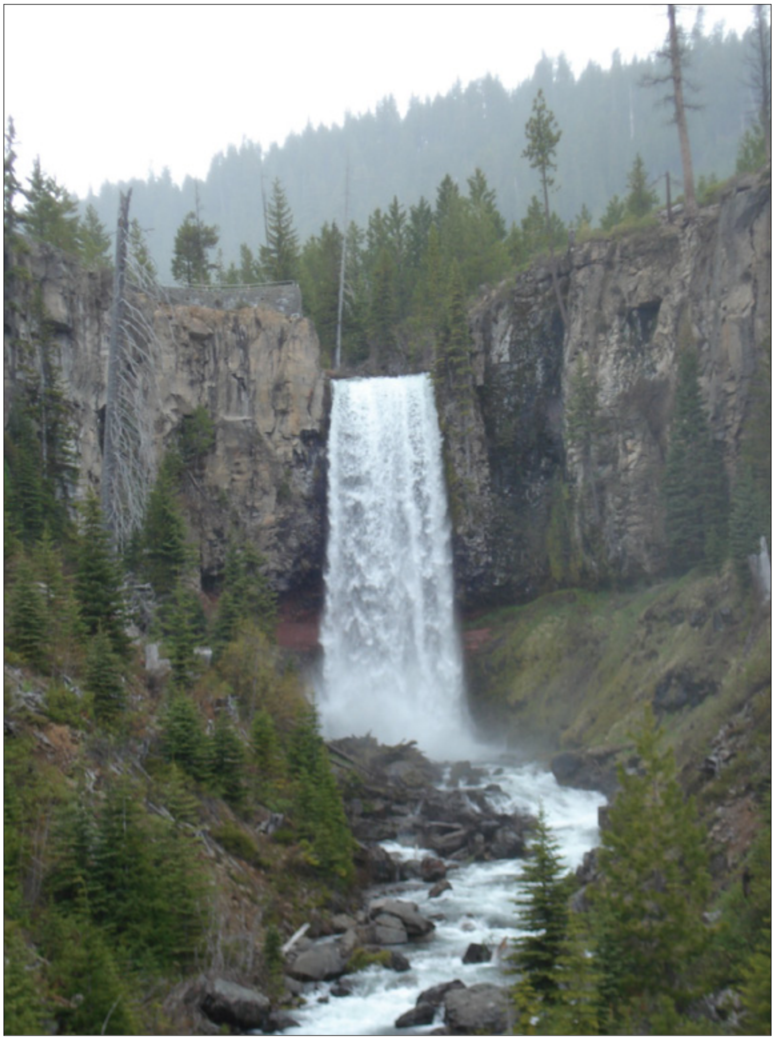

Figure 2.—The water supply for the city of Bend, Oregon, originates on the Drink Project planning area of the Deschutes National Forest. The forest is valued for water supply, recreation, wildlife habitat, timber, and scenery such as this view of Tumalo Falls. Photo by Svetlana Kushsch Schroder, Hancock Forest Management, used with permission.

developed to quantify differences between management alternatives and monitor outcomes. The ecosystem services framework provided a more comprehensive understanding of the benefits of active forest management, potentially enhancing collaborative partnerships and supporting restoration activities.

The Drink Project

The Drink planning area (also on the Deschutes National Forest) is a 17,000-acre area located on the eastern slopes of the Cascade Range and provides a number of key ecosystem services including drinking water for the city of Bend, Oregon (Fig. 2), habitat for a threatened wildlife species (northern spotted owl), and a number of important recreational services (Smith et al. 2011). This project analyzed the effects of fuel treatments designed to reduce fire hazard on ecosystem services that were identified as the most important values of this study area. Tradeoffs between the provision of the ecosystem services of water quality, northern spotted owl habitat protection, and fire hazard reduction were assessed using mathematical models that integrated all these values. Study results in this project area (Kushch-Shroder et al. 2016) showed that management activities planned in areas of high ecological importance, such as northern spotted owl habitat and municipal watersheds, affect the important ecosystem services these areas provide. In the short term, fire hazard reduction led to increases in sedimentation and reduced water quality and some loss of potential northern spotted owl habitat. However, over the longer term, analysis showed that the loss of water quality and northern spotted owl habitat caused by wildfire would be 30–50 percent less than without any treatments to reduce wildfire hazard. These results provide alternative strategies where various objectives are prioritized differently; thus, they present a wide range of choices to meet different requirements and public demands. The knowledge of forest managers can further refine the suggested management plans, creating well informed and effective management strategies.

The Cool Soda Project

Located on the westside of the Cascade Range of Oregon, the Cool Soda area has a fire regime with a combination of mixed severity and stand replacement. This project area included an approximately 10,000-acre "checkerboard" of Forest Service and private land where universities, tribal members, and a number of government agencies collaboratively engaged in an all-lands framework to assess the broad suite of ecosystem services provided by the landscape (Furtwangler et al. 2012). The intent was to improve management of Forest Service land to achieve ecosystem resiliency, while providing direct socioeconomic benefits to local communities and stakeholders. Several key services were addressed in the planning process, including changes in the volume and quality of timber sold, changes in water quality, sustainable recreation, the provision of special forest products including beargrass (*Xerophyllum tenax*) and huckleberry (*Vaccinium* spp.) valued by tribes, and restoration of fish and wildlife habitat. This project was an outstanding example of cross jurisdictional, public-private management with consultation by tribal governments to sustain cultural resources and has been cited as one of the best examples of an all-lands management approach to provide multiple ecosystem services for diverse stakeholders and partners (Furtwangler et al. 2012).

Sustainable Forest Management is the practice of meeting the forest resource needs and values of the present without compromising the similar capability of future generations (Deal 2018). An ecosystem services framework based on sustainable forest management principles could easily be incorporated into stand-level silvicultural prescriptions and may be a highly effective way to demonstrate the provision of important ecosystem services included in forest assessments and plans. Forest management plans and stand silvicultural prescriptions could include both common ecosystem services provided such as sustainable timber supply, wildlife habitat, or reduced wildfire risk but could also include some services that are undervalued or not typically included in forest management plans or stand silvicultural prescriptions, such as special forest products, cultural values, and recreation use. These services are often overlooked or undervalued in typical management plans, but including them in a silvicultural prescription would be an innovative way to both address the protection of some key ecosystem services identified in forest assessments and develop management plans that could enhance or preserve these services. Identifying these key services in the desired future condition would be a suitable starting point from which silviculturists could develop specific management plans to ensure these services will be maintained into the future.

CONCLUSIONS

Ecosystem services frameworks have emerged as a way of framing and describing the comprehensive set of benefits that people receive from nature including commonly recognized goods like timber and fresh water, as well as processes like climate regulation, water purification, and cultural and aesthetic benefits. In the United States, recent regulations such as the Forest Service 2012 Forest Planning Rule now require the agency to include ecosystem services in assessments and forest plan revisions. The Forest Service has been exploring the use of an ecosystem services framework to describe forest values provided by federal lands and to attract and build partnerships with stakeholders to implement projects. This framework includes describing the ecosystem services provided by forest landscapes; examining the potential tradeoffs among services associated with proposed management activities; and attracting and building partnerships with stakeholders who benefit from particular services the forest provides.

An ecosystem services framework should not only help transform the agency into a more effective and relevant organization, but it should also bolster external relationships by strengthening the public's investment in Forest Service activities and articulating a management vision in terms of social values. The Forest Service has sought placed-based applications of the ecosystem services framework to national forest management to better illustrate the concept for policy makers, managers, and forest stakeholders. In particular, forest managers and planners want to demonstrate how the ecosystem services concept can be used in national forest assessments and plan revisions, and to implement ecosystem services in local projects. In summarizing applications of an ecosystem services framework to forest- and project-scale implementations, I hope to demonstrate how modifying stand silvicultural prescriptions to include key ecosystem services should be a central part of forest plans and assessments.

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SHARED STEWARDSHIP AND COLLABORATIVE RESEARCH

Innovations in Partnerships and Tribal Forest Management: A Panel Discussion

Michael Dockry, Michael Benedict, Alexandra Wrobel, and Keith Karnes[1]

ABSTRACT.—Native American forests and tribal forest management practices have sustained Indigenous communities, economies, and resources for millennia. Tribal forest management is multifaceted and every tribe has unique values, history, and management goals. Tribal forests are managed for timber production, species diversity, and spiritual and cultural values. Tribal management often seeks to maintain species diversity, to respect culturally important landscapes, to reintroduce fire into fire-dependent ecosystems, and to protect water resources. Tribal forest management can provide important approaches to build landscape-scale partnerships and management. This panel presentation captured a broad range of tribal forest management practices and partnerships. Panelists discussed strategies for building partnerships with tribes, the role of the Bureau of Indian Affairs in tribal forest management, the Great Lakes Indian Fish & Wildlife Commission and their management strategies, and the Leech Lake Band of Ojibwe's approach to forest management. Panelists highlighted some of their partnerships and successful collaborative approaches to management. The panelists stressed the importance that tribal forests and forestry play within the landscape. Tribal partnerships can be enhanced when agencies listen to tribal perspectives, show mutual respect for tribal perspectives, use common language everyone can understand, and participate tribal community activities.

INTRODUCTION

Native American forests and tribal forest management practices have sustained indigenous communities, economies, and resources for millennia (McGregor 2004, Wilkinson 2005). Tribal forest management is multifaceted and every tribe has unique values, management goals, and history (Dockry and Hoagland 2017, IFMAT 2013, Nabokov 2002). Tribal forests are managed for timber production that supplies tribal and nontribal sawmills (Beck 2005, Wilkinson 2005). They are managed for spiritual and cultural values (Bengston 2004, Berkes 2012). They are managed to maintain a diversity of species, respect culturally important landscapes, reintroduce fire into fire-dependent ecosystems, and protect water resources (Dockry and Hoagland 2017). Tribal forest management can provide important approaches to build landscape-scale partnerships and management (Corrao and Andringa 2016, Sessions et al. 2017).

Across the country, there are many unique forestry projects on Indian reservations that integrate multiple use and cultural resource management. Tribes have always known that in order to manage for high quality timber they need to manage for traditional forest plants and animals—a healthy ecosystem. Before European settlers came to the Great Lakes region in the late 1600s (see White 1991), American Indians managed forests for biodiversity, food, basket materials, and medicinal plants. They viewed tree species, other plants, and animals as interdependent. European settlers witnessed forests that benefited from generations of tribal management of nontimber species (see Cronon 1983, Mann 2005).

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Tribes are sovereign nations. Tribal sovereignty and treaty rights are not something that the government gives tribes; tribes inherently have them because they were here before the United States became a country (for overviews of Federal Indian Law, see Wilkinson 2004 and Wilkins and Lomawaima 2001). Tribal sovereignty and treaty rights are recognized by the U.S. Constitution, court cases, and executive orders. Thus, governments have the responsibility to work with federally recognized tribes. It is not only important to work with the tribes, but it is actually a requirement for federal agencies. State agencies and other countries often have similar requirements for working with tribes and Indigenous people. The federal government should work with tribes on landscape management and programmatic decisions.

The goal of this panel discussion was to raise awareness of tribal forest management and innovative partnerships. This paper outlines general information about tribal lands and explores a broad range of tribal forest management partnerships, the role of the Bureau of Indian Affairs in tribal forest management, the Great Lakes Indian Fish & Wildlife Commission and their management strategies, and the Leech Lake Band of Ojibwe's approach to forest management and their partnership with the USDA Forest Service.

TRIBES AND TRIBAL LANDS

The panel started off with an overview of tribal forest management in the United States presented by panel organizer and moderator, Mike Dockry. There are 573 federally recognized tribes in the United States (BIA 2018). There are also some tribes that have state recognition and some tribes that are seeking either state or federal recognition. Each tribe is diverse with its own cultures, histories, experience, perspectives. Within each tribe, there is a diversity of opinions as well. It is important to remember that all forest lands in the United States were once Indigenous lands and that they have been managed by tribes through generations. Forest lands are inherently important for tribal communities. For centuries, tribes have managed forests through many social, ecological, and economic changes. Tribes have been managing these lands for many different goals including subsistence, cultural activities, ecosystem diversity, economic benefits, and community values. There are many examples of tribal forest management innovations (see Journal of Forestry Special Issue, Dockry and Hoagland 2017). Tribal perspectives and experiences are important additions to discussions on the most pressing forestry issues of our time including invasive species, climate change, sustainability, and human relationships to the land, water, and nonhumans.

When working with tribes, it is important to consider that both commercial enterprises and cultural uses support families and create opportunities for people that include basketry and other cultural uses. Anyone working with tribes should understand that nontimber forest products are just as important as commercial timber. Working with the tribes and respecting tribal goals will support tribal members and help to build cooperation. Of the 573 federally recognized tribes, 334 tribes manage forests and woodlands (IFMAT 2013). Forests are managed by tribes for both commercial and cultural uses. Nationally, tribal forests range in size from 2 acres to 11.7 million acres within 56.2 million Tribal Trust acres and 18.2 million acres of forests and woodland acres.

BUILDING PARTNERSHIPS WITH TRIBES

Tribal partnerships support landscape-level management, are important for fulfilling the federal trust responsibility, and support forest management goals on and off reservations. Dockry et al. (2017) outline five major ways to think about building successful partnerships with tribes: (1) upholding formal relationships and agreements; (2) developing personal relationships; (3) respecting, listening, and building trust; (4) demonstrating leadership and engaged leaders; and (5) working together on projects—doing actual land management projects together or walking the land together. Working together on land management projects in the field forms strong partnerships and informal relationships that have real meaning, build understanding and trust, and get work done that is of value to tribes and the partner institution. Building partnerships with tribes is important because tribes are often interested in implementation of forestry projects on their reservations, treaty ceded lands, and traditional territories if such projects support tribal goals.

It is important to be clear about who is forming the partnership and the partnership's relationship to formal consultation with tribal governments. Government-to-government relationships are between tribal governments and the United States or state government. These partnerships recognize the sovereignty of individual tribes and are integral for fulfilling the federal trust responsibility to federally recognized tribes. Other partnerships recognize tribal sovereignty but alone do not fulfill the federal trust responsibility. These include partnerships with tribal institutions like tribal colleges or tribal natural resource departments—institutions that are usually managed by tribal governments but they are not the tribal government itself. Other partnerships can be formed with intertribal groups like the Intertribal Timber Council. Partnerships with intertribal groups are an important way to build relationships and learn about tribal ways of managing forests but because intertribal groups or tribal institutions are not governments; they do not replace formal government-to-government consultation.

THE BUREAU OF INDIAN AFFAIRS AND TRIBAL FOREST MANAGEMENT

Michael Benedict described some of the many programs and services that the Bureau of Indian Affairs (BIA) provides to tribes. The BIA is divided into several areas: Justice Services, Indian Services, and Trust Services (https://www.bia.gov/bia, accessed February 7, 2020). Trust Services contains the Division of Forestry and Wildland Fire Management (known as BIA Forestry and deals with forest management and forest fire protection), Division of Real Estate Services, Division of Land Titles and Records (keeps track of Indian land boundaries), Division of Probate (deals with heirs of the deceased and property), and Division of Natural Resources (coordinates oversite, monitoring, development, and protection of natural resources). BIA Forestry works in cooperation with the federally recognized tribes. Twenty to 30 years ago, BIA directly managed forested land on reservations. This changed with self-determination and self-governance policies. Now BIA provides less direct management and more support to tribes to manage their own forestry and natural resource management programs.

The BIA Midwest Region serves 36 tribal forestry/natural resources departments in four states: Minnesota, Iowa, Wisconsin, and Michigan with 1.6 million trust acres and 1.2 million forested acres (see: https://www.bia.gov/regional-offices/midwest, accessed February 7, 2020). Tribal nations within the Midwest Region include Ojibwe, Potawatomi, Odawa, Ho Chunk, Oneida, Dakota, Sac & Fox, Menominee, and Stockbridge-Munsee Mohican. The BIA provides technical assistance and funding for forest development and management (reforestation, seed collection, tree planting, scarification, and other means to manage forests), and it works closely with other federal and state agencies on fire management. Tribes have both long-term permanent plot and stand exam inventory programs. BIA forestry supports tribal timber sale programs and works with tribes to write silvicultural prescriptions and forest management plans. Many tribes have innovative forestry and silvicultural projects on their lands. Tribal projects can often be implemented more quickly than other federal projects because there are fewer time-consuming bureaucratic processes than found in other federal agencies.

THE GREAT LAKES INDIAN FISH & WILDLIFE COMMISSION AND TRIBAL TREATY RIGHTS

Alexandra Wrobel discussed the Great Lakes Indian Fish & Wildlife Commission (GLIFWC; www.glifwc.org, accessed February 7, 2020), its mission, and some of its innovative projects. The GLIFWC main office is headquartered on the Bad River reservation in Odanah, Wisconsin. GLIFWC is an intertribal agency with delegated authority to implement off-reservation treaty rights for 11 Ojibwe tribes throughout treaty-ceded lands in northern Minnesota, northern Wisconsin, northern Michigan, and areas of the Great Lakes. These territories were ceded by Ojibwe tribes to the U.S. Government in the treaties of 1836, 1837, 1842, and 1854. While these lands were ceded to the U.S. Government, the Ojibwe tribes retained their rights to fish, hunt, trap, and gather throughout these areas in perpetuity—meaning these rights do not expire. Tribal treaty harvesting rights have led to many years of conflicts and created tension and cross-cultural issues. Over several decades, federal courts reaffirmed tribal treaty rights and GLIFWC was formed to maintain and implement those off-reservation rights and support the tribal right to self-regulate off-reservation. "GLIFWC's existence is based upon the sovereignty of each of its member tribes and it is an agency of delegated authority from those tribes. It is structured to facilitate intertribal consensus on issues of common concern regarding off-reservation treaty rights. It exercises delegated authority and provides expertise in areas of biology, conservation law enforcement, and the development of tribal ordinances which can then be adopted by its member tribes. It has now been in existence for more than 25 years, helping to secure the full and successful exercise of treaty rights that provides for the needs of tribal members, as well as helping to protect and enhance the natural resources and habitats of the ceded territory" (https://www.glifwc.org/Recognition_Affirmation/, accessed February 24, 2020).

GLIFWC accomplishes its mission through interagency and intergovernmental partnerships and cooperation. One example of this interagency cooperation is with the Forest Service. This partnership is supported and structured through a formal memorandum of understanding (MOU) between the 11 GLIFWC member tribes and three units of the Forest Service: the Eastern Region of the National Forest System, the Eastern Region's Law Enforcement and Investigations, and the Northern Research Station (https://www.fs.fed.us/spf/tribalrelations/documents/agreements/mou_amd2012wAppendixes.pdf, accessed February 24, 2020). Through the MOU, the Forest Service acknowledges its role in fulfilling the federal government's treaty obligations and trust responsibilities on ceded lands. The MOU applies to several national forests within ceded territories: the Chequamegon-Nicolet National Forest, the Ottawa National Forest, the Hiawatha National Forest, and the Huron-Manistee National Forest. The MOU details the guidelines for implementing off-reservation treaty rights. The MOU was created through intensive discussions between GLIFWC and their member tribes and the Forest Service to plan how, when, and where treaty harvesting rights would be implemented. The MOU overall provides structure for communication, self-regulation, and self-governance. It has been 20 years since the MOU was signed and is a partnership success story. However, it is important to recognize that the process of building the MOU and partnership took time, a lot of negotiation, arguments, and relationship building—all of which are as important if not more so than just having a formal agreement.

THE LEECH LAKE BAND OF OJIBWE AND FOREST SERVICE PARTNERSHIP

Keith Karnes, forester for the Leech Lake Band of Ojibwe, discussed partnerships with the Forest Service and the Chippewa National Forest. It took time and work to build the relationship between the Leech Lake Band of Ojibwe and the national forest. There were times of tensions and misunderstanding over the years. However, today the relationship is improved and there is a dialogue happening. In 2016, the Leech Lake Band's environmental director sent a letter to the Forest Service stating that the Chippewa National Forest is focused too much on resource extraction and that it was contrary to tribal goals for the national forest. In response, the Chippewa National Forest staff began to work with the tribe to develop plans to achieve desired vegetative conditions that conform to tribal goals. They also began to explore using the Tribal Forest Protection Act (TFPA) to achieve the tribe's vision for forest management (https://www.fs.usda.gov/detail/r5/workingtogether/tribalrelations?cid=stelprdb5351850, accessed February 7, 2020). The Forest Service's Northern Research Station worked on an evaluation that showed Chippewa National Forest pine plantations were too dense and trees were losing their live crowns, so prescriptions for thinning were outlined. The Leech Lake Band was supportive of this evaluation because it made sense and conformed to their management goals. This partnership and thinning goals came from the TFPA project and highlights the importance of using policies to develop sustainable forestry projects that support tribal goals and values. There is still partnership and management work to be done, as there are many different ways to reach goals. Research is important because it helps to change how people think, which is hard to do. Landscape-level management needs to become real and needs to be implemented throughout the region. Landscape-level management needs to include a broad range of forest conditions and multiple forest values—things that require cooperation with research institutions and partnerships across the landscape.

ADVICE FOR MANAGERS AND CONCLUSION

The session concluded with questions from workshop participants. The questions focused on practical advice for building efficient partnerships with tribes. The panelists' advice focused on building relationships by talking to tribes and really listening to what tribes have to say. Showing mutual respect and using language everyone can understand were also important. Participating in tribal events, such as community activities and Pow Wows, can help build trust and relationships. Tribal members often complain that nontribal people do not want to listen to their perspectives. In recent years, however, there seems to be different attitudes from the nontribal natural resource professionals, and they are starting to listen and are actually seeing that tribal management works. This is important because tribal ways of knowing have been accumulated through millennia and are important components of sustainable forest management. Quantitative information is important but spiritual and qualitative understanding of the system makes management stronger. Finally, using formal documents like MOUs and having strong leadership that values tribal partnerships can help form strong partnerships with tribes.

Tribal forest management is important for landscape-level forest management. Tribes have had generations of experiences and knowledge that offer unique perspectives on our forestry and natural resource challenges. This panel outlined how tribal partnerships can play an increasingly important role in natural resource management. The panelists stressed the importance that tribal forests and tribal partnerships have for landscape-level management. Natural resource managers can enhance tribal partnerships by listening to tribal voices, demonstrating mutual respect for tribal perspectives, using language everyone can understand, and participating in tribal community activities. Strong tribal partnerships can lead to strong landscape-level management that confronts 21st century natural resource management challenges.

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Building a Regional Science Framework to Support Shared Stewardship for Landscape-Scale Conservation in Southeast Ohio

Jarel L. Bartig, Louis R. Iverson, and Matthew P. Peters[1]

The Interagency Forestry Team of Ohio (Team) was established in 2008 to combine efforts and facilitate a common vision toward promoting healthy forests, especially oak-dominated forests, among federal and state agencies via a shared stewardship approach. The focus area is a 17-county region of southeastern Ohio that was selected for a Joint Chiefs' Landscape Restoration Partnership Project for 2015–2017 (Fig. 1). The 2016 National Land Cover Database (Yang et al. 2018) estimates Ohio at 34.0 percent forested, and 41.8 percent of this forest resides within the 17-county area. Within this zone are three units of the Wayne National Forest, 17 Ohio State Forests, and multiple Ohio Wildlife Management Areas, State Parks, State Natural Areas and Preserves, and other publicly protected or managed areas that together account for 12 percent of the focus area. Therefore, the vast majority of these forests are privately owned in these dissected, unglaciated landscapes of the Allegheny Plateau (Iverson et al. 2019). These forests, with 77 known species of trees, are among the most diverse in the nation, but adequate regeneration of the oak-dominated forest types has been lacking in the last decades due to a reduction of light to the forest floor in the absence of adequate management and fire (Iverson et al. 2008, Johnson et al. 2009, Nowacki and Abrams 2008). However, research by the USDA Forest Service Northern Research Station since 1995 has shown that a combination of canopy reduction and repeated fire, especially on ridges and southern exposures, can improve advanced regeneration in oak and hickory in southern Ohio (Hutchinson et al. 2012, Iverson et al. 2017).

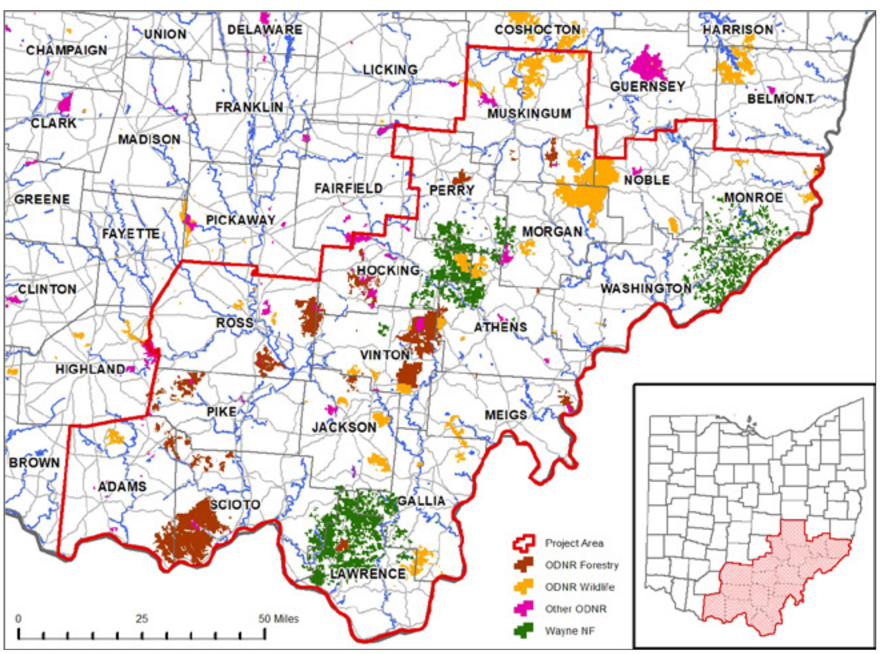

Figure 1.—Southeast Ohio Oak Management Priority Forest Area.

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Figure 2.—Structural makeup of the Ohio Interagency Forestry Team.

The Team is composed of three tiers of operation: leadership, the heads of agencies involved in forest management of the region; middle management, the primary players for planning and on-the-ground implementation; and working groups, teams of specialists focused on specific aspects of the shared stewardship (Fig. 2). As part of the new business model the Team is working under, a regional science framework of data, tools, and training is being developed. One of the tools being developed is an oak investment model (Working Groups GIS Development and ECO team, Fig. 2) to quantify and prioritize silvicultural treatments to promote oak-dominated forest regeneration in the region.

The oak investment model consists of three components: site capability, current vegetation condition, and recommended treatment investments. For site capability, we used an ecomapping approach, based primarily on topographic characteristics, to identify those locations most (and least) suitable and efficient for encouraging oak and hickory establishment and growth (Iverson et al. 2018). These include mapping of 15 landtypes characterized by three forest classes: dry oak forest, dry-mesic mixed oak hardwood forest, and rolling bottomland mixed hardwood forest. The model connects these ecomapping outputs with current vegetation represented by thousands of SILVAH and other sampling plots. Stand reconnaissance and the SILVAH decision-support system is then used to recommend treatments and help identify locations for management investment. SILVAH (Brose et al. 2008) uses a strategic inventory to determine abundance of desirable oak seedlings and barriers to their success, then prescribes silvicultural guidelines for reducing these barriers to regeneration, thereby fostering enhancement of desirable oak seedlings.

This tool is also being used for rapid ecological assessment in support of National Environmental Policy Act (NEPA) planning on the Wayne National Forest, among other applications on public lands. In these efforts, project objectives in expanding early successional wildlife habitat are being coupled with the dual purpose of regenerating oak-dominated forest where sites are suitable, and to expand these objectives to include private lands where there is interest in collective action supported by complementary government programs and authorities.

Prior to the Team's establishment, information sharing among agencies was minimal and project specific. However, since 2008, the flow and accessibility of information has increased and the Team is working toward cross-boundary management that benefits all lands. This approach has already increased project and personnel funding as well as the implementation of on-the-ground treatments, resulting in a positive impact to the forests of the region.

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The Rocky Mountain Research Station–Region 4 Science Partner Program: Partnering Science and Management for Beneficial Outcomes

Nehalem Clark, Kris Rutledge, Mark Bethke, Natalie Little, and Jan Engert[1]

ABSTRACT.—The Rocky Mountain Research Station (RMRS) and Intermountain Region (R4) of the USDA Forest Service are actively improving the science-manager relationship paradigm with an exciting new effort: the RMRS–R4 Science Partner Program. These programs complement existing grassroots science-manager relationships by improving coordination and learning at the project and programmatic levels as well as deploying science resources where needed. We showcase a model for helping the Forest Service achieve its goal of leveraging best available science toward beneficial land management outcomes at meaningful landscape scales.

Incorporating science into management decisionmaking is important for many reasons. The challenges and rationale associated with doing this at meaningful scales is a subject of continued discussion and interest (Beier 2017). The Research and Development (R&D) branch of the Forest Service is integrated as part of the Forest Service mission, providing independent and credible science for agency land managers, while contributing to scientific knowledge globally. While much effort has been put into connecting scientists in managers over the last several decades, there is still more work to be done to create meaningful connections between agency land managers and scientists.

To begin to address this, we have developed an innovative model for interconnecting Forest Service land management with agency science to support knowledge co-production and integration of best available science into land management applications. The Rocky Mountain Research Station (RMRS)–Intermountain Region 4 (R4) Science Partner Program launched in 2015 to enhance collaboration opportunities between RMRS researchers and Intermountain National Forest System (NFS) managers. After several years, not only is the Science Partner Program thriving, it is yielding cost savings, specific advances in management, and the development of meaningful relationships between Forest Service scientists and managers.

Within the Science Partner Program, there are currently 15 discrete Science Partner groups. Each group is comprised of at least one R4 land manager and one RMRS scientist, often including many other collaborators. Each Science Partner group focuses on a specific management challenge or the development of innovative approaches to managing National Forests and Grasslands. As Table 1 depicts, these collaborations range from developing regional goal-efficient monitoring of rare mesocarnivores (e.g., lynx) to supporting Forest Plan revision community collaboration around socioeconomic questions.

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The Science Partner Program goes above and beyond informal or ad hoc scientist-manager relationships with a framework that encourages accountability and forward momentum. Several ingredients have been key to our success:

- The program is co-led by RMRS and R4 staff, which anchor it to the Intermountain Region and Rocky Mountain Research Station Science Programs.
- Quarterly check-in calls with groups provide accountability for continued collaboration;
- Travel funds have been offered annually to support face-to-face interactions and scientists and managers working together.
- The competitive BeSMART microgrant program provides seed money for innovative, collaborative science-manager projects.
- An annual partner workshop is held to support sharing information among the group and with Regional and Station leadership and to evaluate the program model as it evolves.
- We are widely sharing what we are learning with other Forest Service Regions, Stations, and external partners.

Each of the 15 Science Partner groups have achieved or are working toward distinct outcomes, yielding tangible results. We illustrate with the following examples:

- The Boreal Toad Science Partner Group (https://www.fs.usda.gov/rmrs/projects/region-4-science-partner-program-detecting-boreal-toads-using-environmental-dna, accessed February 24, 2020) developed a reliable eDNA marker for boreal toad (*Bufo boreas)*, a western toad species listed as a species of greatest conservation need in New Mexico, Colorado, Utah, and Wyoming. Reliable and sensitive methods for delineating distributions of western toads are critical for monitoring the status of the species and prioritizing habitat conservation efforts. An RMRS wildlife ecologist teamed up with the fisheries biologist on the Dixie National Forest to co-develop appropriate sampling protocol for the complex habitats in which these toads reside. This approach greatly simplifies detection efforts by allowing a single sample to indicate presence across complex wetlands. This innovation is easily deployed to the field and will result in significant cost savings while eliminating the need for time intensive, costly, and inaccurate visual toad surveys. The peer-reviewed publication (Franklin et al. 2018) of this eDNA toad detection methodology lends credibility with regulatory agencies such as U.S. Fish and Wildlife Service (USFWS) and can be an essential piece of rare species planning and management.
- The Climate Change Science Partner Group (https://www.fs.usda.gov/rmrs/projects/region-4-science-partner-program-integrating-climate-change-research-manti-la-sal-plan, accessed February 24, 2020), comprised of a forest biologist, regional sustainability and climate coordinator, and research hydrologist, worked together to make climate change data more understandable and useable to national forests. The team organized a 1-day climate workshop on the Manti-La Sal National Forest to inform the Forest Plan revision process. Down-scaled climate change maps were created for the Manti-La Sal to use in their revision process, and using this process, maps were then developed for all national forests in the lower 48. "National Forest Climate Change Maps: Your Guide to the Future" (https://www.fs.fed.us/rm/boise/AWAE/projects/national-forest-climate-change-maps.html, accessed February 24, 2020) employed state-of-the art science to generate readily available maps that

predict precipitation, air temperature, and snow for individual national forests. This team was an integral part of the Intermountain Adaption Partnership (http://adaptationpartners.org/iap/index.php accessed February 24, 2020) and the resulting General Technical Report (Halofsky et al. 2018a, 2018b).

- Project-level planning, restoration, and forest management, when overlapping with rare forest mesocarnivores such as Canada lynx and fisher, have been highly complex across many Forest Service Regions. Because these species are wide-ranging, occur in low density, and are difficult to detect, having effective monitoring is critical but lacking in many cases (Golding et al. 2018). To address this uncertainty, one Science Partner partnership, the Mesocarnivore Modelling Science Partner Group (https://www.fs.usda.gov/rmrs/projects/region-4-science-partner-program-developing-meso-carnivore-models-across-multiple-regions, accessed February 24, 2020), is developing reliable, goal-efficient monitoring of Canada lynx and other rare mesocarnivores. This partnership effort is leading to more sustainable and less resource intensive monitoring to replace previous failed efforts. The key is to pinpoint where they are and utilize resources appropriately. This project has major implications for future Northern Rockies lynx management direction and subsequent timber harvest and vegetation management in these forests.

The RMRS–R4 Science Partner Program epitomizes data-supported decisionmaking and future policy development, while also increasing analytical capacity and evidence-based land management. The program has greatly improved communication between National Forest Systems in Region 4 and RMRS, which in turn improves the identification of program areas or projects that could benefit from scientific research and involvement. NFS management backed by rigorous science is powerful in combination.

Holistically, we are evaluating this new Science Partner model for the co-production of science with management. We have learned that our model has created powerful, positive feedback loops including:

- Managers and scientists develop high quality relationships that lead to expansive networks across the Region and Station.
- Pilot, site-specific projects can be scaled-up to regional and multiregional applications.
- Significant outside funds and resources can be leveraged with upfront small investments.
- In-person interactions and competitive project micrograntss have resulted in deeply rooted relationships, innovative approaches, and positive outcomes.

Sharing what has been learned with others across the agency and beyond has been a foundational goal of the Science Partner Program. Some of the mechanisms employed are conference and workshop presentations (National Silviculture Conference, Regional Leadership, WO presentations, etc.), developing a web presence (https://www.fs.usda.gov/rmrs/region-4-science-partner-program) for the program, and creating an engaging series of short videos (https://www.youtube.com/playlist?list=PLNsZX2SBTlVmJUigal3RovCyjV-iZl-Cp) about the Science Partner Program. Web pages were viewed over 3,000 times, YouTube videos were watched 2,500 times, and social media impressions numbered more than 9,000 as of July 2019. More critically, this model is being shared as highly beneficial with other Regions and Stations.

Partnerships resulting from the RMRS–R4 Science Partner Program are helping NFS managers improve science-informed decisionmaking and establish networks in the science community. In turn, RMRS scientists are presented with opportunities to work more deeply in application, while increasing their awareness of current NFS issues and processes. Forest Service scientists and managers working together on discrete projects and science-based, actionable outcomes is a powerful model for combining Forest Service R&D with NFS into the future. At the very core of the Science Partner program is improving relationships and customer service in direct support of sustainable management of forests and grasslands.

For others interested in developing a partnership program of this nature, we offer these key components that we believe have led to the success of this program: leadership champions; empowered program co-leads comprised of science and management organization staff; modest funds to support travel and innovative collaborations; and an informal communication and check-in framework that allows individual partner groups to realize their value to the larger program. The aforementioned framework serves to maintain program consistency when individual players change.

Additional information about the Science Partner Program can be found here, including a six-part short YouTube video series highlighting the work of the partner groups: https://www.fs.fed.us/rmrs/region-4-science-partner-program (accessed February 24, 2020).

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Table 1.—Rocky Mountain Research Station–Region 4 science partner groups

Project Co-Leads:
Nehalem Clark, RMRS Science Delivery Specialist
Kris Rutledge, R4 Planning Specialist
Natalie Little, R4 Sustainability and Climate Coordinator

Project Advisors:
Mark Bethke, R4 Budget Director
Jan Engert, Special Assistant Station Director, RMRS

Science partner group	Members	Project overview
Accessible Climate Change Science for the Manti-La Sal National Forest (NF) Forest Plan Revision	Charlie Luce, Research Hydrologist, RMRS Natalie Little, Sustainability & Climate Coordinator, R4 Tiffany Cummins, Wildlife Biologist, Manti-La Sal	This Group worked together to make climate change data more understandable and useable to national forests (now completed). The team organized a 1-day climate workshop on the Manti-La Sal NF to inform the Forest Plan Revision process. Down-scaled climate change maps were created for the Manti-La Sal to use in their Revision process, and using this process, maps were then developed for all national forests in the lower 48 states. National Forest Climate Change Maps: Your Guide to the Future, (https://www.fs.fed.us/rm/boise/AWAE/projects/national-forest-climate-change-maps.html) employed state-of-the art science (to generate readily available maps that predict precipitation, air temperature, and snow for individual national forests. This team was an integral part of the Intermountain Adaptation Partnership (https://adaptationpartners.org/iap/index.php) and the resulting General Technical Report (Halofsky 2018a, 2018b).
Adapting Rangeland Monitoring Strategies	Matt Reeves, Research Ecologist, RMRS Jim Menlove, FIA Analyst, RMRS Chris Miller, Economist, WO Pete Gomben, Regional Appeals/ Litigation, R4	The Range Group (https://www.fs.fed.us/rmrs/projects/region-4-science-partner-program-adapting-rangeland-monitoring-strategies) has leveraged the Rangeland Production Monitoring Service (RPMS) to analyze trends in rangeland vegetation production across Region 4. The RPMS offers spatially explicit data describing rangeland production across all ownerships. This process can help Forest Plan Revisions, improve allotment management plans, and streamline the NEPA process.
Aspen Restoration on the Fishlake NF	Keith Moser, Research Forester, RMRS Danielle Malesky, Entomologist, R4 SP&F Darren Blackford, Entomologist, R4 SP&F Liz Hebertson, Plant Pathologist, R4 SP&F Robert Cruz, Monitoring Coordinator, Forest Health, R4 SP&F John Shaw, FIA Analyst, RMRS John Guyon, Plant Pathologist, R4 SP&F	Aspen regeneration and recruitment on the Pahvant region of the Fishlake NF is not currently occurring. It is believed that fire and coppicing restoration treatments would be unsuccessful if not combined with a better understanding of grazing pressure. This science partner group has joined forces to better understand the drivers of change in these aspen forests and recommended future management.
Boreal Toad eDNA Marker Development	Kevin McKelvey, Research Ecologist, RMRS Tommy Franklin, eDNA Program Coodinator Cynthia Tait, Aquatic Program Manager, R4 Michael Golden, Wildlife Biologist, Dixie NF	The Boreal Toad Science Partner Group (https://www.fs.fed.us/rmrs/projects/region-4-science-partner-program-detecting-boreal-toads-using-environmental-dnahas) developed a reliable eDNA marker for Boreal toad (*Bufo boreas*), a Western toad species listed as a "species of greatest conservation need" in New Mexico, Colorado, Utah, and Wyoming. This innovation is easily deployed to the field and will result in significant cost savings while eliminating the need for time intensive, costly and inaccurate visual toad surveys. The peer-reviewed publication (Franklin et al. 2018) of this eDNA toad detection methodology lends tremendous credibility with regulatory agencies such as the USFWS and can be an essential piece of rare species planning and management.

Science partner group	Members	Project overview
Characterizing Groundwater Depend Ecosystems to Prioritize Conservation Efforts	Kate Dwire, Research Ecologist, RMRS Mark Muir, Soil Scientist, R4 Cynthia Tait, Aquatic program Manager, R4 Jeff Bruggink, Soil Scientist, R4 John Proctor, Botanist, R4	This project (https://www.fs.fed.us/rmrs/projects/region-4-science-partner-program-characterizing-and-conserving-groundwater-dependent) is an interdisciplinary working group focused on collecting, documenting, exchanging, and archiving information about R4 groundwater-dependent ecosystems (GDEs), particularly springs and wetlands. The Colorado Natural Program utilizes aerial photographs and remote sensing techniques to digitally map GDE wetlands in support of forest plan revision. These maps will serve as the basis for site selection and sampling design of inventories focused on GDE wetlands, including prioritization of site sampling of fens.
Cheatgrass Control on Bridger Teton NF	Dave Cottle, Range Management Specialist, BTNF Brice Hanberry, Research Ecologist, RMRS Jeffery Ott, Aquatic Researcher, RMRS	RMRS scientists have teamed up with managers and researchers at the Bridger-Teton NF and Colorado State University to compare herbicide treatments to reduce cheatgrass seedlings, allowing restoration of native sagebrush grassland plant communities. The study (https://www.fs.fed.us/rmrs/projects/region-4-science-partner-programs-cheatgrass-seedling-reduction-restoration-native) will inform future cheatgrass treatment in western Wyoming and beyond.
Dixie NF Fire History/Fire Science	Brian Van Winkle, Fire Ecologist, Dixie-Fishlake NFs Sharon Hood, Fire Ecologist, RMRS Mike Battaglia, Research Forester, RMRS	This project seeks to understand the effects of prescribed burning and how it can be implemented over broad spatial scales and aims to implement the "right kind of fire" and promote a fire resilient forest mosaic across the landscape. In 2019, the Fishlake NF will host the first of the western research prescribed burns as part of the Prescribed Fire Science Consortium. The goal is to facilitate collaborative research on building a mechanistic understanding of fire through annual burn experiments.
Economic & Social Science for Salmon Challis NF Forest Plan Revision	Gina Knudson, Collaboration Specialist, and Nate Anderson, Research Forester, RMRS Joshua Milligan, Revision IDT	The goal of this partnership (https://www.fs.fed.us/rmrs/projects/region-4-science-partner-program-socioeconomic-assessment-and-forest-plan-revision-salmon) is to augment the Forest's socio-economic expertise during the Forest Plan revision process. Two community workshops to dialogue about the condition of the forest products industry were held in Idaho and southwestern Montana. Best available information on forest industry trends and market projections for the Northern Rockies will be synthesized.
Improving Understanding of Pinyon-Juniper and Ponderosa Ecotone Dynamics	W. Keith Moser, Research Forester, RMRS Steve Overby, Soil Scientist, RMRS Duncan Leao, Forester, Humboldt-Toiyabe NF	This group is studing the effects of fire and its interaction with other abiotic and biotic factors on the lower extreme of ponderosa pine, the pinyon/juniper ecotone, and the upper extreme of P-J ecosystems. Forests of the southwestern United States are becoming increasingly stressed due to changing biotic and abiotic factors. Recent drought-induced infestations in Arizona, Nevada, and New Mexico have killed as much as 90 percent of the dominant pinyon species.
Landscape-Scale Forest Restoration on Boise Basin	Theresa Jain, Research Forester, RMRS Kate Dwire, Research Ecologist, RMRS Michael Feiger, Wildlife Biologist, Idaho RD, Boise NF John Wallace, Forester, Idaho RD, Boise NF Nate Anderson, Research Forester, RMRS Travis Warziniack, Research Ecologist, RMRS	RMRS researchers are partnering with managers on the Boise National Forest and scientists at the University of Idaho to develop, implement, and evaluate place-based adaptive management strategies with the goal of improving the resilience of Northern Rockies ponderosa pine stands to fire and other disturbances. The Boise Basin project (https://www.fs.fed.us/rmrs/projects/region-4-science-partner-program-landscape-restoration-boise-basin-experimental-forest) provides a unique opportunity to implement and evaluate a wide range of ponderosa pine management approaches using a management-science partnership framework, implement treatments at a landscape scale, and gain insights into improvements in project planning and decision-making.

Science partner group	Members	Project overview
Mesocarnivore Modelling at Multiple Scales	Kevin McKelvey, Research Ecologist, RMRS Rema Sadak, Wildlife Ecologist, R4 Randall Griebel, Wildlife Biologist, Bridger-Teton NF Jessie Golding, Wildlife Ecologist, RMRS	RMRS scientists are partnering with the Bridger-Teton National Forest (BTNF) and other national forests to create a detailed model of rare mesocarnivores across multiple regions. This project will survey rare mesocarnivores (Canada lynx, fishers, and wolverines) within the Greater Yellowstone Ecosystem. https://www.fs.usda.gov/rmrs/projects/region-4-science-partner-program-developing-meso-carnivore-models-across-multiple-regions.
Pollinator Habitat Restoration Proof of Concept on the Curlew National Grassland	Francis Kilkenny, Research Biologist, RMRS Rose Lehman, Forest Botanist, Caribou-Targhee NFs John Proctor, Regional Botanist, R4	RMRS scientists have teamed up with the Caribou-Targhee National Forest Soil Scientist, Botanist, and Hydrologist to remove Russian olive from riparian habitat in Curlew National Grassland, convert it to biochar, apply to the removal site, plant and monitor native grass and forb species, and determine soil physical and chemical changes from biochar additions. The initial steps of the project (https://www.fs.fed.us/rmrs/projects/region-4-science-partner-program-pollination-restoration-curlew-national-grassland) timeline were accomplished, including the harvesting and chipping of Russian olive and converting it to biochar.
Ponderosa Density and Aggregation	Keith Moser, Research Forester, RMRS Eric Taylor, Silviculturist, Dixie NF Russell T. Graham, Research Forester, RMRS Theresa Jain, Research Forester, RMRS Buddie Carroll, Forester and Silviculturist, Dixie NF	The goal of this collaborative study is to examine the influence of overstory basal area, tree spacing, and site characteristics on overall dwarf mistletoe rating and tree response while exploring combinations of vegetative structural chance that would satisfy Forest Service guidelines for northern goshawk. This group will examine the causes of the presence of Jeffrey pine and related species and projected long-term future trends on the Escalante Ranger District of the Dixie NF.
Post-Fire Reseeding Guidelines for Salmon-Challis NF	Christine Droske, Forest Fuels Specialist, Salmon-Challis NFs Francis Kilkenny, Research Biologist, RMRS	Due to threat of cheatgrass and other native plant invasions following fire, there is a need to develop appropriate post-fire re-seeding guidelines that will yield resilient landscapes in the long term. This partner group will develop guidelines using Salmon-Challis environmental conditions as the basis, which could then be scaled up to large geographies.
Putting FIA Data to Work for Fuels Planning on the Salmon-Challis NF	Kristen Pelz, Forester, I&M, RMRS Christine Droske, Forest Fuels Specialist, Salmon-Challis NFs Joshua Milligan, Plan Revision Team Leader, SCNF Cassandra (Sandy) Kollenberg, GIS Specialists, SCNF	The goal of this partnership between the RMRS Human Dimensions program and the Salmon-Challis National Forest (SCNF), located in east-central Idaho, is to augment the Forest's expertise during the forest plan revision process (https://www.fs.fed.us/rmrs/projects/region-4-science-partner-program-socioeconomic-assessment-and-forest-plan-revision-salmon; https://www.fs.fed.us/rmrs/science-program-areas/human-dimensions; and https://www.fs.usda.gov/scnf). The planning team has identified a need to host community workshops to learn about the state of the forest products industry in Idaho and southwestern Montana. There is also a need to summarize the best available information on forest industry trends and market projections for the Northern Rockies. A near-term goal of this collaboration is to plan and execute the socioeconomic-focused community workshops. The partners are in the planning phase, orchestrating what is the most critical information to provide to stakeholders, resource managers, and scientists, as well as determining who to best present the workshops.

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Adaptive Silviculture for Climate Change Network: Learning From Land Manager-Research Partnerships

Christopher E. Looney, Courtney L. Peterson, Linda M. Nagel, James M. Guldin, Christopher W. Swanston, Maria K. Janowiak, Mike A. Battaglia, Seth W. Bigelow, Leslie A. Brandt, Anthony W. D'Amato, Kevin Evans, Steve B. Jack, Theresa B. Jain, Melissa M. Jenkins, Elaine Kennedy Sutherland, Mary Hammes, Brian J. Palik, Matt C. Tuten, and Christopher W. Woodall[1]

The Adaptive Silviculture for Climate Change (ASCC) project is a collaborative effort that has established a series of experimental silvicultural trials across a network of different forest ecosystem types throughout North America. Scientists, land managers, and a variety of partners have co-developed a series of experimental sites as part of this multiregion study to research long-term ecosystem responses to a range of climate change adaptation approaches (Swanston et al. 2016). Silvicultural treatments at each study site were developed by using a modified process from Swanston et al. (2016). The treatments represent three general climate adaptation options: (1) resistance—maintaining relatively unchanged conditions over time; (2) resilience—allowing some change in current conditions but encouraging an eventual return to reference conditions following disturbance; and (3) transition—actively facilitating change to encourage adaptive responses (definitions modified from Millar et al. 2007).

Urban environments face unique challenges, including extensive invasive plant cover, forest health issues such as emerald ash borer, habitat fragmentation, small management units, pollution, and accelerated climate change due to heat island effects (Ordóñez Barona 2015). The sites of the ASCC Network to date have been developed in wildland forest settings. A new development in the ASCC Network is the extension of the ASCC scientist-manager experimental framework to an urban forest setting. This development will greatly enhance the scope of the ASCC Network, while requiring novel silvicultural approaches to address pressing urban forest challenges, given that the operational, economic, and social feasibility of harvesting to implement ASCC treatments may be limited. At the same time, special

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opportunities presented by urban settings include integration of ASCC experiments into education and outreach opportunities, and public engagement throughout all stages of project implementation and monitoring. Study sites established through urban ASCC projects also have high social value and potential for human dimensions research.

Through a partnership among university researchers, the Northern Institute of Applied Climate Science, the Mississippi Park Connection, and the City of Saint Paul Parks and Recreation, we created the first example of an ASCC experiment in an urban setting. Key management priorities of this area include facilitating recovery from ongoing emerald ash borer-related mortality (~ 25 percent of the canopy layer), sustaining large cottonwood trees used by wildlife, maintaining low-invasive plant abundances, and public engagement. Key climate challenges include precipitation variability and warmer nighttime temperatures. Novel management tactics, including gap creation to sustain large cottonwoods and plantings of future-adapted lower Mississippi River Basin ecoregion species, were implemented in this study. Project design and forest inventory will be completed by fall 2019.

In addition to urban affiliate sites, two more core sites were added to the ASCC Network. The first site is being led by the Canadian Forest Service on the Petawawa Research Forest, Ontario, Canada. Key challenges include sustaining white pine in the face of hardwood encroachment and white pine blister rust. The Petawawa ASCC project will represent the first international ASCC experimental site. A second site is being developed in cooperation with the Colorado State Forest Service. The prospective Colorado State Forest ASCC project, located near Walden, Colorado, extends strategies developed for dry mixed-conifer at the San Juan National Forest, Colorado, ASCC site into higher elevation forest types. The study area is a mixture of spruce-fir and lodgepole pine forest types recently imperiled by bark beetle outbreaks.

The ASCC Network is creating a common data management system to facilitate long-term, cross-site research. This system will enable cross-site studies examining topics such as comparisons of treatment implementation, functional responses of the regeneration and herbaceous layers, and ecosystem responses to disturbance. The need for developing a responsive data management system became apparent after Hurricane Michael narrowly missed the ASCC site in Ichauway, Georgia, in October 2018. This unanticipated natural disturbance has prompted a study examining the implications of ASCC treatments focused on chronic stresses (such as drought) for susceptibility to unpredictable events such as wind storms.

The ASCC Network continues to extend forestry climate change adaptation research from the experimental sites to the broader landscape. Forest growth-and-yield modeling (Climate-FVS; Crookston et al. 2010) is being used to extend San Juan National Forest ASCC strategies to warm-dry, mixed-conifer Forest Inventory and Analysis (FIA) plots across Colorado. We are examining treatment implementation, durability, and alternatives such as artificial regeneration of drought-resistant species. The ASCC Network is also investigating the potential of species mixtures to increase stand productivity, resistance, and resilience using region-wide Interior West FIA data (Ammer 2019). The results will provide a basis for further on-the-ground research at the Interior West ASCC experimental field sites, thereby continuing the cycle of learning from land manager-research partnerships.

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SILVICULTURE PARTNERSHIPS

The Role of Experimental Forests and Ranges for Facilitating Management-Research Partnerships: A Panel Discussion

John M. Kabrick, Olga Romanova, Andrea Hille, Don C. Bragg, Theresa B. Jain, John Lampereur, and John Riling[1]

ABSTRACT.—Three years after the founding of the USDA Forest Service, Director Raphael Zon and Chief Gifford Pinchot initiated a plan to formally designate areas for research and demonstration. In addition to providing important scientific information needed by the Forest Service to practice silviculture, Zon and Pinchot envisioned that these areas would serve as the "meeting grounds" of researchers and managers to help catalyze, develop, and maintain management-research partnerships for the agency. For more than a century, many of them have served these purposes admirably. However, questions remain about their contemporary and future usefulness. This paper reports on the perspectives of a four-member panel of Forest Service experts on the strengths and weaknesses of Experimental Forests and Ranges. In this panel, we also contemplated their future role for providing information and facilitating relationships between research scientists and managers.

INTRODUCTION

In 1908, Raphael Zon presented to USDA Forest Service Chief Gifford Pinchot a novel plan for designating experimental areas on national forests and ranges to conduct research and demonstration for the emerging discipline of forestry in the United States. Zon wrote that "These areas will furnish the most valuable, instructive, and convincing lessons for the public in general, and for professional foresters…and technical and administrative officers…. They should be made the meeting grounds for supervisors, rangers, and guards, where demonstrations may be given…" (Zon 1908). Thus, the experimental forests and ranges (EFRs), as envisioned by Zon and Pinchot, were needed to both inform the fledgling agency and to help catalyze, develop, and maintain the critical management-research partnership that helped define the Forest Service.

For more than a century, research conducted on EFRs has led to the development of numerous outcomes and products that have made EFRs an irreplaceable asset. Countless scientific papers and reports containing management recommendations or lessons learned have been produced. In addition, students and managers of all backgrounds, policy makers, collaborative members, stakeholders, and the general public have gotten educational opportunities and research experience from EFRs. In turn, researchers have learned the value of identifying relevant questions gleaned by working side by side with forest managers. Hence, EFRs have played a critical role in addressing questions raised by important issues facing the USDA Forest Service, and, by extension, the profession of forestry.

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Over the past century, ecosystems and the disturbance drivers affecting them are being transformed, and land managers are increasingly focused on sustaining processes and resilience at multiple scales. As forested ecosystems and management approaches change, the outcomes of silvicultural practices also evolve, resulting in new questions that require scientific guidance. Given changes in management approaches and disturbance drivers, and to rapidly evolving information needs, many questions remain about the future relevance of EFRs and how they can continue to serve the needs of researchers and managers

The Experimental Forests and Ranges Panel is intended to provide a "grassroots" perspective to the National Experimental Forests and Ranges Working Group members and to Forest Service leadership about the future role of EFRs in addressing emerging information needs. These include (but are not limited to):

- Building foundational silvicultural research in the face of uncertainties that include changing conditions (climate or otherwise).
- Enhancing collaboration among researchers, managers, stakeholders, and supervisors.
- Providing relevant and innovative place-based experiments and demonstrations for new science investment .
- Providing field demonstrations for technology transfer to natural resource practitioners across ownerships.

One of the goals of this effort was to compile information for the National Experimental Forests and Ranges Working Group to be shared with Regional Foresters and Station Directors to guide the use and management of EFRs in the future.

PANELISTS

The four panel members consisted of representatives from both the National Forest System (NFS) and Research and Development (R&D). Panelists included Theresa Jain, research forester and Scientist-in-Charge of the Boise Basin Experimental Forest, Rocky Mountain Research Station; Don Bragg, Project Leader, research forester, and Scientist-in-Charge of the Crossett Experimental Forest, Southern Research Station; John Lampereur, District silviculturist, Chequamegon-Nicolet National Forest; and John Riling, forest silviculturist, Boise National Forest.

APPROACH

Panelists were asked to consider a number of topics (questions) and to provide their perspectives and insights about the future use of EFRs. At the panel discussion, audience members were given an opportunity to respond, ask questions, and offer their own experiences and perspectives on EFRs. The goal was to identify the strengths, limitations, and opportunities of conducting research on EFRs and facilitating management-research partnerships. This approach provided insight into what is working well and what needs to be improved to more fully utilize EFRs. The responses to questions below were paraphrased from notes taken during the panel and consequently are not exact transcriptions of the responses.

QUESTIONS AND PANELIST RESPONSES

Question 1. What are the strengths of using EFRs for fostering management-research partnerships and for facilitating the development of relevant research? In other words, what is working well now?

Working together and Sharing Ideas

Lampereur pointed out that research and management are their best when researchers and managers work together to share observations, ideas, and thoughts. Together, they are better able to identify the management issues and research questions than when working alone, as researchers bring critical and analytical thinking and managers are good observers. Riling added that working relationships between researchers and managers continue to make EFRs relevant. Working together forces managers to think critically and allow for growth and development of expertise when researchers introduce different ideas and concepts. The on-the-ground studies inform planning and implementation because managers can bring policy makers, decisionmakers, stakeholders, and collaborators to show possible management outcomes. Developing management activities that are supported or driven by science increases internal and external support and confidence in management direction. Jain, like Riling, noted that EFRs provide places to demonstrate methods and teach important concepts that are not easily grasped from a publication or formal presentation.

Enhanced Research Relevance

Jain noted that when researchers are working side-by-side with managers, the relevance of research increases. For example, when implementing a free-selection regeneration method study at the Priest River Experimental Forest, the study used timber sales and planting contracts. This made the treatment application more practical and, more importantly, more transferrable to National Forest land because the study used NFS standards and guides (Jain et al. 2008). Using an EFR model allows for different world views and perspectives to enhance the innovation and "art" of silviculture. Lampereur best captured the value of this researcher-manager interaction by stating that working together is essential for identifying and solving relevant problems and that relationships between researchers and managers should be fostered and strengthened through networking on EFRs.

Strength of Long-term Studies

Bragg noted that a real advantage to EFRs is the ability to conduct long-term studies and monitoring projects at larger operational scales, making silviculture studies more valuable over time. Also, managers can return to these sites and observe the changes that have occurred over longer periods—a critical requirement to understanding outcomes of forest management practices. It is through this observation and the face-to-face interactions between forest managers and research scientists that EFRs become an ideal place to learn.

Candid Interactions

Jain noted that another advantage with silviculture studies on EFRs lies in the responsibility for treatments being placed on the researcher, who is accustomed to critical evaluation and feedback. Thus, on these studies, managers do not feel they have to defend their actions, but they are able to be open, critical, and provide their opinion and feedback. Similarly, stakeholders and collaborators can also provide their opinion and feedback. These interactions are valuable for understanding different perspectives, values, and ultimately for gaining trust and respect.

Question 2: What are the limitations of using EFRs, especially with regard to agency relevance and to foster management-research partnerships? In other words, what is not working well?

Logistical Issues

A primary challenge associated with EFRs are associated with implementing treatments. Many treatments applied on EFRs are implemented by NFS staff. This is not a major problem when NFS staff are nearby, but Bragg noted that the Crossett Experimental Forest in southern Arkansas is 3 hours from the Ouachita National Forest staff responsible for management. This distance creates enormous logistical challenges for implementing silvicultural treatments.

Differing Priorities and Challenges between NSF and R&D

To further complicate the logistical difficulties, Bragg observed that researchers and managers do not always share the same priorities. For example, prescribed fire treatments on a research study may not be applied in a timely manner due to forest burn prioritization schedules, particularly when burn windows are limited. Researchers working on EFRs also need the ability to implement nonstandard practices—even to install treatments that "break the system"—in order to understand cause-and-effect in natural ecosystems. However, EFRs often do not have the administrative capacity to implement those practices, making it hard to do certain experiments critical to the understanding of how an ecosystem works.

Similarly, Riling pointed out that NFS and R&D staff often have different challenges, objectives, and interpretations of policy. For example, the Boise National Forest is in the middle of an environmental assessment that includes the 8,740-acre Boise Basin EFR, where active management, such as thinning and burning for research purposes, are proposed. Multiple factors have contributed to delays in the National Environmental Policy Act (NEPA) planning process; contracting NEPA added another layer of complexity. Interpretation on NEPA policy has differed between NFS and R&D for the project, specifically whether experimental treatments on EFRs must be consistent with Forest Plan standards and guidelines or if a project-specific Forest Plan amendment is warranted.

Differing Funding Priorities

Some limitations are related to funding priorities and funding availability for research on EFRs. Lampereur observed that local research needs are not always considered essential on the national level. Often, national-level projects receive funding priority. However, national-level issues may not be as relevant to the day-to-day management needs, creating little incentive for managers to engage in this research. Locally, there may be insufficient funding to hire seasonal workers to gather the data on the EFRs. Good partnerships with NFS managers can help to resolve funding issues by sharing resources, but this requires that researchers and managers build good personal relationships and work together to identify and conduct studies that are of mutual interest.

Staffing and Workplace Turnover

Another limitation of EFRs relates to staffing and workforce turnover. Jain pointed out that EFRs were originally intended for long-term research. Personnel turnover, whether in R&D or NFS, makes maintaining long-term studies challenging. Turnover not only poses the risk for loss of institutional memory of long-term research projects, it also affects the development of critical researcher-manager relationships. For example, it is not always clear who to contact due to high personnel turnover, which can sever lines of communication between researchers and managers. Presently, many EFRs are understaffed and many rely on the NFS for assistance in the field. With high staff turnover at the Forest level, EFR scientists-in-charge may find managing an EFR to be a burden rather than an asset, leading to loss of the value of the EFR. Although it is not possible to control agency turnover, it is possible to plan for it, starting with a shared vision for what is required in decisionmaking.

Question 3: What are some ways to overcome some of these limitations? What can be done to fix the problems?

Build Professional Relationships

Riling suggested that some of the limitations related to implementing studies on EFRs could be overcome if researchers and managers develop personal relationships. These relationships are strengthened with face-to-face conversations and time spent walking together in the woods. The value of these relationships needs to be recognized and there needs to be support for research that arises from management-research partnerships on EFRs. For instance, it is important to have an advocate for research in the NFS who helps build continuity and ensures that it is carried over from project to project through time. Other issues can be addressed by establishing a communication strategy that identifies points of contact, including interdisciplinary counterparts, between researchers and managers. It is more often the case that individuals from both sides establish connections, but it is rare that the whole interdisciplinary team works together as a group.

Foster Interdisciplinary Partnerships

Jain suggested that creating an interdisciplinary research team that matches those in the NFS (like wildlife biologist paired up with wildlife scientist) could help with establishing an interdisciplinary partnership. A major challenge is the lack of funding for implementing the interdisciplinary team's projects because funding is often focused on single-discipline studies (e.g., wildlife) and there is no established mechanism to fund interdisciplinary research. One possible solution is to think innovatively. An example of this is the "Region 4 Science Partner Program" (https://www.fs.fed.us/rmrs/region-4-science-partner-program), which was established to enhance collaboration opportunities between RMRS researchers and Region 2 NFS managers. Another way to get researchers and managers to work closer together is by writing the project proposals together, considering innovative ways of funding EFRs through NFS, working together to figure out how the work can be mutually beneficial, and helping each other to implement tasks (even with lack of funds).

Place Greater Emphasis at Local Levels

Lampereur recommended placing more emphasis on setting priorities at local levels to strengthen researcher-manager relationships. Lampereur noted that during the last 20 years, the centralizing of budgets in the Forest Service has reduced funding for research on EFRs. Thus, a lot of the influence in decisionmaking has moved from local levels to regional and national levels. Consequently, local personnel have less ability to set research priorities on EFRs, reducing manager engagement in studies. More trust is needed to empower employees at the lower level so that research priorities can be identified. Leadership that specifically encourages research and management to work together should be emphasized. As an example, annual meetings to discuss issues, concerns, and needs could help facilitate work on EFRs. When making connections between R&D and NFS staff is a priority, partnerships can be built more effectively.

Connect Managers and Researchers

Bragg noted that the Southern Research Station (SRS) has initiated efforts that may potentially fix some of the communication problems between managers and researchers. The SRS has hired a liaison to interact among the Region and the Station and that person is also making connections between researchers at EFRs and managers in the NFS. There are also ongoing discussions at the SRS to determine how scientists can serve better the information needs of NFS managers. This includes face-to-face interactions and regular meetings to discuss joint research and Forest priorities.

ADDITIONAL CONSIDERATIONS

Put the Right People in Charge

David Gwaze, the National Silviculturist, responded to one of Jain's comments related to staffing EFRs with researchers who view EFRs as an asset. He asked the panelists how can the Agency ensure that a scientist-in-charge will be an advocate for their EFR? Jain echoed that there is a process needed to determine whether the scientist-in-charge will be a good fit when he or she is assigned to manage an EFR. Even during the hiring process, expectations and responsibilities should be clearly stated for researchers who have assigned responsibilities for EFRs. An important part of the interview process for these researchers could include searching for and selecting a person who believes in their use and will be an advocate for EFRs. Also, the career benefits associated with being a scientist-in-charge of an EFR should be made clear. Bragg observed that researchers in the Forest Service are career oriented and that working at a single location like an EFR may not be a good fit for some research interests, making it more imperative that the right person must be put in the right place. Furthermore, R&D administrators and scientists need to continually examine how EFRs can be used to address new ideas and future research questions that benefit both EFRs and scientists assigned to work on them.

Reward Staff for Working on EFRs

Jim Guldin, SRS Silviculturist, pointed out that R&D continues to get funds through the Forest Inventory and Analysis (FIA) program and that there may be opportunities to expand the relationship between FIA and EFRs. He also suggested that those "responsible" for the EFR may not be supportive of the work of "outside" scientists or feel like it infringes on their territory and that this barrier should be broken. Jain responded that this is a personnel issue rather than a resource issue, pointing out that scientists-in-charge are not recognized or compensated for investing in partnerships that do not lead rapidly to publications and scholarly outputs. Because it may take many years for long-term studies, such as those conducted on EFRs, to produce publishable results, a researcher may be reluctant to engage with others until the study begins to yield results. This could change if researchers are specifically rewarded for forming collaborative research on EFRs.

Clarify Roles and Responsibilities

Tom Schuler, the National Program Lead for silviculture in R&D, pointed out that there is greater clarification in the newly revised Forest Service Manual Chapter 4060 "Research Facilities and Areas" to aid with managing and using EFRs. Prior to the most recent update, this chapter had been largely the same since 2005 and provided very little guidance regarding who is responsible for maintaining the infrastructure of EFRs and how research is implemented. Thanks to the efforts of many people around the country, including members of the National Experimental Forest Working Group and many of the staff in the Washington Office, the proposed revision to the chapter greatly clarifies the roles and responsibilities and will help facilitate better cooperation among scientists and managers. This revision is still in review but it is anticipated to be available soon.

Keep Detailed Study Records and Make them Available

Greg Edge of the Wisconsin Department of Natural Resources suggested that collaborating with researchers on long-term studies can be frustrating at times, especially when data are not easily located, or plot boundaries are not properly marked, leading to treatments that may be compromised. He wanted to know how partners can help protect and maintain long-term research. Lampereur responded that there are cases when managers implement prescribed burns or timber sales without knowledge of a research site due to lack of communication between researchers and managers—something that is less likely to happen on the EFRs. Similarly, another reason EFRs are valuable is that establishment records were produced and archived for most studies providing documentation for reestablishing study plot boundaries even where they are not adequately marked on the ground. Bragg added that there is an ongoing process of data digitization on many EFRs. For example, in the SRS there are long-term datasets (such as 80 or 100 years of streamflow data or climate data) that remain in their original format (strip charts). The SRS has been investing in the translation of analog to digital forms, and then making it available and accessible for all to use. Detailed record keeping and data availability increase the likelihood that a long-term study will reach fruition and yield useful research products, making the investment in the collaboration more worthwhile for researchers and managers.

Recognize that Mutual Interests are Likely to be Funded Interests

One final observation was made by Jason Jerman, supervisory forester at Idaho Panhandle National Forests, who stated that if there are questions that need to be answered, there should be a will to find those answers and pull together limited resources to address them. It is important to advocate for EFRs so that researchers and managers each have a vested interest in studies conducted on them. Shared interests can create new opportunities in utilizing funding and resources.

SUMMARY AND CONCLUSIONS

The panelists each believed that EFRs are important for developing relevant information needed by managers and administrators, and for fostering management-research partnerships. It was noted that practicing foresters are keen observers in the field and that these observation skills lead to the development of testable hypotheses. Researchers possess high level analytical skills and the means for translating observations into experiments and research studies. Hence, working together, researchers and managers can answer questions that are meaningful and scientifically sound. It also was stated that knowledge about how forests respond to management often requires long-term studies and that EFRs are ideally suited for this purpose. In addition, many EFRs are of sufficient size that these studies can be conducted at operational scales. Where there are strong researcher-manager relationships, the associated studies that are conducted on EFRs tend to be highly relevant to practicing foresters. In turn, EFRs help strengthen management-research partnerships by providing a venue for candid conversations about the efficacy of specific management practices and a safe place for managers to provide honest feedback and test new questions.

Most of the limitations associated with the use of EFRs were related to logistics, differing priorities, funding, and staff turnover. Some EFRs are located 100 or more miles away from the scientist's duty station, making study development, installation, maintenance, and data collection more challenging. Most EFRs require collaboration with NFS foresters for implementing experimental treatments such as timber harvests or prescribed burns, which requires coordination between researchers and managers. This also means managers may have to alter their work plans to accommodate the researcher's in some instances by shifting priorities to meet the rigorous timing of treatments required by most research studies. Additionally, researchers working on EFRs depend on assistance from District staff to navigate the NEPA process and prepare the necessary documentation. Proposed studies on an EFR may include treatments that are at odds with the objectives of the Forest Plan. For researchers to maintain this level of assistance from District staff, considerable time must be invested in nurturing relationships between researchers and managers. This is difficult where researchers have limited capacity in time and resources to invest in these relationships, or where NFS staff turnover requires the researcher to frequently begin new relationships with new staff members. Furthermore, for NFS staff to be engaged, studies on EFRs need to be relevant to current management questions.

Resolving the communication gaps, overcoming limitations, and thereby strengthening management-research partnerships will require commitments by Forest Service leadership, administrators, researchers, and managers. Administrators at all levels need to remain committed to supporting research on EFRs and support managers and researchers working *together* to develop science-based solutions to management problems. This includes both funding support to maintain infrastructure and by explicitly rewarding researchers and managers that work together. This also requires R&D leadership to set as a priority to hire some researchers that have an obligation to manage the EFRs in their jurisdiction, to conduct research on them that supports agency mission areas, and to advocate for wider use of EFRs. Similarly, NFS administrators need to ensure that District staff associated with local EFRs work in partnership with research staff.

The panelists believe that EFRs remain important places for experiments that support the mission of the Forest Service and other land management agencies and organizations. Though research questions continue to evolve, the need for scientifically supported management recommendations remains more important than ever. In an era of declining budgets, developing and maintaining strong working relationships between forest land managers and researchers is imperative to ensure smart, relevant, and effective studies are conducted on EFRs. Globally, these EFRs provide a unique opportunity to conduct long-term research that informs forest management and strong management-research partnerships helps ensure that research on EFRs is informed by the information needs of managers. Perhaps the greatest strength of EFRs is that they continue to provide, in Zon's words, a "meeting grounds for supervisors, rangers, and guards" (Zon 1908), thereby facilitating management-research partnerships in the USDA Forest Service.

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National Advanced Silviculture Program: A Panel Discussion

David Gwaze, Marcella Windmuller-Campione, Tara Keyser, and Carrie Sweeney[1]

FIRST PANEL – NASP DIRECTORS

Panelists

- Marcella Windmuller-Campione, University of Minnesota
- Eli Sagor, University of Minnesota
- John Bailey, Oregon State University
- Kevin McGarigal, Northern Arizona University
- Wayne Clatterbuck, University of Tennessee

Moderator: David Gwaze, National Silviculturist, USFS

Panel discussions began with Gwaze providing a general explanation and history of National Advanced Silviculture Program (NASP). NASP is a graduate-level training in silviculture and forest ecology for USDA Forest Service employees seeking to be certified as silviculturists. The training is open to employees of other Federal and State agencies. NASP is conducted in collaboration with four leading academic institutions. To become a certified silviculturist, a participant should possess 3 years of related experience, participate in the four NASP modules as well as appropriate local modules (regional courses), and write and defend a silvicultural prescription.

The Forest Service silviculture certification process began in the early 1970s as a result of forest management controversies of the 1960s. In the early days of certification, continuing education for silviculturists were met using regionally administered programs. From 2002 to 2004, the Washington Office of the Forest Service reviewed the regional modules and decided to standardize the training by creating the National Advanced Silviculture Program. The first NASP cohort began in 2007.

Gwaze introduced the coordinators of each module. Each coordinator described his or her module and answered three questions:

1. What are the goals and objectives associated with your module?
2. How has your module evolved since inception in 2007?
3. How have you integrated the relevant research results and instructors from Forest Service Research & Development (R&D) into the module?

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Module 1: Ecological Systems, Marcella Windmuller-Campione and Eli Sagor

The first module is the Ecological Systems Module and is co-directed by Marcella Windmuller-Campione and Eli Sagor, who took over this module from Linda Nagel in 2016. This module would not be possible without the support of the Department of Forest Resources and the College of Food, Agricultural and Natural Resource Science within the University of Minnesota. The broad goals of the module are to provide a solid foundation in silvics, ecosystem processes, disturbances, and the influence of scale on different processes. The aim is to connect foundational theory delivered through lecture material with application through multiple field trips, activities, and group discussions.

The big change that was implemented after 2016 was shifting some of the content into pre-NASP YouTube videos to allow greater time for active learning during face-to-face class time, increase ease of review of material compared to lecture notes, and allow sharing of material within and across agencies. The directors collaborate with Forest Service R&D, especially on topics related to climate change, about which Chris Swanston and Maria Janowiak of the Northern Institute of Applied Climate Science, along with Linda Nagel, present 6 to 7 hours of material. In addition, the participants spend a day leaning how future climate may affect forests at the SPRUCE experiment site at Marcel Experimental Forest (https://www.nrs.fs.fed.us/disturbance/climate_change/spruce/). This is a collaborative effort between university researchers and Forest Service scientists, including Randy Kolka and Stephen Sebestyen of the Forest Service's Northern Research Station. Finally, Morgan Varner (now with the Tall Timbers Research Station and Land Conservancy in Tallahassee, FL) teaches about fire ecology. There are also many other Forest Service R&D researchers that have influenced and shaped the national and local modules.

Module 2: Inventory and Decision Support, John Bailey

Goals and objectives are built around understanding the quantitative side of forestry and understanding the context of calculating and viewing data. The module includes the following topics at multiple scales: inventory, mensuration, sampling, statistics, monitoring, economics, tree growth, stand density, mortality, modeling, yield, forest planning, and policy and legal dynamics around decisionmaking. The module consists of pre-NASP work, lecture, computer lab work, and field work.

Additions throughout the years include additional pre-NASP work, additional material on statistics and economics, and more hands-on activities in addition to readings. Participants also use the Forest Vegetation Simulator (FVS; https://www.fs.fed.us/fvs/) so it can be used for multiple purposes, including the stand chosen for certification

Bailey collaborates with Erin Smith-Mateja (FVS staff member) in modeling exercises as well as Siuslaw National Forest silviculturists on field trips.

Module 3: Landscape Ecology, Kevin McGarigal

The purpose of this module is to enhance participants understanding of landscape ecology and theory as applied to the study and management of public lands. The participants gain a broad understanding of the methods for detecting and characterizing landscape pattern, the causes of pattern, the implications of pattern to populations, communities and ecosystems, the mechanisms by which pattern and process change through time, and the strategies by which humans manage landscapes. The module focuses on topics relevant to silviculturists including landscape definition (conceptual/analytical models of landscape structure), implications of pattern to populations, communities and ecosystems (connectivity, metapopulations, landscape genetics), drivers of landscape pattern (disturbance regimes), and landscape dynamics and range of variability modeling.

Since 2007, the module has evolved by reducing topic material by 30 percent, doubling half-day field trips, increasing time allocated to hands-on lab projects (8 half days), increasing laboratory focus on a local case study, and increasing lab emphasis on silviculture (pattern and process at the district, project, and stand levels).

The module partners with Forest Service's Rocky Mountain Research Station scientists Sam Cushman (landscape ecology and genetics), Bob Keene (disturbance regimes), and Northern Research Station's Eric Gustafson (landscape modeling). Field trips are coordinated with Coconino National Forest silviculturists Mark Nabel and Andy Stevenson. The main challenge is the logistics, including receiving approval of Forest Service personnel to participate.

Module 4: Advanced Silviculture, Wayne Clatterbuck

Through NASP, Clatterbuck has trained more than 400 silviculturists in the last 12 years. More than 85 percent of those who attended NASP have received silvicultural certification. The module's overall goal is to go beyond those practices in the silviculture and stand dynamics textbooks to evaluate practices that create complexity on the landscape, including uneven-age, crop tree release, two-age, deferment cuts, variable density thinning, and various retention levels. The general format of the module includes lectures in the mornings with field activities in the afternoon; the course cumulates with a stand prescription or capstone project. In the module, participants strive to understand pros and cons of various pathways to move from present conditions to desired future conditions. Adaptive silviculture is a primary topic since change is part of the process, whether from unplanned disturbances, forest health events, or climate variability. Silviculturists are disturbance engineers!

Speakers with silvicultural expertise from across the country serve as instructors to provide a variety of perspectives. This allows participants to connect with different instructors based on their region or expertise. In this manner, even though most of the exercises are in the oak-hickory forest type, the foundational silvicultural principals can be applied to the participant's locale.

Changes to course material over the last 12 years include coordinating harvesting systems with silvicultural practices, working in savannas and woodlands, changing timelines and travel so participants' lives are not interrupted for four consecutive weekends. Travel days to and from the module have been on Monday and Friday, rather than Sunday and Saturday. Adaptive silviculture prescription development has also been incorporated into the curriculum.

SECOND NASP PANEL – FORMER NASP PARTICIPANTS

Panelists

- Jason Jerman, Region 1, Idaho Panhandle National Forests
- Katherine Reynolds, Region 10, Tongass National Forest
- Chad Fitton, Region 9, Wayne National Forest
- Joshua Hanson, Region 9, Allegheny National Forest

Moderator: Marcella Windmuller-Campione

Windmuller-Campione introduced four former NASP participants and each addressed the following questions:

1. Describe how you used research or researcher connections you gained during the NASP modules to develop your NASP project.
2. Describe how the research-management partnership in the national NASP modules allowed you to gain and share knowledge related to becoming a certified silviculturist.
3. Describe how you use these research connections in your career as a certified silviculturist.

Jason Jerman

Jerman took away multiple pieces from the NASP classes but one piece that resonated with him builds off of Clatterbuck's message: importance of the foundational or primary principles. In Module 4, there were multiple researchers from other regions and different systems who shared their perspectives and views. From this module and others, Jerman gained additional experience learning how to look at research and glean the principle of research not just the prescription that came out of it, figuring out how and when and where those principles apply in ecosystems he is working with. This has become especially important in his currently job to be able to communicate decisions to stakeholders and other Forest Service employees.

Katherine Reynolds

Reynolds used the local module training and local specialists to help guide her prescription work. She was always trying to apply national modules to her local needs. After NASP, Reynolds was able to connect things from classes back to her own forests. For example, the SPRUCE climate experiment at the Marcel Experimental Forest in Module 1 was impactful, as it made her think about how climate change will affect both forests and society in southeastern Alaska.

There is a great effort to coordinate a yearly silviculture workshop in Region 10 to foster relationships. It really helps bring the silviculturists and Forest Service researchers together and improve research-management connection.

Chad Fitton

Fitton focused on resource conditions that he developed during NASP. His project focused on developing a prescriptions for a shortleaf pine-oak stand. He enhanced his understanding of native pine and pine-oak stands by attending NASP and working with FVS staff member Chad Keyser. Also, he worked with scientists from the Northern Research Station, notably Todd Hutchinson, for ecological underpinnings in southeast Ohio, and Susan Stout, Joanne Rebbeck, and Pat Brose with utilizing the SILVAH-Oak program. To fine tune his shortleaf prescription, he worked with Clatterbuck. Fitton has also worked with Forest Service geneticists Paul Berrang (Region 9) and Barb Crane (Region 8) for seed source and seedling selection.

Joshua Hanson

Hanson greatly benefited from the research and management connections established during NASP. After completing his certification, he feels confident in his ability to describe alternatives and explain those alternatives to the public. This was highlighted in his prescription which involved a broadcast herbicide treatment. He credited research findings as the basis for the continuation of the use of herbicides as a tool.

In Hanson's opinion, the existing research-management partnership is the primary reason the NASP program has been so successful. Where else can you receive 9 weeks of graduate-level instruction from four different academic institutions? In addition to providing fantastic locations, facilities, and curriculum, the module directors bring in an incredible number of guest speakers—presenting science that ranges from established and accepted (tree physiology, stand dynamics, silvicultural principals, etc.) to cutting edge (SPRUCE, B4WarmED, oak savannahs, etc.). Hanson also feels the field tours are better than most, primarily because they include a mix of both experimental and operational treatments. These tours also encourage and allow time for lengthy discussions. NASP is a wonderful opportunity to meet people across the agency, to share ideas. Hanson believes that NASP is one of the best programs he has been part of, in part because of the partnership between rand management.

SUMMARY

Discussions during this session included an overview and history of the National Advanced Silviculture Program. Panel members provided participants an opportunity to meet and learn from NASP directors about the content, importance, and changes associated with their respective modules. Former NASP participants discussed the importance of making connections with Forest Service R&D scientists through the program and how this relationship influenced them going through the certification process. Certifying silviculturists through NASP remains a top-priority training program for the Forest Service. As forest ecosystems and the practice of silviculture evolve, the importance of up-to-date science based research remains critical to assist silviculturists with decisionmaking tools they can use to manage the nation's forest lands. NASP provides an important link between Forest Service R&D and the National Forest System.

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Research and Management Partnerships for Resolving Regeneration and Recruitment Challenges in Hardwood–Softwood Mixtures in Eastern North America

John M. Kabrick, Kenneth L. Clark, Anthony W. D'Amato, Bethany L. Muñoz Delgado, Daniel C. Dey, Laura S. Kenefic, Christel C. Kern, Tara L. Keyser, Benjamin O. Knapp, David A. MacLean, Patricia Raymond, Callie J. Schweitzer, and Lance A. Vickers[1]

ABSTRACT.—Naturally occurring mixtures of hardwoods and softwoods are found throughout the eastern United States and Canada. They are compositionally diverse and appear to have originated from a complex array of natural disturbances or past harvesting. Contemporary mixedwood stands can be difficult to regenerate and manage because individual species of these mixtures have differing shade tolerances, growth rates, longevities, phenology, and crown and root structure. Consequently, they often cannot be sustained without deliberate silvicultural efforts to regenerate and recruit desirable species. Despite the difficulties, foresters are interested in managing hardwood–softwood mixtures because of the many benefits that they confer including increased resistance to pests and diseases, improved habitat diversity, enhanced climate change resilience and adaptability, and increased diversity of forest products. The interest in and the challenges related to managing these mixtures have led to the development of many research-management partnerships across the eastern United States and Canada to resolve regeneration and recruitment problems. Here we discuss the regeneration and recruitment challenges for a variety of hardwood–softwood mixtures across the eastern United States, identify the research-management partnerships that have developed to address them, and describe how these partnerships are leading to solutions.

INTRODUCTION

Mixedwoods are stands that include mixtures of hardwoods and softwoods, with neither component comprising more than approximately 75 to 80 percent of the composition (Helms 1998). There are many different naturally occurring mixedwood types presently recognized throughout eastern North America including hemlock–yellow birch, white pine–northern red oak–red maple, shortleaf pine–oak, and loblolly pine–hardwood (see Table 2 for scientific names of tree species). However, data from the USDA Forest Service's Forest Inventory and Analysis (FIA) program indicate extensive acreages of hardwood–softwood mixtures, even for forest types that nominally include only hardwoods or softwoods (Table 1). Mixedwoods can occur as isolated stands within hardwood- or softwood-dominated landscapes or they can cover a large proportion of a forest landscape.

There is growing interest in managing mixed-species forests worldwide (Bravo-Oviedo et al. 2018, Waldrop 1989), and in eastern North America there is a particular interest in mixtures of

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Table 1.—Estimates of forest land area by forest-type across for 24 northeastern U.S. states[a], according to Forest Service Forest Inventory and Analysis Program data. Data from USDA Forest Service 2019.

Forest type	Hardwood	Softwood	Mixedwood	Area with no trees ≥5 in. d.b.h.	Total
	………………	………………	*acres*	………………	………………
Aspen/birch	8,008,668	709,436	5,782,817	1,165,786	15,666,706
Douglas-fir		3,785	3,546		7,330
Elm/ash/cottonwood	11,720,566	151,667	2,068,484	390,278	14,330,995
Exotic hardwoods	301,784	6,803	17,957	5,854	332,399
Exotic softwoods	8,965	342,164	251,753	19,617	622,499
Fir/spruce/mt. hemlock		10,707		1,924	12,632
Loblolly/shortleaf pine	18,649	831,189	895,953	29,823	1,775,613
Maple/beech/birch	29,596,562	309,479	14,885,989	449,198	45,241,228
Nonstocked	612,345	279,316	75,439	632,599	1,599,700
Oak/gum/cypress	695,445	31,078	99,482	2,957	828,961
Oak/hickory	57,036,881	226,789	7,367,792	925,432	65,556,894
Oak/pine	140,323	257,907	5,496,269	118,519	6,013,018
Other eastern softwoods	44,763	541,042	369,110	56,506	1,011,422
Other hardwoods	1,239,787	200,656	471,935	271,451	2,183,829
Other softwoods			971		971
Pinyon/juniper		156,156	42,581	463	199,200
Ponderosa pine		1,217,560	76,040	14,244	1,307,845
Spruce/fir	55,278	10,738,601	4,433,130	1,060,993	16,288,001
White/red/jack pine	71,643	4,389,780	4,650,373	292,540	9,404,336
Total	109,551,660	20,404,116	46,989,618	5,438,184	182,383,578

[a] In addition to the 20-state region defined in footnote 2 (page 131), forest land from an additional four states are included in these estimates: North Dakota, South Dakota, Nebraska, and Kansas. Mixedwood stands are defined on page 129.

hardwoods and softwoods growing together in the same stand (Kabrick et al. 2017). Mixtures are of interest because they provide compositionally and structurally diverse habitats (Comeau 1996, Girard et al. 2004, Jung et al. 1999) and because, compared to pure stands, they are more resistant or resilient to contemporary insect outbreaks and diseases (Campbell et al. 2008, Su et al. 1996). They produce a diverse revenue stream that is more economically resilient to changes in timber markets. They have the potential to produce more biomass, store more carbon, and produce more timber due to their structural complexity and vertical stratification that occurs because of differences in the growing space requirements of the component species. There is some evidence supporting the hypothesis that mixedwoods are equally or better adapted to forecasted changes in climate than their pure hardwood or softwood analog (Kabrick et al. 2017).

However, despite occurring naturally throughout eastern North America, mixedwoods are often a challenge to manage due to differing shade tolerances, growth rates, longevities, phenology, and crown and root structure of the component species (Kelty et al. 1992, Pretzsch 2014, Prévost 2008). In addition, historical land use in some regions often selectively removed conifer species from mixedwoods, limiting current availability of on-site seed sources (Kelty and D'Amato 2006). Species within mixedwoods often employ differing regeneration and growth strategies. Consequently, regenerating and recruiting mixtures can be challenging. Without carefully timed disturbances, mixedwoods transition into softwood or hardwood stands.

THE MIXEDWOOD INITIATIVE

The interest in restoring or managing mixedwoods and the long-standing challenges associated with their regeneration and tree recruitment in the eastern United States and Canada led to the development of many local partnerships between scientists and managers (Table 2). Partnerships often developed as isolated collaborations in response to local mixedwood management challenges. Many of these partnerships in the United States were between USDA Forest Service Research and Development scientists and National Forest managers or with state land managers. Many of these studies also included university partners. Although some of the studies focused on examining whether an increasing hardwood or softwood component in pure stands increased resistance or resilience to contemporary or emerging pest problems, most focused on resolving regeneration and recruitment problems in mixedwoods.

In April 2014, leadership within the Forest Service, Northern Research Station (hereafter referred to as Station), recognized that there were a number of research-management partnerships across the Station and beyond the 20-state Station boundary[2], each addressing information needs for managing hardwood–softwood mixtures. Station management proposed that a larger partnership would foster broader thinking about mixedwood ecology and silviculture and serve as a means for linking opposite corners of the Station and their partner land management agencies and universities around a common problem. By working together across the Station and beyond its borders, the scope of this research-management effort would expand, providing a more integrated and broadly cohesive problem identification and knowledge from a larger network of scientists and managers to more effectively identify and resolve some of the silvicultural issues. Funding was identified to help initiate this effort to be used for developing special sessions or symposia and work sessions organized by the scientific team members of the partnership. This effort become known among its members as the “Mixedwood Initiative.”The founding scientific team members of the Mixedwood Initiative included Northern Research Station scientists and a number of their associates from other government agencies and universities (Table 3) including members from several U.S. states and Canadian. This group’s approach was to pursue a research program working with management partners addressing the following themes and questions:

1. Resilience/resistance

- Are mixedwoods more resistant/resilient to contemporary or emerging pests and pathogens, or to changing climates, compared to their hardwood or softwood counterpart alone?
- Can resistance or resilience of mixedwoods be enhanced by management?

2. Function and services

- Do mixedwoods yield more merchantable biomass or store more carbon than their hardwood or softwood counterparts alone?
- Do mixedwoods contain a more diverse community of flora or provide more diverse habitats than their hardwood or softwood counterparts alone?

[2] Northern Research Station boundaries consist approximately of the area between Maine, west to Minnesota, south to Missouri, and east to West Virginia.

Table 2.—Examples of local partnerships for examining the benefits and addressing the silvicultural issues associated with managing mixedwood stands

Forest type	Partnerships	Project themes	Persistent issues
Shortleaf pine–oak (*Pinus echinata* Mill., *Quercus* spp.)	Mark Twain National Forest, research group NRS-11[a], Univ. of Missouri, Univ. of Tennessee	Regenerating and recruiting shortleaf pine to restore mixed pine–oak forests and woodlands	Information is needed for managing intense hardwood competition during shortleaf pine recruitment; interest in the role and timing of fire, herbicides, stock types (bareroot vs. container) for successful shortleaf pine regeneration and recruitment
Shortleaf pine–white pine–oak (*Pinus echinata* Mill., *Pinus strobus* L., *Quercus* spp. L.)	Pisgah National Forest, research group SRS-4157[a], Virginia Tech Univ.	Examining effects of planting stock (bareroot vs. container) on survival, growth, and competition with naturally regenerated hardwood and softwood species (e.g., eastern white pine) Quantifying effects of top-kill (clipping vs. burning) during different seasons (dormant/fall vs. spring/growing) on resprouting potential and subsequent growth of shortleaf pine.	Information is needed for managing intense hardwood competition during recruitment phase; lingering questions about the role and timing of prescribed fire, herbicides, and stock types (bareroot vs. container) for successful establishment and recruitment
Loblolly pine–oak (*Pinus taeda* L., *Quercus* spp. L.)	Bankhead National Forest, research group SRS-4157[a]	Regenerating oaks in former loblolly pine plantations; using mixedwoods as an intermediary to restoring hardwood forests	Information is needed about the establishment of oak under partially harvested loblolly pine stands and how to transition loblolly pine plantations into diverse, oak-dominated hardwood forests
Pitch pine–oak (*Pinus rigida* Mill., *Quercus* spp. L.)	New Jersey Forest Fire Service, New Jersey Env. Protection, research group NRS-6[a], Dartmouth College, Rutgers Univ.	Quantifying resistance and resilience of oak – pine mixtures to gypsy moth and southern pine beetle	Information is needed about how climate is affecting the ecological processes and successional changes in this region
Hemlock–hardwoods (*Tsuga Canadensis* [L.] Carr., mixed hardwoods)	Research groups NRS-7 and NRS-11[a], Clarion Univ., State of Wisconsin Board of Commissioners of Public Lands	Developing and evaluating silvicultural methods for regenerating and recruiting eastern hemlock and yellow birch (*Betula alleghaniensis* Britton) along with other hardwoods and softwoods	Information is needed about how to produce a suitable seedbed for light-seeded species such as eastern hemlock and yellow birch that require exposed mineral soil and woody debris in addition to canopy gaps created through single-tree or group selection for regeneration and recruitment

continued

Table 2.—Continued

Forest type	Partnerships	Project themes	Persistent issues
Eastern white pine–northern red oak (*Pinus strobus* L., *Quercus rubra* L.)	Research group NRS-7 [a], Univ. of Maine, Paul Smith's College, Univ. of Vermont	Developing and evaluating silvicultural methods for the regeneration and recruitment of oak–pine mixtures	Information is needed about how to manage hardwood competition during softwood recruitment, particularly on rich sites; lack of appropriate light conditions for maintaining advance regeneration of species prior to overstory disturbance
Northern white-cedar–mixed hardwoods (*Thuja occidentalis* L., hardwoods)	Research group NRS-7 [a], Laval Univ., Univ. of Maine, Cooperative Forestry Research Unit, The Nature Conservancy, Wisconsin Dept. of Natural Resources, Canadian Forest Service, Quebec Ministry of Forests, Parks, and Wildlife	Developing methods for regenerating and recruiting northern white-cedar along with other hardwoods and softwoods	Information is needed for resolving a region-wide problem with regeneration and recruitment of northern white-cedar, particularly where browsing by white-tailed deer (*Odocoileus virginianus)* is high and where harvesting practices favor competing species
Spruce–fir–hardwoods (*Picea rubens* Sarg., *Abies balsamea* (L.) Mill., hardwoods)	Research group NRS-7 [a], Univ. of Maine, Laval Univ., Canadian Forest Service, Quebec Ministry of Forests, Parks, and Wildlife, Univ. of Vermont.	Developing and evaluating silvicultural systems for maintaining mixed species composition and the structural attributes and functions needed for sustainable production and resiliency to climate change	Information is needed about the regeneration and recruitment of red spruce, balsam fir, yellow birch (*Betula alleghaniensis* Britton) along with sugar maple and other hardwoods
Fir–hardwoods (*Abies balsamea* [L.] Mill., hardwoods)	Univ. of New Brunswick, Natural Resources Canada	Quantifying the resistance and resilience of fir–hardwood mixtures to spruce budworm defoliation	Information is needed about how increasing the hardwood component in fir–hardwood mixtures reduces balsam fir defoliation by spruce budworm (*Choristoneura fumiferana* Clem.)

[a] Research groups refer to administrative designations within the USDA Forest Service Research and Development program. NRS designates groups that are part of the Northern Research Station; SRS designates groups that are part of the Southern Research Station.

Table 3.—Founding science partners of the Northern Research Station's "Mixedwood Initiative"

Name	Affiliation	Mixedwood forest type
John M. Kabrick	USDA Forest Service, Northern Research Station, Columbia, MO	Shortleaf pine–oak
Kenneth L. Clark	USDA Forest Service, Northern Research Station, New Lisbon, NJ	Pitch pine–oak
Anthony W. D'Amato	University of Vermont	White pine–northern red oak Spruce–fir–hardwoods
Daniel C. Dey	USDA Forest Service, Northern Research Station, Columbia, MO	Shortleaf pine oak
Laura S. Kenefic	USDA Forest Service, Northern Research Station, Bradley, ME	Spruce–fir–hardwoods
Christel C. Kern	USDA Forest Service, Northern Research Station, Rhinelander, WI	Hemlock–hardwoods
Benjamin O. Knapp	University of Missouri	Shortleaf pine–oak
David. A. MacLean	University of New Brunswick	Fir–hardwoods
Patricia Raymond	Ministère des Forêts, de la Faune et des Parcs du Québec	Spruce–fir–yellow birch
Justin D. Waskiewicz	Paul Smith's College	White pine–northern red oak

3. Ecology and silviculture

- Are mixedwoods stable forest types or transitional states?
- How are trees arranged spatially and vertically in mixedwoods?
- How are mixedwoods regenerated where they contain species with widely differing regeneration mechanisms, shade tolerances, and growth strategies?
- How are mixedwoods thinned or tended where they contain species with widely differing growth rates, longevities, and tolerances?
- What are the historical and contemporary recruitment dynamics for mixedwoods across broad spatial scales?

The Mixedwood Initiative is not limited exclusively to its founding members. Other scientist-manager partners working on mixedwoods are joining the effort and are participating in mixedwood meeting sessions and publishing papers along with the founding members.

PARTNERSHIP ACCOMPLISHMENTS

The Mixedwood Initiative goal is to produce three major types of accomplishments. The first was to maintain local scientist-manager partnerships to develop practical information and publications needed for evaluating the benefits of managing for various mixtures occurring in the eastern United States and Canada. The second was to develop synthesis publications addressing the benefits and silvicultural challenges of eastern mixtures and to identify common issues, processes, and problems occurring in mixedwoods in different ecoregions. The third was to engage with managers and fellow scientists in a variety of conference sessions and field workshops to share local and broader-scale findings related to the benefits and silviculture of mixedwood types. Examples of accomplishments are listed in Table 4 and include publications describing findings from local experiments, a synthesis publication, and sessions in conferences and workshops organized by the Mixedwood Initiative team members.

Table 4.—Accomplishments of the Mixedwood Initiative and partnerships since its inception in 2014

Accomplishment	Product Examples
Development of locally important, practical information and publications needed for evaluating the benefits of or managing for various mixedwoods occurring in the eastern US and Canada	Publications 1. Kenefic, L.S. [et al.]. 2014. Silvicultural rehabilitation of cutover mixedwood stands. *See full citation in Literature Cited section.* 2. Kabrick, J.M. [et al.]. 2015. Effect of initial seedling size, understory competition, and overstory density on the survival and growth of Pinus echinata seedlings underplanted in hardwood forests for restoration. *See full citation in Literature Cited section*. 3. Puhlick, J.J. [et al.]. 2016. Factors influencing organic-horizon carbon pools in mixed-species stands of central Maine, USA. *See full citation in Literature Cited section.* 4. Raymond, P. [et al.]. 2016. Patch cutting in temperate mixedwood stands: what happens in the between-patch matrix *See full citation in Literature Cited section.* 5. Raymond, P.; Bedard, S. 2017. The irregular shelterwood system as an alternative to clearcutting to achieve compositional and structural objectives in temperate mixedwood stands. *See full citation in Literature Cited section.* 6. Raymond, P. [et al.] 2018. Assessing the single-tree and small group selection cutting system as intermediate disturbance to promote regeneration and diversity in temperate mixedwood stands. *See full citation in Literature Cited section.* 7. Zhang, B. [et al.]. 2018. Effects of hardwood content on balsam fir defoliation during the building phase of a Spruce Budworm outbreak. *See full citation in Literature Cited section.* 8. Jin, W. [et al.]. 2018. How can prescribed burning and harvesting restore shortleaf pine-oak woodland at the landscape scale in central United States? Modeling joint effects of harvest and fire regimes. *See full citation in Literature Cited section.* 9. Kern, C. [et al.]. 2019. Mounds facilitate regeneration of light-seeded and browse-sensitive tree species after moderate-severity wind disturbance. *See full citation in Literature Cited section.* 10. Muñoz Delgado, B.L. [et al.]. 2019. Northern mixedwood composition and productivity 50 years after whole-tree and stem-only harvesting with and without post-harvest prescribed burning. *See full citation in Literature Cited section.* 11. Power, H. [et al.]. 2019. Basal area and diameter growth in high-graded eastern temperate mixedwood forests: the influence of acceptable growing stock, species, competition, and climate. *See full citation in Literature Cited section.* 12. Puhlick, J.P. [et al.] 2019. Crop tree growth response and quality after silvicultural rehabilitation of cutover stands. *See full citation in Literature Cited section.*
Development of synthesis publications and scientific products for assessing the benefits and silvicultural challenges of all eastern mixedwoods and to look for common issues	Publication 1. Kabrick, J.M. [et al.]. 2017. Managing hardwood-softwood mixtures for future forests in eastern North America: assessing suitability to projected climate change. *See full citation in Literature Cited section*.
Engagement with managers and fellow scientists in a variety of conference sessions and field workshops	Conferences and Workshops 1. New England Society of American Foresters (SAF) annual winter meeting (Fairlee, VT; March 2015) Three-talk session: Mixedwood Management. 2. National Silviculture Workshop (Baton Rouge, LA; October 2015) Presentation: Managing "Mixedwoods" for Future Forests in Eastern North America: Current State of Knowledge and Research Needs. 3. SAF national convention (Madison, WI; November 2016) Nine-paper session moderated by J.M. Kabrick and B.O. Knapp: The Benefits and Challenges Of Managing Hardwood – Softwood Mixtures In Eastern North America. 4. Eastern CANUSA (Burlington, VT; October 2016) Presentation: Managing Multi-aged Mixedwood Stands: Perspectives from the Penobscot Experimental Forest in Maine, USA. 5. Presentation: Northern mixedwood site productivity 50 years after whole-tree and stem-only harvesting, with and without prescribed burning. 6. Eastern CANUSA (Fredericton, NB; October 2018) Four-paper session moderated by D.A. MacLean: Mixedwood Management. 7. North American forest ecology workshop (Flagstaff, AZ; June 2019) Eight-paper session: Promoting Forest Resistance and Resilience Through Mixedwood Management.

KEY FINDINGS

Our assessments related to resistance and resilience to pests and pathogens and future climate suitability suggests that mixedwoods provide many advantages compared to pure hardwood or softwood stands. For example, balsam fir (*Abies balsamea*) grown with hardwoods in the Great Lakes-St. Lawrence forest region in Quebec has proportionally less defoliation from spruce budworm (*Choristoneura fumiferana)* than pure fir stands or plantations (Zhang et al. 2018). Preliminary data from the mid-Atlantic region of the eastern United States suggest that pitch pine (*Pinus rigida*) mixed with oak (*Quercus* spp.) has lower mortality from southern pine beetle (*Dendroctonus frontalis*) attacks than high-density, pine-domiz nated stands. Oaks in these pitch pine–oak mixtures also appear to have less defoliation by gypsy moth (*Lymantria dispar)*. Data from the Forest Service's Climate Change Tree Atlas (Prasad et al. 2014) suggest that most mixtures occurring in the eastern United States are composed of tree species that were equally or better suited to climate change scenarios than are pure stands (Kabrick et al. 2017).

Regardless of mixedwood type, our assessment suggests that regenerating or recruiting the softwood component is a universal problem in eastern mixedwoods. In the absence of appropriate disturbances, many mixedwood forests transition into hardwood-dominated stands. Thus, maintaining mixedwoods requires conditions for the establishment, early growth, and recruitment of limiting species, such as eastern hemlock (*Tsuga canadensis*), red spruce (*Picea rubens*), or shortleaf pine (*Pinus echinata*), to be carefully managed. Considerations include maintaining the seed source and creating suitable seedbed for limiting species by exposing mineral soil through mechanical scarification for yellow birch (*Betula alleghaniensis*) or hemlock (Kern et al. 2017, 2019) or prescribed burning for pines (Clabo and Clatterbuck 2015), or by retaining highly decayed deadwood for spruce (Raymond and Bédard 2017) or hemlock (Kern et al. 2017). In the absence of conditions suitable for germination, underplanting pine (Kabrick et al. 2015) or spruce (Kenefic et al. 2014, Raymond et al. 2018) or other artificial methods may be required. Controlling the microclimate to meet the shade and light requirements of varying species can be accomplished with irregular shelterwoods or group selection in spruce–hardwoods (Raymond et al. 2018), shelterwoods in fir–hardwoods (Raymond and Bédard, 2017), or shelterwood and seed tree methods in shortleaf pine–oak (Kabrick et al. 2015). Competition control can be accomplished via mechanical or chemical treatments in northern temperate forests or prescribed fires in central and mid-Atlantic regions (Fig. 1).

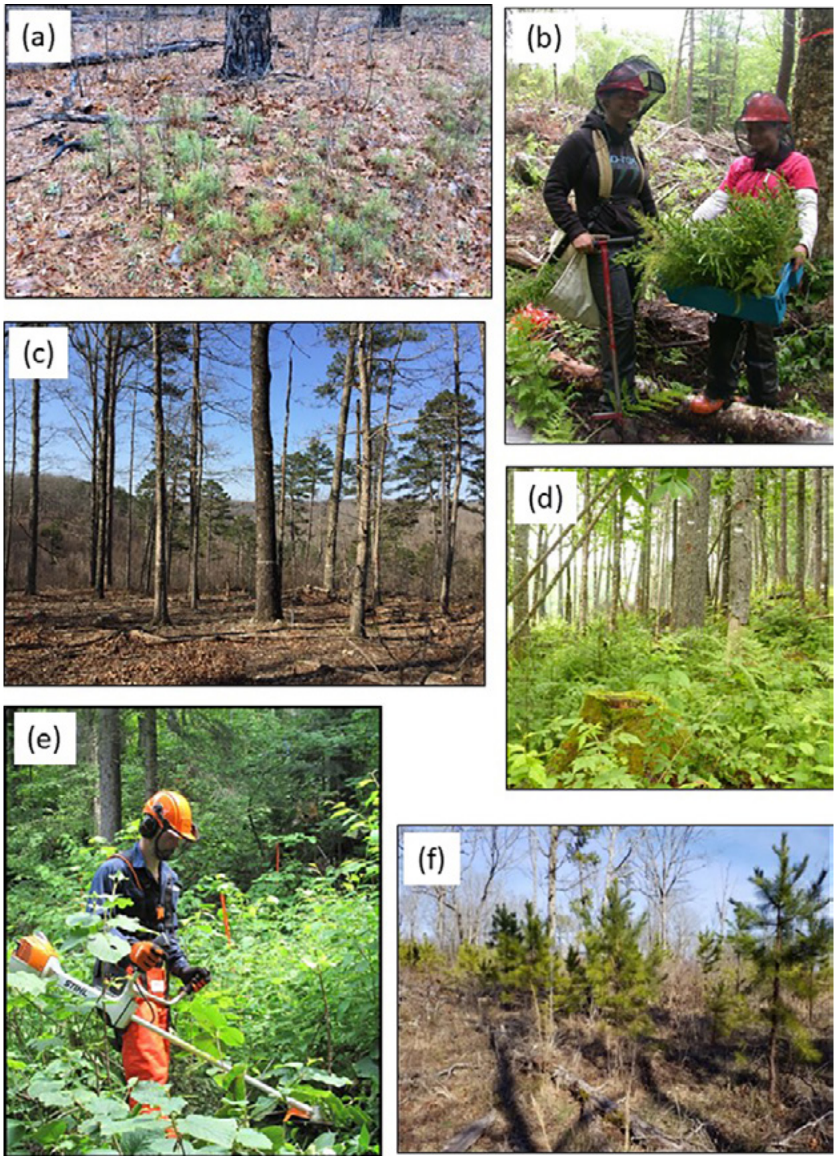

Figure 1.—Methods to facilitate regeneration and recruitment of mixedwoods including (a) maintaining a suitable seedbed such as with prescribed burning for shortleaf pine in pine–oak mixes, (b) underplanting species such as red spruce in spruce–fir–hardwood mixes, controlling the microclimate to meet the shade and light requirements of varying species accomplished through partial cutting such as with shelterwood and seed tree methods (c) or irregular shelterwoods (d); and controlling hardwood competition via mechanical (e, f) and chemical methods or prescribed fire. Photos a and f by the USDA Forest Service; photo c by Benjamin Knapp, used with permission; photos b, d, and e by Patricia Raymond, used with permission.

SUMMARY

Hardwood–softwood mixtures offer benefits but also many silvicultural challenges. The Mixedwoods Initiative was formed in northeastern North America to assess benefits and resolve management problems with sustaining these types. During the past 5 years, members of the Mixedwood Initiative have developed research and information products needed for managing for mixedwoods through scientist-manager partnerships. These partnerships facilitate local and regional collaboration among scientists and managers for producing practical information relevant to managers, and highly technical information of interest to a broader scientific audience for advancing knowledge about mixedwood ecology and silviculture. This initiative has created a powerful collaborative framework for guiding a long-term, regional research agenda focused on the silviculture and ecology of these critically important forest types.

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Managers and Scientists Unite to Adapt a Shelterwood Prescription to Shift Stand Dynamics for Competitive Oak Reproduction

Callie J. Schweitzer, Jared Calvert, Stacy Clark[1]

ABSTRACT.—USDA Forest Service, Southern and Northern Research Station scientists partnered with the Daniel Boone National Forest in Kentucky on a long-term silviculture project focused on enhancing the status of oak in upland hardwood stands under the auspice of the Heathy Forests Restoration Act of 2003. In an attempt to grow small oak natural reproduction into more competitive height classes, we applied herbicide to deaden undesirable midstory trees and to increase sunlight penetrating the forest floor in the first phase of a two-phase shelterwood treatment. We successfully increased the number of larger oak reproduction. However, small red maple stems also responded and are dominating the regeneration cohort. Prior to final harvest, we worked to amend the prescription and to add a preharvest herbicide treatment to target these competitive understory red maple stems. Along the way, many challenges have been addressed, including public education about the need to do applied research on a stand-level basis to discern results prior to recommending prescriptions across landscapes. The value added of having managers and researchers stand together to deliver this message has contributed to the ongoing success of this project.

INTRODUCTION

Three documents came together to make this study and the internal Forest Service partnership between managers on the Daniel Boone National Forest (DBNF) and scientists in the Southern and Northern Research Stations, a reality. The first was the Healthy Forests Restoration Act (HFRA) (Healthy Forests Restoration Act of 2003). This act had two titles (subsections) that were used to develop our program. The first is Title II, which gave authority to obtain information to overcome barriers to production and use of biomass (there was a harvesting and economic facet to this study that will not be covered in this paper). The second is Title IV, which gave authority to develop a program of research to combat infestations by forest damaging insects and diseases with a goal to improve forest health and to reduce forest susceptibility. The second document was the approved Land and Resource Management Plan for the DBNF (hereafter referred to as the Forest Plan) (USDA Forest Service 2004), from which we designed a large-scale, long-term study and wrote a study plan, which became the third document. The study was based solely off of the management detailed in the Forest Plan.

For the DBNF in 2005, the most prevalent damaging insect on the horizon was the gypsy moth (*Lymantria dispar dispar*). The gypsy moth had devastated upland oak (*Quercus*) forests in the northeastern United States, and the forests of the DBNF were certainly at risk for attack (Liebhold et al. 1992). We knew some basics about the gypsy moth: oaks were preferred, particularly those with small or damaged crowns or in subordinate canopy positions (Fajvan and Gottschalk 2012). Also, gypsy moth decline episodes had been documented in oak forests over the past 150 years, and research to address its negative impact on forests had yielded

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some results (Gottschalk 1993, Starkey et al. 1989, Voelker et al. 2008). Although the spread of the gypsy moth has been slowed, it continues to march southward (Tobin et al. 2009).

In the eastern United States, there are abundant oak forests to host the gypsy moth. Approximately 194 million acres of forests are typed as oak, with the most prominent being the oak-hickory (*Quercus-Carya*) type. Oak-hickory forest type dominates the DBNF. So what's up with oak in eastern upland hardwood forests? Essentially, with changes in people demographics, policy, and other social issues, the disturbance regime in these forests has been greatly altered; we have diminished disturbances related to both timber harvesting and fire, as well as removal of many grazing and browsing animals from the forest (Clatterbuck 2019). The loss of the American chestnut (*Castanea dentata* Marsh. [Borkh.]), and the unique disturbance that created, has ceased. We have an age-class shift across all forest types in the east, including oak-hickory, so that 60 to 70 percent of our forests are between 40 and 100 years old (Shifley et al. 2012). These forests are closed canopy and the understories are dominated by more shade-tolerant species than we had in the past (Nowacki and Abrams 2008). All these factors have contributed to the oak regeneration-recruitment problem. We rely on natural reproduction to regenerate our oak forests, and we know that larger oak seedlings and saplings have the best chance of surviving a regeneration event and thus contributing to the composition of the next stand (Sander 1972). The challenge is that we lack large advanced oak reproduction in our stands due to low understory light levels, and we cannot rely on stump sprouts as the larger diameter oaks have a lower probability of sprouting (Weigel et al. 2017).

We have in these forests an "oak bottleneck" (Dey 2014). These forests still have plenty of mature oaks that produce acorns, and germination and establishment are not limiting factors. The challenge is recruiting small oaks into competitive sizes (Dey and Parker 1996, Johnson et al. 1989, Loftis 1990a, Lorimer et al. 1994, Dey and Parker 1996, Sander 1979).

The strategies for this study centered around making our oak forests as healthy and resilient as possible, with an emphasis on the reproduction cohort. The prescriptions we implemented and studied were to (1) increase the component of young oaks; (2) create or enhance oaks in dominant crown positions, which would be less susceptible to mortality following a gypsy moth defoliation event; and (3) increase nonpreferred gypsy moth tree species. For this paper, we are focusing on the oak shelterwood prescription. This has been purported to be one of the most intensive methods to regenerate oak on productive sites where small advanced reproduction exists along with copious competition from other species (Brose et al. 2008, Craig et al. 2014, Hutchinson et al. 2016, Janzen and Hodges 1987, Lockhart et al. 2000, Loftis 1990b, Miller et al. 2017, Parrott et al. 2012, Schweitzer and Dey 2011). The goal of the oak shelterwood is to (1) remove competition in the mid-story to allow small advanced oak reproduction the light needed to develop into a more competitive position; (2) recruit oaks into larger size classes (>5 feet tall) in sufficient numbers; then (3) remove the overstory canopy in a single harvest.

Although we used official authorities and took steps to insure compliance, the public was leery and unhappy. We had a categorical exclusion under the HFRA based on the research component, comments were solicited, and scoping was done. The scoping field trip was a joint adventure by the managers and the scientists. Partly due to public interest, the project was covered by the local press. The Associated Press published an article that led with a sentence about logging (Alford 2005), not about restoration or healthy forests. Others followed suit, including the Cincinnati Enquirer (2005), which was a more robust article and mentioned saving the forest, and The (Louisville, KY) Courier-Journal (Bruggers 2005), which put the DBNF on an "endangered forest" list. Enter the united front of the managers and researchers. Because we were able to show the study plan, the cooperative agreements, and the systematic basis for the study, in conjunction with the Forest Plan, the study went forward (see overview in Schweitzer et al. 2014).

STUDY DESIGN AND AREA

The study was designed as a large-scale, long-term replicated study that used the DBNF Forest Plan as the treatment template. There were five stand-level silvicultural prescriptions or treatments in this study that were a mix of intermediate stand treatments and regeneration treatments (Schweitzer et al. 2014). Here, we concentrate on only one treatment, the oak shelterwood, which was replicated five times.

The Cold Hill Area is located in the Central Escarpment subsection of the Northern Cumberland Plateau Section of the Eastern Broadleaf Forest Province (221 Hb; Bailey 1995). Smalley (1986) described the landtype as the Low Hills Belt association of the mountains and dissected plateau subregion of the Northern Cumberland Plateau. The soils are loamy, formed in residuum weathered from sandstones and conglomerate, and found on broad, flat ridges at elevations of 1000–1250 feet (Smalley 1986). The upland hardwood forests on these sites are predominately sub-xeric types, dominated by oak species, approximately 70 to 100 years old, and have been subjected to repeated disturbances, including selective logging and fire. The six oak shelterwood stands ranged in size from 20 to 30 acres, with an average size of 24 acres. Total basal area (BA) ranged from 100 to 110 square feet per acre, and relative stand density ranged from 60 to 104 percent (Gingrich 1967).

Phase I Oak Shelterwood

We established twenty 0.1-acre vegetation measurement plots in each stand and measured plots before treatment and seven growing seasons after treatment implementation. Plot centers were permanently marked with rebar and global positioning system coordinates were captured for each. We permanently labeled all trees 4.6 inches diameter at breast height (d.b.h.; measured 4.5 feet above ground), measured distance and azimuth to plot center, and recorded species, vigor status, and d.b.h. Within each 0.1-acre plot, we established a 0.01-acre subplot where we enumerated reproduction (trees ≤1.5 inches d.b.h.) by species and 1-foot height class. On these same reproduction subplots, we randomly selected five seedlings that were permanently marked, and species, status, height, and basal diameter were recorded. At 1 year post-treatment, we surveyed status, species, and d.b.h. for all stems ≥1.5 inches d.b.h. on five 0.025-acre plots to access the effectiveness of this treatment in killing midstory stems (1.6 inches d.b.h. to 4.6 inches d.b.h.).

The herbicide treatment was performed using stewardship contracting (Omnibus Consolidated and Emergency Appropriations Act 1999) that allowed the Forest Service to apply the value of timber products removed as an offset against the costs of services received. Undesirable tree species <3 inches d.b.h. were treated with a thinline basal bark treatment using triclopyr ester. Midstory trees >3 inches d.b.h. were treated with a stem injection method using triclopyr amine. The prescription description was to remove non-oak midstory and understory trees without creating any gaps in the overstory to allow increased penetration of ambient light to the oak seedlings in the understory.

RESULTS

Midstory and Overstory Trees

The oak shelterwood stands had 23 species in the midstory and overstory stratum, with 142 stems per acre (SPA) and 99.1 square feet per acre of basal area (BA). Diameters ranged from 4.6 to 33.9 inches. Stem density and basal area were dominated by oaks (black, chestnut, northern red oak, scarlet oak, and white oak; see Table 1 footnote for scientific names of oak species), with 71 SPA and 63.9 square feet per acre BA and a diameter range of 4.6 to 30.9 inches (Table 1). Red maple (*Acer rubrum* L.) densities were 39 SPA with 13.2 square feet per acre BA with diameters 4.6 to 18.5 inches d.b.h., and shortleaf pine (*Pinus echinata* Mill.) had

Table 1.—Overstory and midstory stand structure, including d.b.h. range, stem density (SPA), and basal area (BA), for selected species pretreatment (2009), 1-year post-treatment (2010) and seven growing seasons post-treatment, for stands in the oak shelterwood treatment prescription on the Daniel Boone National Forest, KY

	D.b.h. range	SPA	BA
	inches	*Count per acre*	*ft^2 per acre*
	All species		
2009	4.6-33.9	142	99.1
2010	4.5-34.8	141	105.9
2016	4.2-36.1	91	92
	Quercus spp.[a]		
2009	4.6-30.9	71	63.9
2010	4.7-34.8	70	68.8
2016	4.7.36.1	58	64.4
	Acer rubrum (L.)		
2009	4.6-18.5	39	13.2
2010	4.5-18.9	39	14.5
2016	4.9-19.4	19	11.9
	Oxydendrum aboreum (DC)		
2009	4.7-10.0	10	2.6
2010	4.7-10.5	10	2.7
2016	5.4-11.4	4	1.5
	Carya spp. (Nutt.)		
2009	4.9-22.6	5	3.6
2010	5.1-23.0	5	3.7
2016	5.1-23.9	4	3.0
	Pinus echinata (Mill.)		
2009	11.2-21.7	7	11.6
2010	11.3-22.0	7	11.7
2016	11.6-22.6	2	3.8

[a] Oak species include white oak [*Quercus alba* (L.)], scarlet oak [*Q. coccinea* (Muench.)], chestnut oak [*Q. prinus* (L.)], northern red oak [*Q. rubra* (L.)] and black oak [*Q. velutina* (Lamarck)].

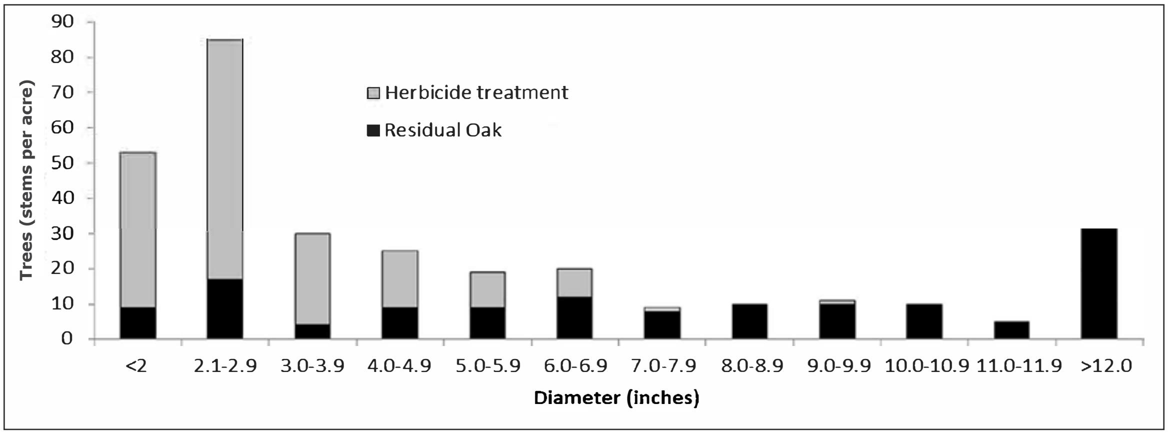

Figure 1.—Stems per acre (SPA) of all tree species, by diameter class, for stems treated with herbicide in Phase I of the oak shelterwood prescription, and the residual stand diameter distribution, Daniel Boone National Forest, KY.

11.6 square feet per acre BA with 7 SPA, and d.b.h. ranged from 11.2 to 21.7 inches. One year post-herbicide treatment, stand structure and composition was relatively unchanged, with total BA at 105.9 square feet per acre, dominated by 68.8 square feet per acre BA of oak, 14.5 square feet per acre BA of red maple and 11.7 square feet per acre BA of shortleaf pine. Across all stands, one tree per acre died of natural causes after 1 year; dead trees were either oaks or red maple.

In the oak shelterwood treatment, we injected with herbicide 176 SPA that averaged 3.0 inches d.b.h. and ranged from 1.6 to 9.1 inches d.b.h. (Fig. 1). Of the stems treated with herbicide, 60 percent were red maple, 7 percent were yellow-poplar (*Liriodendron tulipifera* L.), and the remaining 33 percent were a combination of various species including blackgum (*Nyssa sylvatica* Marsh.), sourwood (*Oxydendrum aboreum* DC), sassafras (*Sassafras albidum* [Nutt.f. Nees.]), bigleaf magnolia (*Magnolia macrophylla* Michx.), and serviceberry (*Amelanchier aborea* [Michx. f. Fern.]).

After seven growing seasons, the midstories and overstories were again dominated by oak, but there was considerably greater mortality, 8 SPA per year. The overall BA was 92 square feet per acre with 91 SPA, dominated by oaks (58 SPA and 64.4 square feet per acre BA) and red maple (19 SPA and 11.9 square feet per acre BA) (Table 1). Mortality was noted in 16 different species, and the greatest mortality was for red maple (three died per year) and for the oaks (two SPA died per year).

Reproduction

All woody species were enumerated in the reproduction survey plots, including small shrubs such as the *Vaccinium* species and *Viburnum* species. Twenty-six woody species were initially identified within the reproduction cohort of stems greater than one foot tall up to 1.5 inches d.b.h., and stem density for all species was 12,687 SPA (Table 2). The pretreatment stem density for red maple was 31 percent of the total reproduction density, while oak constituted 21.5 percent of the total. The largest size class (>4 feet tall up to 1.5 inches d.b.h.) was dominated by red maple and hickory, with only 43 large oaks per acre. Large red maple seedlings were 11 times the density of that of large oak seedlings. Besides red maple and hickory, species with greater densities of large reproduction when compared to oak were viburnum, blackgum, yellow-poplar, flowering dogwood (*Cornus florida* L.), and big leaf magnolia.

Table 2.—Reproduction stems per acres of species by size classes and totals, for pretreatment (pre) and seven growing seasons post-treatment (post), for stands in the oak shelterwood treatment prescription on the Daniel Boone National Forest, Kentucky. Values for oak species are presented in Figure 2. Data presented as ranked highest to lowest for pretreatment density. Row summation may not match Total due to rounding.

Species (authority)	Sample time	<1 ft	>1-2 ft	>2-3 ft	>3-4.5 ft	>4.5 ft-1.5 inch d.b.h.	Total
Acer rubrum (L.)	pre	2187	797	340	140	493	3957
	post	11257	1837	950	477	1377	15897
Quercus spp.	pre	2077	430	147	37	43	2733
	post	2823	763	253	180	163	4183
Vaccinium spp. (L.)	pre	1413	123	7	0	7	1550
	post	1550	690	20	3	3	2267
Carya spp. (Nutt.)	pre	467	263	93	83	120	1027
	post	457	297	160	100	220	1233
Viburnum spp. (L.)	pre	250	130	107	70	63	620
	post	20	33	43	33	23	153
Nyssa sylvatica (Marsh.)	pre	323	113	53	20	63	573
	post	193	130	37	13	80	453
Sassafras albidum (Nutt.) Nees.	pre	330	120	43	13	33	540
	post	167	117	37	37	127	483
Liriodendron tulipifera (L.)	pre	200	47	33	40	67	387
	post	77	27	13	23	117	257
Cornus florida (L.)	pre	230	53	10	10	53	357
	post	203	40	20	17	40	320
Amelanchier arborea (Michx.) Fern.	pre	160	70	37	17	23	307
	post	93	63	47	37	100	340
Magnolia macrophylla (Michx.)	pre	77	33	27	23	63	223
	post	43	10	7	3	53	117
Rhododendron spp.	pre	203	3	0	0	0	207
	post	3	0	0	0	0	3
Oxydendrum aboreum (DC)	pre	13	20	10	3	33	80
	post	3	7	3	10	43	67
Fraxinus spp. (L.)	pre	27	10	3	0	3	43
	post	17	13	3	3	10	47
Ilex decidua (Walt.)	pre	13	10	10	3	3	40
	post	40	17	3	0	20	80
Prunus serotina (Ehrh.)	pre	3	10	0	0	3	17
	post	3	13	0	0	10	27
Fagus grandifolia (Ehrh.)	pre	0	0	7	3	7	17
	post	0	3	0	0	20	23
Castanea dentata (Marsh.) Borkh.	pre	0	0	0	7	0	7
	post	0	3	0	0	10	13
Ostrya virginiana (K. Koch.)	pre	0	0	3	0	0	3
	post	3	0	0	0	0	0
Euonymus spp. (L.)	pre	0	0	0	0	0	0
	post	113	10	10	3	3	140
Tsuga canadensis (L.) Carr.	pre	0	0	0	0	0	0
	post	3	0	0	0	10	13
Diospyros virginiana (L.)	pre	0	0	0	0	0	0
	post	0	0	3	3	0	7
Magnolia acuminata (L.)	pre	0	0	0	0	0	0
	post	0	3	0	0	0	3
Ulmus spp. (L.)	pre	0	0	0	0	0	0
	post	3	0	0	0	0	3
Pinus echinata (Mill.)	pre	0	0	0	0	0	0
	post	3	0	0	0	0	3

Seven years after deadening the midstory, red maple, oak, and hickory all increased in total density (Table 2). Large oak seedlings increased to 163 SPA, and large oak seedling density ranked third behind red maple and hickory. Red maple increased in all size classes, and was 60 percent of all the reproduction stems, while 16 percent was oak. Fifty-seven percent of the largest size class was red maple (a 10 percent increase from pretreatment values), and 6.7 percent was oak (a 3 percent increase). The total density, by species, of viburnum, blackgum, sassafras, yellow-poplar, flowering dogwood, bigleaf magnolia, rhododendron spp., and sourwood all declined compared to pretreatment densities, and the declines were most prominent in the smaller size classes; there was most likely recruitment by many of these species into the open growing space created when the midstory died, and the stem densities in the largest size class for blackgum, sassafras, yellow-poplar, serviceberry, and sourwood all increased.

Of the five oak species tallied in the pretreatment reproduction cohort, scarlet oak was 35.5 percent of the total oak density, followed by white oak (28.9 percent), black oak (21.2 percent), chestnut oak (13.9 percent), and northern red oak (<1 percent). This ranking was the same post-treatment. Within each size class, the density of all five species increased, except for scarlet oak in the largest size (a decrease of 7 SPA) and white oak in the >2- to 3-foot size class (a decline of 47 SPA) (Fig. 2). These white oak stems most likely recruited into the next larger size class, which increased from 7 to 80 SPA. Within each oak species group, the percentage of stems declined for all species for the smallest size class, with a concurrent increase in the percentage in the next three size classes (Fig. 2).

We followed the growth of 150 tagged seedlings, which included 16 different species. Seedlings averaged 3.1 feet in height and had average basal diameters of 0.4 inches. After seven growing seasons, 75 percent of the tagged seedlings were alive, and they were 3.7 feet tall with 0.6 inch basal diameters. Relative height growth was greatest for red maple (1.3 feet), followed by black oak (1.2 feet). The oaks (black, chestnut, scarlet, white, and northern red) averaged 0.6 feet of relative height growth and 0.7 inches of relative basal diameter growth. After seven growing seasons, the oaks and red maple had the same basal diameters (0.5 inches), but red maple absolute height was 2 feet greater (4.8 feet tall) than that for the oaks (2.8 feet tall).

DISCUSSION

Across the Cumberland Plateau, oaks dominate in the overstory, and while oak reproduction exists, it is often lacking in competitive numbers and stature. Although not measured and reported in this study, other studies have shown that reducing the midstory in these types of stands increased the light penetration to the understory, and that light environment was one of the primary drivers of the reproduction cohort response (Dey et al. 2012, Lhotka and Loewenstein 2009, Lorimer et al. 1994, Miller and others 2017, Schweitzer and Dey 2011). After seven growing seasons, we did observe an increase in the number of understory oaks as well as an increase in the size of these oaks. Concurrent with that, however, was a more substantial increase in a major competing species, red maple.

Other studies on similar sites in Kentucky have found that red maple can be competitive with oak in the reproduction cohort, especially after some type of disturbance (Arthur et al. 1997, Lhotka 2012, Tift and Fajvan 1999). In a Kentucky-based study of the response of the understory to treatment of the midstory, Parrott et al. (2012) found dominance by red maple in the larger reproduction size classes. The use of herbicide to reduce the midstory and facilitate increased light to the understory was predicated on studies by Sander (1979), Loftis (1983), and Johnson et al. (1989), in which the directed disturbance via herbicide was to

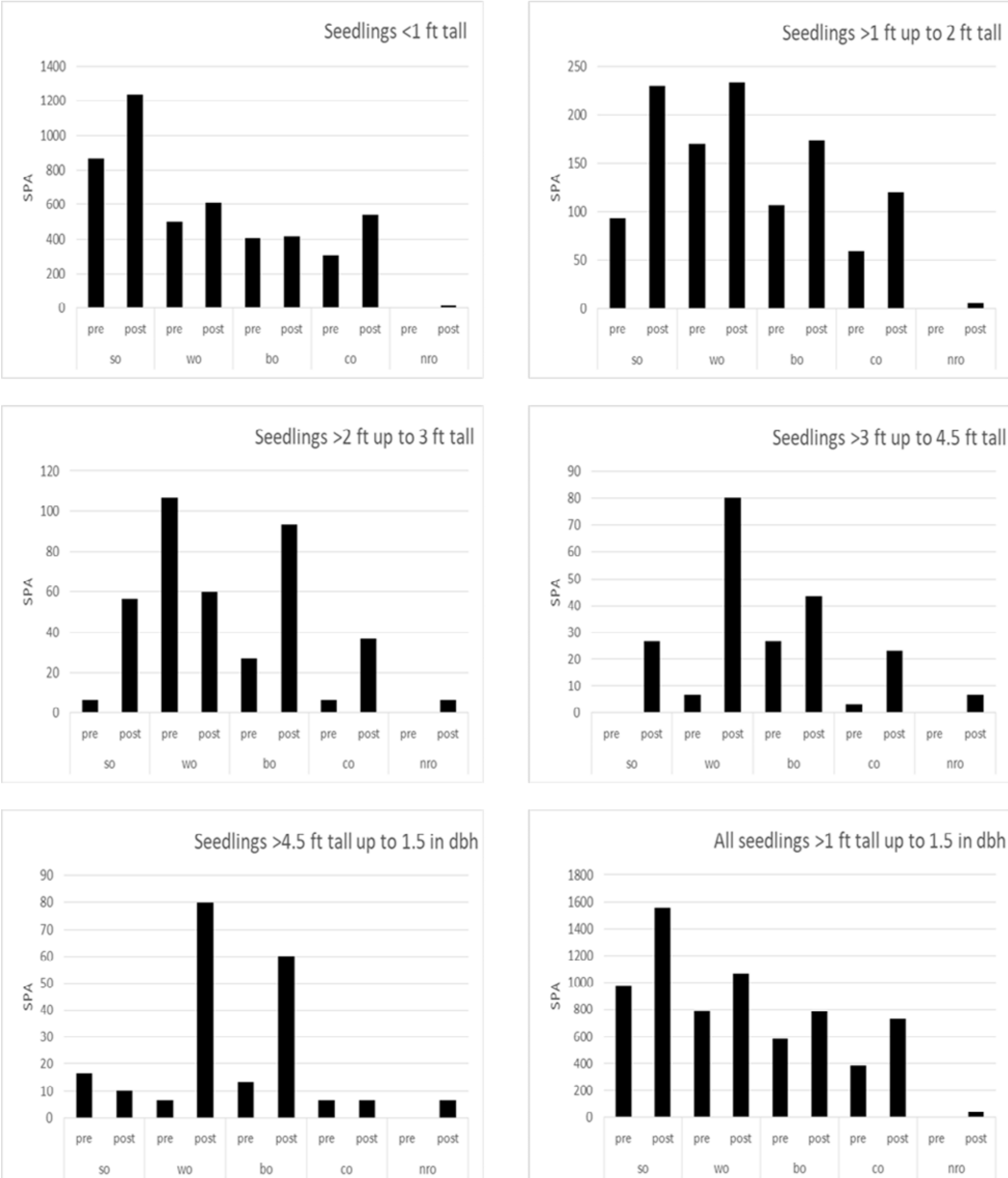

Figure 2.—Reproduction density in stems per acre (SPA) for five oak species for pretreatment (pre) tallies and 7 years post midstory herbicide (post) tallies. Five graphs represents a seedling size class for stands treated with Phase I of an oak shelterwood prescription on the Daniel Boone National Forest, KY. The final graph (lower right) shows a cumulative total of all size classes >1 ft. So= scarlet oak; wo = white oak; bo = black oak; co = chestnut oak; nro = northern red oak. See Table 1 for list of scientific names.

stimulate oak growth over other species. In many initial studies using a midstory herbicide as the first phase in a two-phase shelterwood prescription, results have been mixed (Brose et al. 2008; Craig et al. 2014; Hutchinson et al. 2016; Janzen and Hodges 1987; Schweitzer and Dey 2011, 2017). Differences in site conditions and past disturbance regimes, as well as in current stand structure, age, and composition may be influencing the outcome to a greater extent than predicted. The lack of frequent disturbances may be changing forest conditions that are less favorable to oak regeneration; this lack of management may be causing mesophication toward red maple and other shade tolerant species (Nowacki and Abrams 2008).

We are examining the response of this specialized oak shelterwood prescription at the level of a stand, as delineated by silviculturists and foresters, not at a plot or experimental unit. The range in variation is greater, but through the work in this study, we have learned that implementation at a stand level is not an issue. Contractors and managers worked together to describe and thoroughly execute the midstory herbicide treatment at this scale. Because we were not able to curb the response of the red maple, another treatment will be necessary before the final overstory removal. This treatment will be solely aimed at reducing the density and competitive capacity of the red maple. Discord over the semantics of the next phase notwithstanding, it can be considered a Phase II of the oak shelterwood prescription, with an additional site preparation treatment. This second phase will consist of another treatment using herbicide, followed by the final phase which will be a shelterwood with reserves regeneration harvest leaving 10-15 square feet per acre residual BA.

Preparation for Phase II Oak Shelterwood

Managers and scientists worked together to implement the management and research for this project. The proposal for the Cold Hill Phase II Silvicultural Assessment Project (Phase II Project) was put forth in October of 2017 (USDA Forest Service 2018a) and a field trip was held in November 2017, where managers, scientists, and faculty from the University of Kentucky discussed the current state of knowledge and research and management needs this project was addressing. A final biological assessment and evaluation, needed to address issues related to any potential federally listed endangered species and critical habitat (USDA Forest Service 2018b), was prepared.

The U.S. Fish and Wildlife Service (USFWS) identified 26 federally listed species as potentially occurring on or adjacent to the DBNF (see Table 1, USDA Forest Service 2018b). Twenty-two of these species were determined to be not within the area of influence for Phase II. Four species were analyzed within the biological assessment and evaluation (BAE) and were found to occur or have suitable habitat, or both, within or near the area of influence of the Phase II Project (USDA Forest Service 2018b). These four species—gray bat (*Myotis grisescens*), Indiana bat (*M. sodalis*), Virginia big-eared bat (*Corynorhinus townsendii virginianus*), and northern long-eared bat (*M. septentrionalis*)—were selected for detailed analysis within the BAE. In addition, 43 designated critical habitat segments were identified as occurring on or adjacent to the DBNF by the USFWS, however, none of these segments are located within the area of influence of the Phase II Project.

For the gray bat and Virginia big-eared bat, a determination of "not likely to adversely affect" was given on the basis that gray bat may benefit by the proposed action. The long-term effects of the Phase II Project will provide stands that are more open and have more open corridors while maintaining a supply of suitable roost trees. For the Indiana bat, a determination of "likely to adversely affect" was given based on the fact that some harvest activities are anticipated between April 1 and September 15. The area cut during this period will be monitored and reported by calendar year to ensure compliance with the incidental take statement provided in the USFWS biological opinion (USDI Fish and Wildlife Service 2007). For northern long-eared bat, a determination of "likely to adversely affect" was given based on the effects disclosed in the programmatic biological opinion on implementing the final rule.

A "no impact" statement was given for most of the sensitive species on the basis that all project work is contained within upland, terrestrial areas in stands of timber and do not provide habitat for most of the sensitive species. It was found that the project was consistent with the actions and provisions outlined in the Forest Plan, and consistent with USFWS formal consultation (USFWS 2007, USDA Forest Service 2004). Prior to signing the decision memo in April 2019, managers on the forest noted that this was first time a project involving commercial timber harvesting was able to get through the public comment period without a single negative comment; the partnership with research was touted as a primary reason.

The contract we devised specified using a herbicide in a site preparation treatment for natural regeneration. The goal is to reduce as many sources of red maple competition as possible to allocate growing space to the existing oak seedlings. Specifications and treatment timing followed that of Kochenderfer et al. (2012) and recommendations from consulting forester Christopher Will (pers. comm., Central Kentucky Forest Management Inc., 301 Stanford Ave, Danville, KY 40422; office phone 859-238-2212). All red maple trees within each stand that are 0.5 inches d.b.h. up to 11.9 inches d.b.h. shall receive cut-surface herbicide application treatment with imazapyr (Arsenal® AC herbicide, BASF Chemical Inc., Research Triangle Park, NC). Trees 0.5 inches d.b.h. to 2 inches d.b.h. shall be completely severed using a sharp cutting tool (cut stub treatment) at a point below 3 feet in height from the ground measured from the uphill side of the tree. Herbicide shall be applied at a rate of 1.5 milliliters (ml) (0.05 oz.) of solution per inch of d.b.h. of the tree being treated unless specified otherwise. Hack-and-squirt application will be used to treat trees greater than 2 inches d.b.h. Incisions using hatchets or machetes will be made at a rate of one incision per inch of d.b.h., spaced evenly around the stem with overlapping incisions. Herbicide shall be applied at a rate of 1.5 ml of solution per incision. Incisions shall be made with a downward motion to ensure that herbicide is allowed to enter the incision site when applied from a calibrated spray bottle or other calibrated application device. Treatment will be conducted between the months of August and November. A shelterwood with reserve two-age regeneration harvest will be conducted 1 to 2 years following the herbicide treatment. Residual trees to be retained will be selected based on species and tree vigor, with a goal of 10 to 15 square feet per acreresidual BA.

CONCLUSIONS

Long-term silviculture studies applied at a stand level via partnerships between USFS managers and researchers are essential to driving forest management in a sustained manner. This sustainability is manifested in not only the biological, but also in the social arena. We are able to demonstrate applied, and adaptable, management, under the scrutiny of peer-reviewed science. Because we had detailed data pertaining to the response of the Phase I treatments, we were able to better corroborate technical and scientific quality with the public and others. For this specific oak shelterwood treatment, we will not be able to determine regeneration success until after the parent stand has been removed. Repeated measurements on replicated stands will allow us to discern the specifics of the stand-level responses, and our detailed analyses will aid in providing quantitative descriptions of needed prescription phases to manage these upland hardwood stands across a variety of sites and conditions. The depth and breadth and longevity of this project, as well as its ongoing acceptance and implementation, was made possible through a strong management-research partnership.

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National Advanced Silviculture Program Region 9 Local Lake States Module

Marcella Windmuller-Campione, Eli Sagor, Madison Rodman, and Carrie Sweeney[1]

ABSTRACT.—The National Advanced Silviculture Program (NASP) is composed of four national modules and one regional or local module. The University of Minnesota hosted the Lake States Regional Module in 2018. We implemented changes to how the program was offered, including broadening the participant pool and shifting the delivery method. Broadening the participation pool allowed for greater collaboration among agencies. The blended delivery method, half online and half in-person, reduced costs, reduced length of travel for participants, and made resources such as reports, documents, maps, more easily accessible in participants' offices. We utilized multiple methods of active learning during the online sessions and focused on field activities and field trips when meeting in person. Overall, participants gave high ratings to the 2018 offering both in terms of content and effective delivery.

KEY WORDS: silviculture, online teaching, active learning, continuing education, blended classroom

INTRODUCTION

The National Advanced Silviculture Program (NASP) is a national, graduate-level training required for USDA Forest Service personnel to become certified silviculturists. The curriculum includes three national modules, each 2 weeks long, and a fourth module that is 3 weeks long. The modules are as follows:

- Modue 1: Ecological Systems
- Modue 2: Inventory and Decision Support
- Modue 3: Landscape Ecology
- Modue 4: Advanced Silviculture Topics

In addition to the four national modules, students take an additional regional or local module, which delves deeper into important regional topics. In 2018, the University of Minnesota hosted the Lake States Regional Module (hereafter referred to as Regional Model) at the University of Minnesota, Cloquet Forest Center (CFC), Cloquet, MN. The Regional Module is generally hosted every other year; in 2018 students in this module were primarily from Michigan, Wisconsin, and Minnesota. The overarching goal of the Regional Module is to focus on silvicultural systems, ecosystem services (hydrology, soils, wildlife, etc.), and how to manage for multiple objectives for regionally important forest types. Specific objectives were (1) to synthesize content about silviculture, forest ecosystems, wildlife, and related fields for application to Lake States forests; (2) to focus on practical opportunities and programs to support implementation of creative, scientifically sound silviculture within individual agencies

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and across agencies; (3) to work through solutions to barriers and opportunities including markets, technology, operational issues, protecting site quality, and other factors specific to our region; and (4) to build relationships and learn how forestry practices are done in other organizations operating in the same region.

Recently, this module has focused on the Good Neighbor Authority (GNA), which allows the USDA Forest Service to enter into agreements with state forestry agencies to do the critical management work to keep our forests healthy and productive. This focus appeals to a diverse group of forest managers.

MODIFICATIONS TO THE MODULE IN 2018

Based on previous feedback and discussions, two large modifications were made to the Lake States Regional Module: broadening enrollment and shifting the delivery method. The Regional Module was advertised through the University of Minnesota's Sustainable Forests Education Cooperative (Coffin et al. 2001) as "Advanced Silviculture for the Lake States." Enrollment in the 2018 course included state, county, local, and other forest management agency employees, as well as USDA Forest Service personnel. There was no difference in the content offered to Forest Service and non-Forest Service participants, however, only Forest Service NASP students received grades for the course. By including other agencies, the goal was to foster relationships across ownership boundaries, bring diverse perspectives and experiences of forest management to the course, and provide a means for discussing common issues and management solutions related to forest management and silviculture in the Lake States region. Field trip experiences provided additional opportunities for agencies to share knowledge. The field experiences were hosted by county, private forest industry, academics, federal agencies, and nonprofit organizations and highlighted different opportunities and constraints.

One opportunity created by the expanded participant pool was to build interagency relationships and focus discussion on the GNA, which was discussed at the regional level by the Forest Service and at the local level by the Wisconsin Department of Natural Resources. Having students from within and outside the Federal system helped to build understanding of the opportunities and constraints of implementing collaborative projects.

The second modification to the module was the transition to a blended online and in-person format. The goals of the blended delivery method were to reduce cost, reduce time away from home, and increase the ability of participants to leverage key local resources, such as maps, stand data, and other documents, and projects students were already working on.

REVIEW WORK AND ONLINE CONTENT

Participants were assigned content to review prior to the start of the module. This included nine videos on foundational information (offered via YouTube at z.umn.edu/NASP-videos) and papers on regional research. Given the added diversity of the audience, this helped to ensure that all students entering the class had a similar level of basic knowledge. In addition to the content, all students were required to complete a technology check to ensure a working microphone and web camera prior to the start of class. Since our first meeting as a class was online, the module directors and students created self-recorded video introductions. These videos were 1 to 3 minutes long and included information on each participant's education, work history, and hobbies.

The online content was divided into six online modules and was offered 2 days a week for the 3 weeks prior to the in-person session. The online tools that we utilized were the Canvas Learning Management System, PollEverywhere live polling, Webex videoconference, and Google Drive and Forms. The six modules followed these broad themes:

- Day 1: Introductions and Silvicultural Systems
- Day 2: Climate Adaptation
- Day 3: Good Neighbor Authority and Silvics
- Day 4: Prescription Writing, Forest Health, and Lowland Forests
- Day 5: Silvics and Silviculture, Fisheries, and Adaptation
- Day 6: Soils, Hydrology, Wildlife, and Forest Management.

To maintain engagement during the online sessions, the short lectures were interspersed with small-group breakout discussions, independent and group activities, and written reflections.

IN-PERSON CONTENT

Since each day's online content focused on the more fundamental concepts and content-based lecture material (i.e., day 1 applied forest ecology and silviculture theory), the in-person time as a class was mostly spent in the field. Five of the six days consisted of field trips and active learning opportunities with state, county, Federal, and private land organizations to discuss silvicultural systems. Field trip leaders were specifically asked to give a background on stand condition and information such as site characteristics, as well as allow students time to "wander" and hypothesize reasons certain silvicultural decisions were made. This shifted field trip stops from a one-way flow of information to a more active and engaging environment between students and field trip leaders. The final day of class consisted of presentations on applying concepts from the class to a local issue of importance.

CONCLUSIONS

Overall, the blended Lake States Regional Module was rated highly in both content and delivery methods. Students were surprised by how engaging the online sessions were and provided positive feedback, especially from those enrolled in the full NASP program who particularly appreciated the reduced travel required to complete this module. We plan to continue offering the module in its blended format in the future and make continuous improvements.

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SILVICULTURE, ADAPTATION, AND MONITORING

Adapting Bottomland Hardwood Forests to a Changing Climate

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ABSTRACT.—Bottomland hardwood forests will face challenges in a changing climate from altered hydrology and shifting habitat suitability for key species. Scientist-manager partnerships have been developed across the Upper Mississippi River to assess the vulnerability of bottomland hardwood forests to climate change and to develop and implement adaptation strategies using the Climate Change Response Framework developed by the Northern Institute of Applied Climate Science. Strategies include planning for more frequent and severe flooding by planting more flood-tolerant species, and planning for increases in temperature by planting species and genotypes from more southern areas. We describe two projects that are implementing these strategies: (1) A network of demonstration projects in southern Illinois and Indiana, and (2) A replicated experiment to assess alternative adaptation strategies is currently underway as part of the Adaptive Silviculture for Climate Change Network.

KEY WORDS: floodplain forests, adaptive silviculture, climate change adaptation, scientist-manager partnership

INTRODUCTION

Bottomland hardwood forests provide important ecosystem services such as nutrient cycling, flood control, wildlife habitat, and recreational opportunities. These forests are already impacted by human-induced stressors such as land conversion, fragmentation, and altered hydrology. Changes in climate may create challenges from increased precipitation, changing habitat suitability for dominant tree species, shifting flood regimes, and altered bottomland forest-dependent wildlife migration patterns. Taken together, these ecosystem types may be among the most vulnerable to climate change (Brandt et al. 2014).

We addressed these challenges by applying the Change Response Framework (hereafter referred to as Framework; Swanston et al. 2016) to two contrasting bottomland systems along the Mississippi River. The Framework is a collaborative approach to help land managers

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understand the potential effects of climate change on forest ecosystems and integrating climate change considerations into management that incorporates four main components:

- Scientist-manager partnerships
- Vulnerability assessments
- Adaptation resources
- Demonstration projects

A main focus of the Framework is the coproduction of assessments and adaptation projects involving scientists and managers at a landscape scale.

Bottomland Hardwoods in the Middle Mississippi

In the first example, Ducks Unlimited, Cypress Creek and Patoka River U.S. Fish and Wildlife Service Refuges, the USDA Forest Service's Shawnee National Forest, and the Northern Institute of Applied Climate Science applied the framework to bottomland forests in rural areas in Illinois and Indiana. In a 2015 workshop, 20 managers and scientists from the region used information in the Central Hardwoods Ecosystem Vulnerability Assessment and Synthesis (Brandt et al. 2014) to identify key impacts to the region. The following key impacts were identified through a facilitated process: (1) Increases in heavy precipitation events; (2) Increases in total runoff and peak streamflow during the winter and spring, which could lead to increases in the magnitude and frequency of flooding; (3) Increases in runoff and soil erosion; (4) Reduced habitat suitability for wet bottomland tree species at the lowest elevations in the landscape; (5) Shifts in habitat suitability of bottomland trees due to changes in temperatures; and (6) Changing migration patterns of waterfowl.

The group used the "Adaptation Workbook" (Swanston et al. 2016) to develop a joint project to address these impacts, later funded by the Wildlife Conservation Society's Climate Adaptation Fund. Strategies included diversifying the species composition and genetic stock of hardwood tree species used for reforestation efforts, such as planting pin oak and willow oak (*Quercus palustris* and *Q. phellos*), seedlings from farther south in the Mississippi Alluvial Valley, and using increased numbers of baldcypress (*Taxodium distichum*) and tupelo (*Nyssa sylvatica*). Species selection was based on modeled projections using the Climate Change Tree Atlas (Iverson et al. 2008, Prasad et al. 2014). Strategies also focused on providing more productive wintering habitat for waterfowl species that are not expected to migrate as far south, such as mallards (*Anas platyrhynchos*), American black ducks (*Anas rubripes*), gadwalls (*Mareca strepera*), and wood ducks (*Aix sponsa*). We implemented this strategy by focusing on managing for mast-producing tree species that provide a food source for these wildlife species. Implementation began in 2016 at reforestation sites at the Patoka River and Cypress Creek Refuges and at Oakwood Bottoms on the Shawnee National Forest. Sites will be monitored for species survival and changes in species richness and diversity.

Mississippi River National River and Recreation Area

In the second example, the University of Minnesota, Mississippi Park Connection, The Mississippi National River and Recreation Area (MNRRA), Colorado State University, City of St. Paul (MN) Parks and Recreation, and the Northern Institute of Applied Climate Science developed a replicated experimental design as part of the Adaptive Silviculture for Climate Change Network (Nagel et al. 2017). A workshop of about 30 representatives across multiple scientist and management organizations along the upper Mississippi River was convened in 2019. Key climate change impacts identified in this workshop were similar to those identified in the Middle Mississippi, but had a greater emphasis on interactions with urbanization and recreation. Wildlife was still an important part of management goals, but opportunities for wildlife viewing of raptors, such as bald eagles, was emphasized over waterfowl for hunting. The participants worked collaboratively to develop three alternative adaptation treatments:

- Resistance: Maintain relatively unchanged conditions over time. For this site, the treatment will:
  - o Maintain a closed canopy condition of current species composition, focusing on trees that are characteristic of the existing forest type, such as Dutch elm disease-resistant American elm (*Ulmus americana*), silver maple (*Acer saccarinum*), and cottonwood (*Populus deltoides*).
  - o Promote or enhance native regeneration.
- Resilience: Allow some change in current conditions, but encourage an eventual return to reference conditions. For this site, the treatment will:
  - o Promote future-adapted flood and drought-tolerant species native to the upper Mississippi River. Species under consideration include swamp white oak (*Quercus bicolor*), hackberry (*Celtis occidentalis*), and sycamore (*Platanus occidentalis*).
  - o Create gaps for regeneration, using natural gaps from dying green ash (*Fraxinus pennsylvanica*), removing hazard trees, and removal of small-diameter less desirable species such as boxelder (*Acer negundo*).
- Transition: Actively facilitate change to encourage adaptive responses to changing conditions. For this site, this treatment will:
  - o Incorporate future-adapted species and genotypes from farther south along the Mississippi River (e.g., Illinois, Iowa, Missouri). Species under consideration include black tupelo (*Nyssa sylvatica*), sweetgum (*Liquidambar styraciflua*), and pin oak (*Quercus palustris*).
  - o Create gaps with feathered edges to establish diverse microsites for planting future-adapted species.

The project, also funded by the Wildlife Conservation Society's Climate Adaptation Fund, was established at Crosby Farm Park in the city of St. Paul, MN, starting in 2019, and will be expanded to other sites along the MNRRA in 2020. The project will include three replicates of each treatment plus three replicate control treatment areas. Baseline data in 24 one-tenth acre circular plots were collected in summer 2019. Measurements include overstory composition, condition, diameter at breast height (d.b.h.; 4.5 ft above ground), height, and the composition and size of saplings and seedlings. Two 1-m^2 quadrats will be established within each plot to measure herbaceous composition and cover. Removals of small diameter trees and planting of saplings in each treatment will occur in winter and spring 2020. Monitoring of survival, growth, and forest health, among other measures, will be conducted over a 20-year period and treatments will be compared to control areas. Results from this study will be statistically analyzed and shared in scientific journals as well as with managers and the general public recreating in the area.

CONCLUSIONS

These two projects exemplify how scientist-manager partnerships can be effectively used at a landscape scale to address climate change impacts and co-develop adaptation strategies to meet mutually beneficial goals. Lessons learned and monitoring data collected from these projects will be helpful to other managers of floodplain forests when assessing adaptation options and developing strategies. They will also provide important information to researchers studying floodplain forests about species range limits and potential adaptation to changing climates.

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Post-Variable Density Treatment Monitoring in Dry-Site Mixed Conifer Stands with Unmanned Aircraft Systems

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ABSTRACT.—Variable density thinning (VDT) post-treatment monitoring is challenging and potentially costly because resulting stand structure is not well characterized by small area plots used in forestry. Unmanned aircraft systems (UAS) offer a potential solution for efficient VDT monitoring via rapid survey and subsequent generation of a stem map. In this study we used a UAS to survey and estimate spatial dispersion and stand structure (e.g., basal area, trees per acre, and quadratic mean diameter) in untreated and VDT-treated stands. Results showed evidence of increased clustering in the treated stand at intertree distances between 17 and 25 feet while the untreated stand exhibited a pattern of random dispersion. UAS-derived stand structure estimates differed in comparison to stand exam estimates with UAS underestimating basal area and trees per acre and overestimating quadratic mean diameter. However, comparison between UAS estimates in the treated and untreated stands revealed expected trends of decreased density and increased diameter. UAS survey and data processing time was less than one-fifth of the time required for common stand exams. Given the increased time efficiency, the biased UAS estimates are likely an acceptable tradeoff for VDT monitoring. Although this study demonstrates the utility of UAS for post-treatment monitoring, additional testing through research and management collaboration is required to refine the method and quantify error.

INTRODUCTION

Federal forest managers in the west are increasingly embracing novel silvicultural treatment methods in an effort to restore fire resiliency and ecosystem function to a landscape that has been altered by over 100 years of fire suppression (Churchill et al. 2013, Stephens et al. 2016). Variable density thinning (VDT) is a promising tool for such restoration in specific forest types that increases spatial heterogeneity by creating variable density stem clusters Churchill et al. 2013, Clyatt et al. 2016, Larson and Churchill 2012). Although monitoring VDT treatments is essential to providing feedback for the adaptive management process and responding to the reporting requirements established by the Collaborative Forest Landscape Restoration Program, it has the potential to be costly because the resulting stand structure is not well characterized by conventional small area plots.

Unmanned aircraft systems (UAS) technology has been shown to produce quantitative and interpretive data that is meaningful to forest managers in numerous applications and offers a potential solution for increasing efficiency of post-treatment monitoring activities (Bedell et al. 2017, Pádua et al. 2017, Wing et al. 2014). Although the USDA Forest Service has been conservative in the implementation of UAS technology, the 2018 modernization agenda

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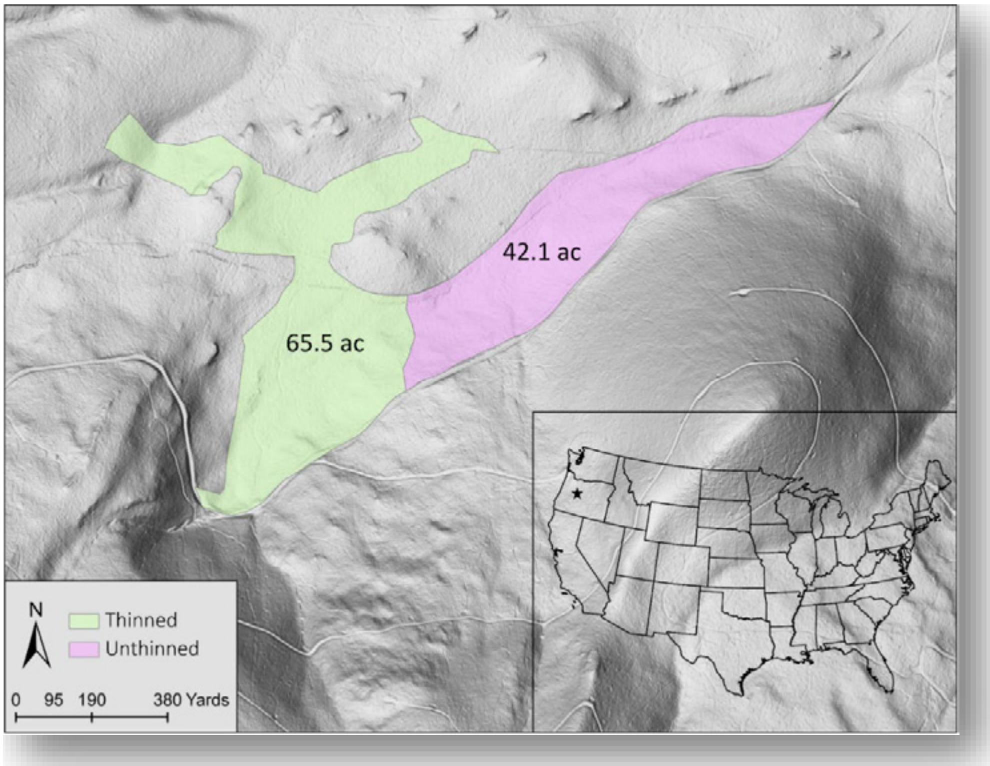

Figure 1.—Study area on the Deschutes National Forest near Sisters, OR.

(USDA Forest Service 2018) and a 2018 Executive Order[2] all but ensure eventual integration, making the current era an optimal time to think about how to best leverage this technology.

In this management-driven research and development (R&D) collaboration, we examine the efficacy of using a UAS-based methodology to survey post-treatment stand structure and spatial dispersion of a VDT treatment in a dry mixed-conifer stand.

STUDY AREA

The study site consisted of two adjacent dry mixed-conifer stands on the Deschutes National Forest near Sisters, OR (44.160° N, 121.618° W) (Fig. 1). Stand compositions and spatial dispersions were nearly identical before treatment and were dominant to *Pinus ponderosa* (ponderosa pine) with an *Abies concolor* (white fir) understory component. The larger stand of 65.5 acres was prescribed a VDT treatment to increase the presence of stem clustering while the smaller stand (42.1 acres) was unthinned to provide a reference condition for comparison.

[2] Executive order 13855 of December 21, 2018, 84 FR 45. Executive Order for promoting active management of America's forests, rangelands, and other federal lands to improve conditions and reduce wildfire risk.

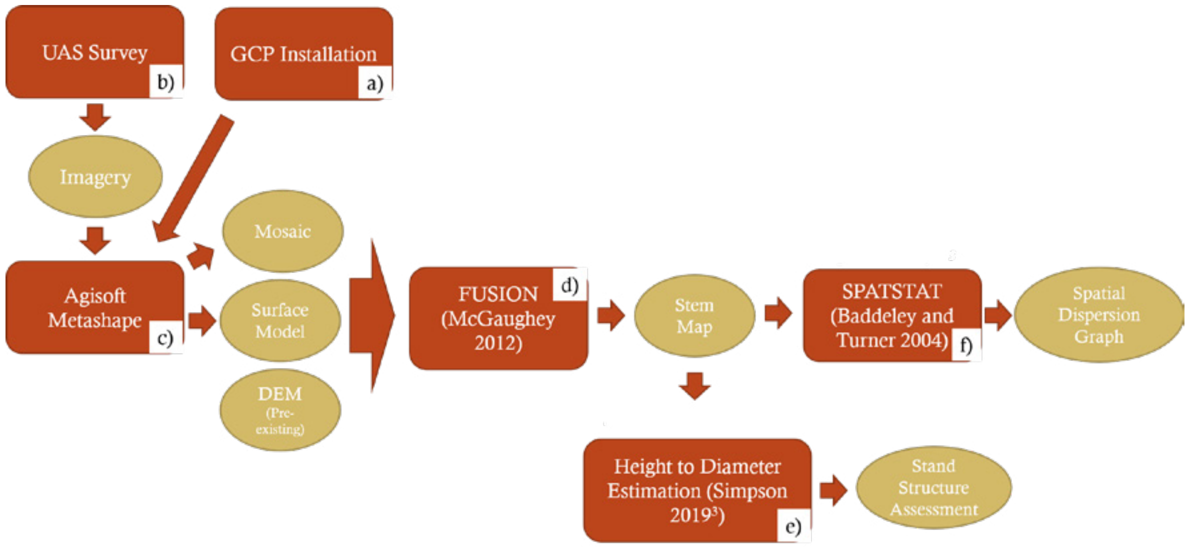

Figure 2.—UAS image processing and analysis workflow.

METHODS

While stem maps are the preferred method for quantifying post-VDT spatial heterogeneity (Larson and Churchill 2012), they can be costly due to the need to visit every tree. In effort to reduce this cost burden, we used UAS to collect the data necessary for assessing stand structure and creating remotely sensed stem maps for the ultimate purpose of quantifying spatial heterogeneity. A conceptual processing workflow (Fig. 2) shows how stem maps were produced from UAS imagery. The UAS survey took place on 11 October 2018 near solar noon in full unobstructed sunlight. Eight ground control points (GCPs) were installed and surveyed with a high accuracy global positioning system (GPS) for the purpose of improving georeferencing accuracy during image processing (Fig. 2a). The UAS survey (Fig. 2b) was conducted with a DJI Phantom 4 Pro which can produce imagery at 1.3-inch resolution when flown at an altitude of 400 feet above ground level. UAS navigation was automatic and used a preplanned 75 percent overlap/sidelap flight plan created in DJI's GS Pro application (Dà-Jiāng Innovations, Shenzhen, Guangdong, China).

Image processing (Fig. 2c) occurred in Metashape ver. 1.5.0 (Agisoft 2019), which ingested the image set and GCP data to produce a georeferenced mosaic and a digital surface model (DSM). The DSM and a pre-existing LIDAR-derived digital elevation model (DEM) were input into FUSION's CanopyMaxima function (McGaughey 2017) (Fig. 2d) to produce a stem map. The output stem map was a georeferenced dataset complete with estimates of relative tree height and crown diameter.

Comparison of thinned and unthinned stand structure was conducted by feeding the stem map data into a height-to-diameter allometric equation[3] to estimate diameter, which was ultimately used to estimate stand level tree density (trees per acre or TPA), quadratic mean diameter (QMD) and basal area (BA; square feet per acre) (Fig. 2e). As a form of validation, these data were compared to the results of post-treatment common stand exams (CSE) with 23 and 26 plots in the unthinned and thinned stand, respectively. CSE plots consisted of variable radius plots randomly allocated within each study unit with selection of trees <5

[3] USDA Forest Service internal unpublished report by Mike Simpson, forest ecologist. For more information, email at michael.simpson@usda.gov.

inches diameter at breast height (4.5 feet above ground; d.b.h.) for subsequent height and d.b.h. measurement occurring with a 20 basal area factor prism. Trees <5 inches d.b.h. were selected for measurement based on a 1/10th acre circular plot and 1/100th acre circular plot for the thinned and unthinned stands, respectively.

Spatial dispersion (Ripley 1976) (Fig. 2f) was quantified by feeding the stem map into the pairwise correlation function (PCF) algorithm in the SPATSTAT package (Baddeley and Turner 2004) in R ver. 3.5.3 (R Core Team 2017) for the thinned and unthinned stand. PCF produces a density-independent estimate of dispersion that can range from 0 to infinity where 0 is perfectly uniform, 1 is random and anything greater than 1 is clustered.

Work-hours were tallied and compared to man-hours invested in the UAS survey and analysis to assess time differences between the two CSE and UAS methods.

RESULTS AND DISCUSSION

Absolute differences of BA, QMD, and TPA between the UAS and CSE estimates suggest that UAS method underestimated TPA in the thinned stand and underestimated both TPA and BA in unthinned stand. (Fig. 3). Since QMD is a function of TPA and BA, the differences between estimation methods for stand structure are in line with expectation given that the stem map likely under represents suppressed crowns, and because the unthinned stand has more suppressed trees the magnitude of underestimation is higher than in the thinned stand. The fact that the error is explainable suggests that it might be possible to improve accuracy by the integration of field data in a model-assisted approach to account for bias (Kangas et al. 2018, McRoberts et al. 2018). It is important to note that these estimates should

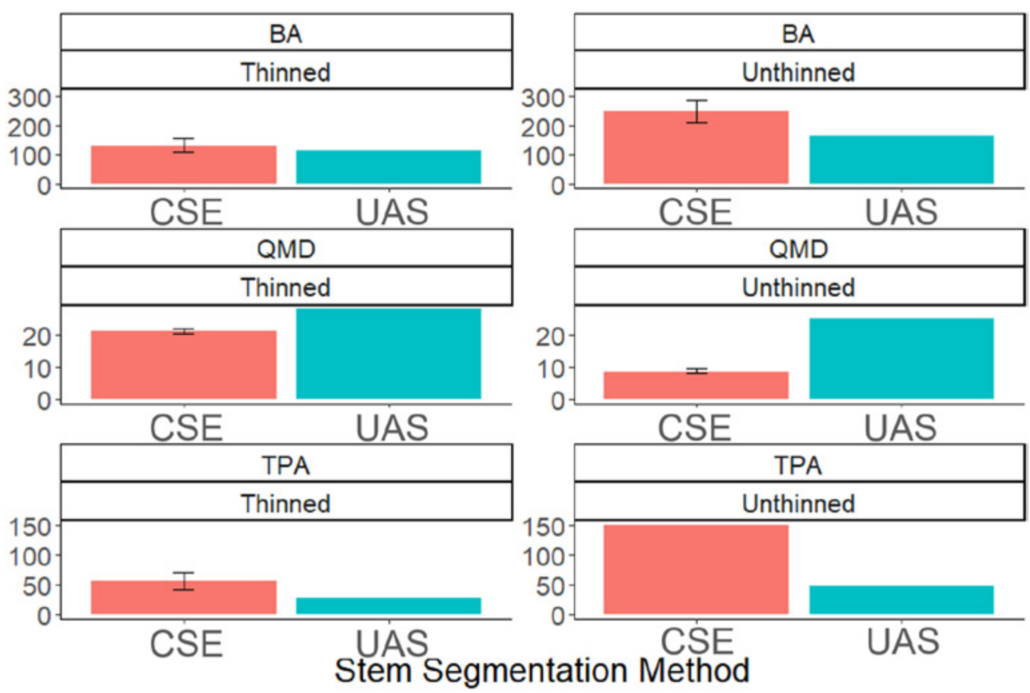

Figure 3.—Common stand exam (CSE) and unmanned aircraft system (UAS) estimates of stand structure in the thinned and untinned stands as characterized by basal area in units of ft^2 per acre (BA), quadratic mean diameter in inches (QMD), and tree density (trees per acre or TPA). CSE estimates are plot means with 95 percent confidence intervals shown with error bars. UAS estimates do not have confidence intervals since observations were not derived from samples and characterization of UAS estimate uncertainty was beyond the scope of this pilot project.

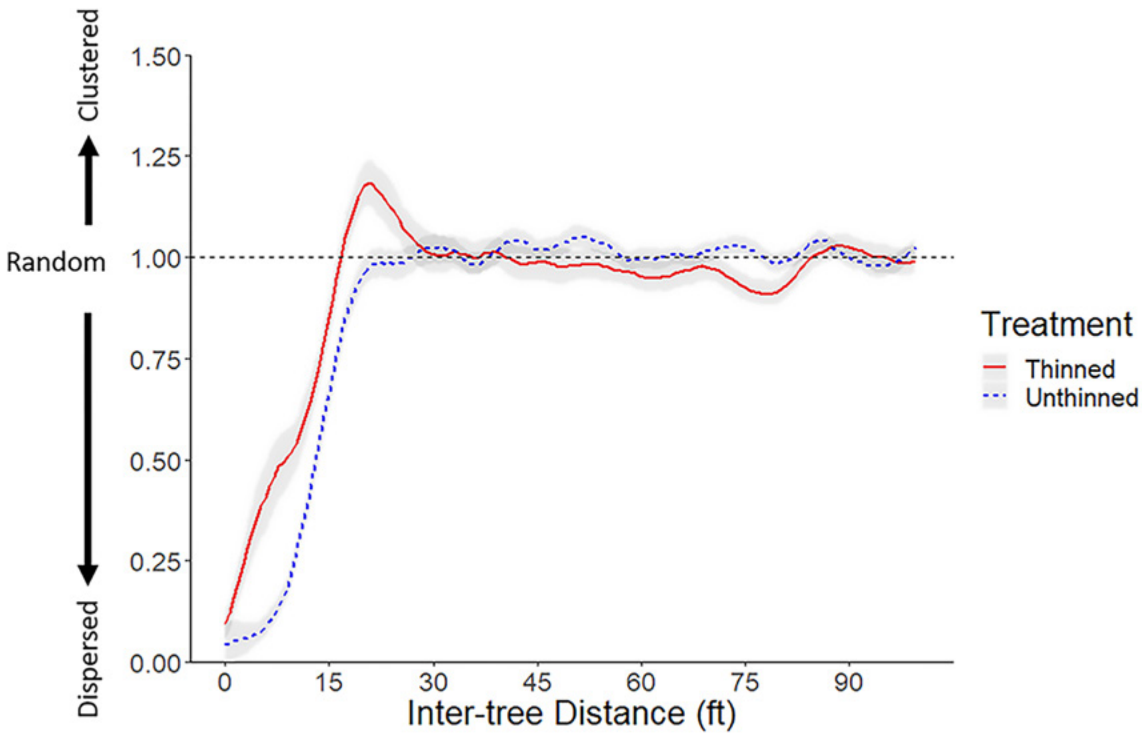

Figure 4.—Spatial dispersion of the thinned and unthinned stands as a function of inter-tree distance relative to a random Poisson distribution reference (dashed line). The transparent (grey) band around each line is the 95 percent confidence interval.

be considered carefully and in the context of management-driven error tolerances before drawing conclusions about meeting silvicultural objectives. Despite the inaccuracy of the absolute TPA and BA estimates from UAS, the method captured the same directional trends between unthinned and thinned stands as the CSE estimates with TPA and BA reducing after thinning and QMD increasing. When the costs of field estimates are considered, knowing that the method is capturing the representative qualitative indications may be acceptable for addressing the monitoring requirements of collaborators.

The results of the PCF analyses indicate evidence of clustering in the thinned stand at inter-tree distances between 17 and 25 feet whereas the unthinned stand exhibits evidence of random dispersion (Fig. 4). The strongly dispersed signal apparent in both the thinned and unthinned stands at distances less than 17 feet is likely associated with the minimum inter-bole distance of neighboring trees. Omission and commission errors are inherent in stem maps derived from UAS (and LIDAR) data with suppressed trees (under dominant and codominant trees) being omitted and mature trees with complex crowns being detected as multiple trees (i.e., commission; Popescu and Wynne 2004). Although the influence of these errors are not quantified, we are confident that the assessed spatial clustering pattern in the thinned stand is representative of true conditions because (1) clustering is evident in the post-treatment imagery, (2) both stands exhibited the same spatial dispersion pattern prethinning, and (3) clustering is likely underestimated because suppressed trees in the clusters were likely not detected by the stem mapping algorithm thus reducing the strength of the clustering signal.

Overall, the entire UAS workflow took approximately 12 work-hours while the CSEs took 64 work-hours resulting in an 81 percent time savings using the UAS method instead of CSE. It is worth noting that UAS surveys become more time efficient as survey areas increase because flight time is a very small portion of the overall workflow, so larger areas may show larger divergences in time costs depending on how variability influences CSE intensity. Further time savings could be gleaned by the utilization of real-time kinematic (RTK)-capable UAS, such as the Phantom 4 RTK, which would potentially negate the need for GCPs.

This pilot study was of limited scope in order to assess feasibility. Future study in quantifying efficiency gains, characterizing the uncertainty in UAS stand structure estimates, and evaluating the influence of stem mapping errors on estimates of spatial dispersion should be undertaken with replication in multiple forest types and multiple stand structures before a definitive conclusion on the UAS methodology can be made.

UAS survey methodology shows promising potential for rapid assessment of spatial dispersion in dry-site conifer dominant stands post VDT treatment given the method's ability to quantify changes in spatial dispersion, detect trends in stand structure, and reduce survey work-hours. While additional research is needed to fully understand the utility of the method, the positive indications of this study suggest that UAS utilization for post-harvest monitoring is a matter of when and not if.

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Sharing the Load to Develop Young-Growth Silviculture for Forage and Biodiversity in Southeast Alaska

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ABSTRACT.—Approximately 170,000 ha have been logged on the Tongass National Forest since the early 20th century, resulting in a vast network of young, and even-aged Sitka spruce–western hemlock stands. Many of these stands are in a stem exclusion phase, with dense overstories that competitively shade out understories. In 2001, a USDA Forest Service planning committee convened to develop multiple resource treatments to examine the effects of precommercial thinning, resulting in a collaborative, long-term project to improve knowledge and catalyze the Tongass-Wide Young Growth Studies (TWYGS) project. This project was designed collaboratively, implemented by partners across the Tongass, and monitored via the Forest Service's Pacific Northwest Research Station. Of the four TWYGS experiments, one has been measured three times in 16 years since treatment. We examine forest development following three levels of precommercial thinning in 15- to 25-year-old stands: unthinned, 4.3 m spacing, and 5.5 m spacing. Results from 5, 10, and 16 years highlight key differences in understory cover and forage biomass between thinned and unthinned treatments. We identify tradeoffs between overstory and understory development following treatment, which will have impacts on future management planning. TWYGS is a hallmark of management-research collaboration, and provides much needed insight into young-growth silviculture throughout the temperate rainforest.

INTRODUCTION

Large-scale commercial logging in southeast Alaska began in the 1950s employing clearcutting as the predominant regeneration method. Stand development following clearcutting in southeast Alaska coastal rainforests typically includes natural regeneration of western hemlock (*Tsuga heterophylla* Raf. Sarg.) and Sitka spruce (*Picea sitchensis* Bong. Carr.) (Alaback 1982a, Deal et al. 1991) and rapid growth of *in situ* red alder (*Alnus rubra* Bong.) and shrubs (Alaback 1980, Robuck 1975). This phase of stand development, referred to as stand initiation (Oliver and Larson 1996), generally lasts for 15 to 25 years, depending on site quality. Within 10 years of clearcutting, newly established conifers begin to overtop the shrubs, and crown closure may be complete by 25 years (Harris and Farr 1974), leading to the stem exclusion phase of stand development. Stem exclusion occurs most rapidly on productive sites and may not occur for decades on in low-productivity sites. During the stem exclusion phase there is a nearly complete elimination of vascular understory vegetation (Alaback 1980, 1982b, 1984; Tappeiner and Alaback 1989). A century after harvest, the understory vegetation begins to re-establish but does not become well developed until the stand reaches 120 to 150 years of age as patch dynamics motivated by individual tree death opens the stand in the understory reinitiation phase (Alaback 1982b, 1984; Oliver and Larson 1996; Tappeiner and

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Alaback 1989). But until this phase of stand development, even-aged conifer stands in the stem exclusion phase after clearcutting are often recognized as having broadly negative consequences for wildlife and fish (Dellasala et al. 1996; Hanley 1993; Meehan et al. 1984; Schoen et al. 1981, 1988; Thedinga et al. 1989; Wallmo and Schoen 1980), particularly where dense, homogeneous canopy cover causes the loss of understory plants. Where even-aged stands form variable and patchy canopies, or in low-productivity areas, heterogeneous overstory cover and resource availability may promote or extend understory cover. Young-growth forests (i.e., second-growth, third-growth, etc.; forests developing following clearcutting old growth) present a challenge to forest managers attempting to maintain or improve understory plant communities for wildlife habitat while enhancing wood production.

There are about 295,000 ha of young-growth forest in southeast Alaska: 170,000 ha on the Tongass National Forest (NF), 18,000 ha on Alaska state lands, and 107,000 ha on Alaska Native corporation lands. Many young-growth stands are now entering or are well into the stem exclusion phase. Management strategies are needed for minimizing the length or the impact of this phase of stand development (i.e., near or total absence of understory vegetation), whether this be a change in rotation length, regeneration method, or intermediate treatments. Successful silvicultural treatments will either delay the onset or hasten the end of the stem exclusion phase, mitigating its effect by increasing light transmission through the overstory canopy.

From the 1970s to the 1980s, while the pulp industry was strong and active management was primarily focused on maximizing timber yield, forest managers typically prescribed precommercial thinnings to 2.4 to 3.0 m spacing, often at 15 to 25 years old. Throughout the 1990s, silviculturists on the Tongass NF increased spacing standards to 4.3 to 4.9 m and tried several alternatives to standard precommercial thinning: variable spacing, wide spacing (5.5 m or more), gaps and thickets, retention of hardwoods, etc. These operational treatments rarely followed the principles of experimental design and lacked appropriate controls, replication, and random assignment of treatments necessary to quantify consequences. Districts worked independently and there was no forest-wide coordination of testing. Follow-up monitoring, analysis, or reporting of these trials was done in only a few cases. It became apparent that a purely operational approach employing administrative studies or demonstration case studies would not yield credible evaluation of silvicultural options suitable to guide future management.

Nevertheless, the most useful long-term empirical evaluation of silvicultural options requires their application at a scale appropriate to routine forest management—i.e., tens of hectares, rather than the fractions of a hectare typical of research plots. Thus, managers and research ecologists collaborated to employ an adaptive management approach to evaluating young-growth silvicultural treatments. Adaptive management is one of several approaches to reduce uncertainty in difficult management environments (Peterson et al. 2003). Redford et al. (2018) paraphrase the early development of adaptive management ideas by Walter and Holling (1990) as an approach that “seeks to structure learning from actions to improve the likelihood of achieving desired outcomes.” The Tongass-Wide Young-Growth Studies (TWYGS) project is an attempt to leverage the unique knowledge, skills, and resources of both managers and researchers to solve important young-growth management questions by employing active adaptive management under a research plot framework.

This paper documents the motivation, design, and establishment of TWYGS; reports findings from 16 years of measurement in the first of the four TWYGS studies to come online; and highlights the science-management partnership that has been integral to the success of such a long-term adaptive management project.

BACKGROUND AND OBJECTIVES

Past research has investigated the effectiveness of several silvicultural treatments on preventing or minimizing the stem exclusion phase of stand development. These include thinning, pruning, and enriching deciduous species composition in conifer stands. Because ecological processes in forests can differ markedly from region to region, we examined forestry literature from the Pacific Northwest, coastal British Columbia, and southeast Alaska.

Thinning in Conifer Stands

Precommercial thinning became common practice on the Tongass NF in the late 1970s, where it has since been applied to approximately 81,000 ha of young-growth stands in the forest. Traditionally, thinning has been used to reallocate resources and increase growth on selected crop trees and maximize timber outputs, but other possible benefits include delaying the onset of the stem exclusion phase, increasing understory plant diversity, and improving wildlife habitat (Nyland 2016). Attempts to re-establish understory herbs and shrubs through thinning young-growth conifer stands have had mixed success. For example, Deal and Farr (1994) found that thinning of young even-aged stands promoted tree growth but did not extend herbaceous production, and that wide spacing resulted in the establishment of a new cohort of western hemlock regeneration. On the other hand, Cole et al. (2010) found that precommercial thinning intensity had no effect on understories; rather, all thinning intensities (750, 500, 370, and 250 trees ha^{-1} in 16 to 18 year old stands) resulted in a 7-year pulse (the duration of the study) in understory vegetation production beyond the productive pretreatment conditions.

As part of the Forest Service Alaska region's second-growth management program (SGMP), five demonstration sites in southeast Alaska were commercially thinned in 1984–1985. The purpose of the study was to evaluate the ability of commercial thinning to enhance wood production, understory vegetation, and quality forage for Sitka black-tailed deer (*Odocoileus hemionus sitkensis*). Three separate thinning treatments were applied: (1) uniform individual tree selection (ITS), not to be confused with "selection" regeneration harvests or thinning methods; (2) strip + ITS, 7.6-m strips with 100 percent removal and matrix thinned to 6.1- to 7.6-m spacing, and (3) strip, alternating 6.1-m cut and leave strips. Thirteen to 14 years after treatment, strip and strip + ITS treatments had the greatest total understory biomass, but biomass was dominated by conifer regeneration (Zaborske et al. 2002). The ITS treatment had less understory biomass per hectare, but over half the biomass was in shrubs, ferns, and forbs which had greater nutritional value for deer. Estimates of deer-forage availability showed that the ITS treatment, which was the most conventional approach of the three treatments, created better forage resources for deer than did the other treatments, and that summer forage availability was similar to the values estimated for old-growth forest (Zaborske et al. 2002).

Other research has identified the effect of gap-making on understory development. Although not technically thinning, creating gaps in a stand is an intermediate treatment intended to improve its value to wildlife. Harris and Barnard (2017) found that understory biomass was eight times greater in gaps (150-m^2 to 430-m^2 openings) than in untreated skips, 23 years after treatment. Although gaps commonly recruit abundant western hemlock regeneration (Alaback, unpublished[2]; Harris and Barnard 2017), these studies suggest that small gaps or patchiness within stands prolong localized but enduring understory vegetation pools useful for deer forage.

[2] Unpublished report. Alaback, P.B. 2010. An evaluation of canopy gaps in restoring wildlife habitat in second growth forests of southeastern Alaska. 15 p. On file at the USDA Forest Service Pacific Northwest Research Station – Juneau Forestry Sciences Laboratory.

Pruning Conifers

In the early 1990s, five field trials were established in southeast Alaska to monitor the response of western hemlock and Sitka spruce to thinning and pruning (Petruncio 1994). Followup monitoring showed that developing high-quality clear wood in Sitka spruce was doubtful owing to the development of epicormic branches on pruned tree boles (Deal et al. 2003). Although pruning may not fully achieve wood-quality objectives, it may have added value for habitat objectives. Recent field observations of Petruncio's (1994) experiments suggest that thinning plus pruning was more effective than thinning alone in promoting understory diversity and abundance. Understory response was not measured immediately before and after thinning and pruning, so we can draw only limited inferences from it, but it is reasonable to conclude that pruning increased understory vigor by admitting sidelight from the low solar angles common to these northern latitudes.

Mixed Red Alder-Conifer Stands

Recent studies of mixed-conifer and red alder stands have indicated that alternative pathways to the stem exclusion phase (i.e., loss of understory vegetation) are possible following clearcutting in southeast Alaska (Hanley 2005). Logging practices used after 1970 aimed to reduce site impacts, and consisted of high-lead log yarding in which trees are carried through the air and soil disturbance is minimized. Following this type of logging, dense, uniform conifer stands develop to the exclusion of understory plants. Pre-1970 methods of logging resulted in considerable soil disturbance which made excellent seed beds for red alder to colonize (Ruth and Harris 1979). In contrast to the dense, uniform conifer stands following high-lead logging, alder-conifer mixed young-growth stands have a species-rich and highly productive understory with biomass quantity similar to that found in old-growth stands, with species composition tending toward devil's club (*Oplopanax horridus* (Sm.) Miq.), salmonberry (*Rubus spectabilis* Pursh), red elderberry (*Sambucus racemosa* L. var. *racemosa*), and ferns (Deal 1997, Hanley and Barnard 1998, Hanley and Hoel 1996, Hanley et al. 2006). This species-rich understory persists for as long as 45 years after logging with heavy forest floor scarification. Understory species richness was highest in stands with 18 to 51 percent alder and lowest in pure conifer or pure alder stands (Deal et al. 2004).

Management of Young-Growth Forests to Improve Wildlife Habitat

The response of birds to thinning of young-growth stands is highly variable and dependent upon foraging and nesting requirements particular to each species (Weikel and Hayes 1997, 1999). Although some species of birds increase in abundance following thinning, others have declined, and others have shown no measurable change (Adam et al. 1996, Dellasalla et al. 1996, Hagar et al. 1996, Hayes et al. 1997, Weikel and Hayes 1997). Many studies comparing thinned and unthinned stands have correlated differences in bird abundance with tree density, but have not documented other changes in vegetation resulting as a byproduct of thinning (i.e., understory vegetation, presence of snags, presence of hardwoods) that may be important to birds for nesting or foraging. Dellasalla et al. (1996) identified an increase in two species, dark-eyed Juncos (*Junco hyemalis*) and hermit thrushes (*Catharus guttatus*), to the percentage of forb cover, a habitat feature found to be higher in thinned than unthinned stands. Hagar et al. (1996) found that warbling vireos (*Vireo gilvus*) responded not only to thinning but also to associated habitat features such as tree species composition, cover of certain understory plants, and density of hardwoods.

The importance of hardwoods to birds breeding in coniferous forests of the Pacific Northwest and southeastern Alaska is not clear, but several studies suggest that mixed forest stands are higher quality habitat than pure conifer stands. Low bird diversity (southeast Alaska; Kessler and Kogut 1985) and abundance (British Columbia; Schwab 1979) have been found in dense young-growth conifer stands. Both bird abundance and diversity are positively associated with the density of deciduous trees in young-growth forests (Gilbert and Allwine 1991, Huff and Raley 1991, McComb 1994). The simple stand structure and sparse understory below dense young-growth canopies may limit the number of nest sites available to birds, and reduce nest concealment, a feature associated with successful nesting for some open-cup nesting species (reviewed by Kelly 1993, Martin 1993). Deciduous vegetation in coniferous stands is an important component for successful nesting in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantations in British Columbia (Easton and Martin 2002). Nesting density was higher in mixed than coniferous young-growth stands in southeast Alaska, where five species, including two cavity nesters, were found using red alder as a nesting substrate. Multiple studies suggest red alder is an important foraging substrate (De Santo, in preparation[3]; Gilbert and Allwine 1991; McComb 1994) and is preferred over conifers by some forest birds (Weikel and Hayes 1999). Furthermore, insect biomass is sometimes greater in deciduous vegetation (Allan et al. 2003, Stiles 1980, Willson and Comet 1996, Wipfli 1997), providing a necessary food source for insectivorous wildlife (e.g., birds, bats, small mammals).

Investigations suggest that some small mammals, such as shrew-moles (*Neurotrichus gibbsii*) and Trowbridge's shrews (*Sorex trowbridgii*), are more abundant in red alder stands than in conifer stands in Oregon (Gomez 1992). In southeast Alaska, Hanley (1996) found no significant differences between mixed red alder-conifer and nearby old-growth stands (primarily composed of conifers) in the abundance or growth rate of common shrews (*S. cinereus streatori*), deermice (*Peromyscus keeni*), or long-tailed voles (*Microtus longicaudus litoralis*), suggesting that habitat quality for these species in even-aged mixed stands may be equal to that of old-growth forests. Shrub cover in young-growth stands is positively associated with the abundances of some small mammals of the Olympic Peninsula (*Sorex trowbridgii*, *Clethrionomys gapperi*, *Neurotrichus gibbsii*, *Peromyscus oreas*, *P. maniculatus*; Carey and Johnson [1995]) and in the Oregon Coast Range (Townsend's chipmunks, *Tamias townsendii*; Hayes et al. [1995]).

Food value of understory vegetation for Sitka black-tailed deer depends on plant species composition and biomass (Hanley et al. 2012). Understory deer forage value was greater in alder and mixed alder-conifer stands than pure conifer stands (Hanley and Barnard 1998). In another study, both shrub and herbaceous production were positively correlated with red alder basal area in young-growth stands, which in turn was highly correlated with food resources for deer in summer but not in winter (Hanley et al. 2006). Understory species composition is very important for deer, with blueberry (*Vaccinium* spp.) shrubs and evergreen forbs most important in winter. Evergreen forbs (e.g., bunchberry dogwood [*Cornus canadensis* L.], five-leaved bramble [*Rubus pedatus* Sm.], fernleaf goldthread [*Coptis aspleniifolia* Salisb.], and threeleaf foamflower [*Tiarella trifoliata* L.]) are especially difficult to manage for because they are shaded by both overstory trees and understory shrubs. Thus, the temporal dynamics of stand development are an important consideration in silvicultural treatment design (Hanley 2005).

[3] De Santo, T. Manuscript in preparation. Passerine use of coniferous and mixed second-growth forests in southeast Alaska. Manuscript in preparation. On file at the USDA Forest Service Pacific Northwest Research Station – Juneau Forestry Sciences Laboratory.

Study Objectives

The TWYGS adaptive management project was designed to explore differences among silvicultural treatments of young-growth forests to meet multi-resource objectives. These studies assess the ability of intermediate silvicultural treatments to provide for wood production, wildlife habitat, and subsistence resources. The primary research objectives are to evaluate the response of vascular understory plants and overstory trees to several silvicultural practices—thinning (both by conventional means and by girdling), pruning, planting of red alder, and treatment of thinning slash. These studies are intended to last a minimum of 20 years in order to adequately assess the dynamic vegetation responses to silvicultural treatment.

The experimental treatments are intended to meet four general objectives:

1. Develop a more diverse vertical and horizontal forest structure than is found in unmanaged young-growth stands.
2. Reduce the length of time spent in the stem exclusion phase of stand development by delaying its onset or hastening the transition to understory re-initiation phase.
3. Increase (compared to no action) and maintain understory plant species richness, abundance, and productivity, especially key forages for Sitka black-tailed deer.
4. Maintain or improve wood production with sufficient quantity and quality to yield commercial products.

TWYGS includes four experiments, described in depth in the following section (Table 1):

1. A test of mixed hardwood-conifer stands, created by planting red alder at low and moderate densities in 0- to 5-year-old stands. This age range should allow for the successful planting and establishment of red alder, a shade-intolerant species.
2. A test of moderate and heavy precommercial thinning in 15- to 25-year-old stands. This is the normal age range for precommercial thinning in southeast Alaska.
3. A test of moderately heavy precommercial thinning combined with two pruning treatments, in 25- to 35-year-old stands. This is the typical age for pruning in southeast Alaska.
4. A test comparing girdling and conventional precommercial thinning, with and without slash treatment, in stands over 35 years old. This treatment examines stands beyond the typical age range for precommercial thinning (though not yet large enough for commercial products), but was representative of the many older, productive, young-growth stands within the beach fringe, where timber harvesting is currently restricted on the Tongass NF.

Table 1.—Replicates and areas by TWYGS experiment. Experiment 1 is a test of mixed hardwood/conifer stands, created by planting red alder at low and moderate densities, Experiment 2 is a test of moderate and heavy pre-commercial thinning, Experiment 3 is a test of moderately heavy pre-commercial thinning combined with two pruning treatments, and Experiment 4 is a test a comparing girdling and pre-commercial thinning with slash treatment.

Experiment	Age range (years at treatment)	Blocks (remaining)[a]	Total area (ha)	Average area (ha) per unit	Year treated
1	0-5	23 (23)	359	15.6	2003
2	15-25	20 (18)	712	35.6	2002
3	25-35	19 (13)	718	37.8	2002-3
4	35+	17 (17)	211	12.4	2006

[a1]Values in parentheses refer to the number of blocks still in the study as of 2019.

PROJECT ESTABLISHMENT

Experimental Design, Site Selection, and Layout

Each of the four experiments used a randomized complete block design, with 17 to 23 blocks established throughout the Tongass NF (excluding Yakutat Ranger District) from 2002 to 2006 (Fig. 1). In most cases the experimental blocks were laid out within a single harvest unit, which was divided into three to five experimental units, depending on the number of treatments in the experiment (Fig. 2). In some blocks, the experimental units were created from adjacent harvest units to increase experimental unit sizes.

Young stands needed to meet several criteria to be included in this study. All harvest units had a site index of at least 22.9 m (50-yr basis; Farr 1984) and were located at elevations lower than 365 m above mean sea level. Most units had a southerly aspect so they would be in deer winter range. Within-unit site productivity, stand density, and stand composition were required to be relatively uniform. Units were not previously thinned or weeded.

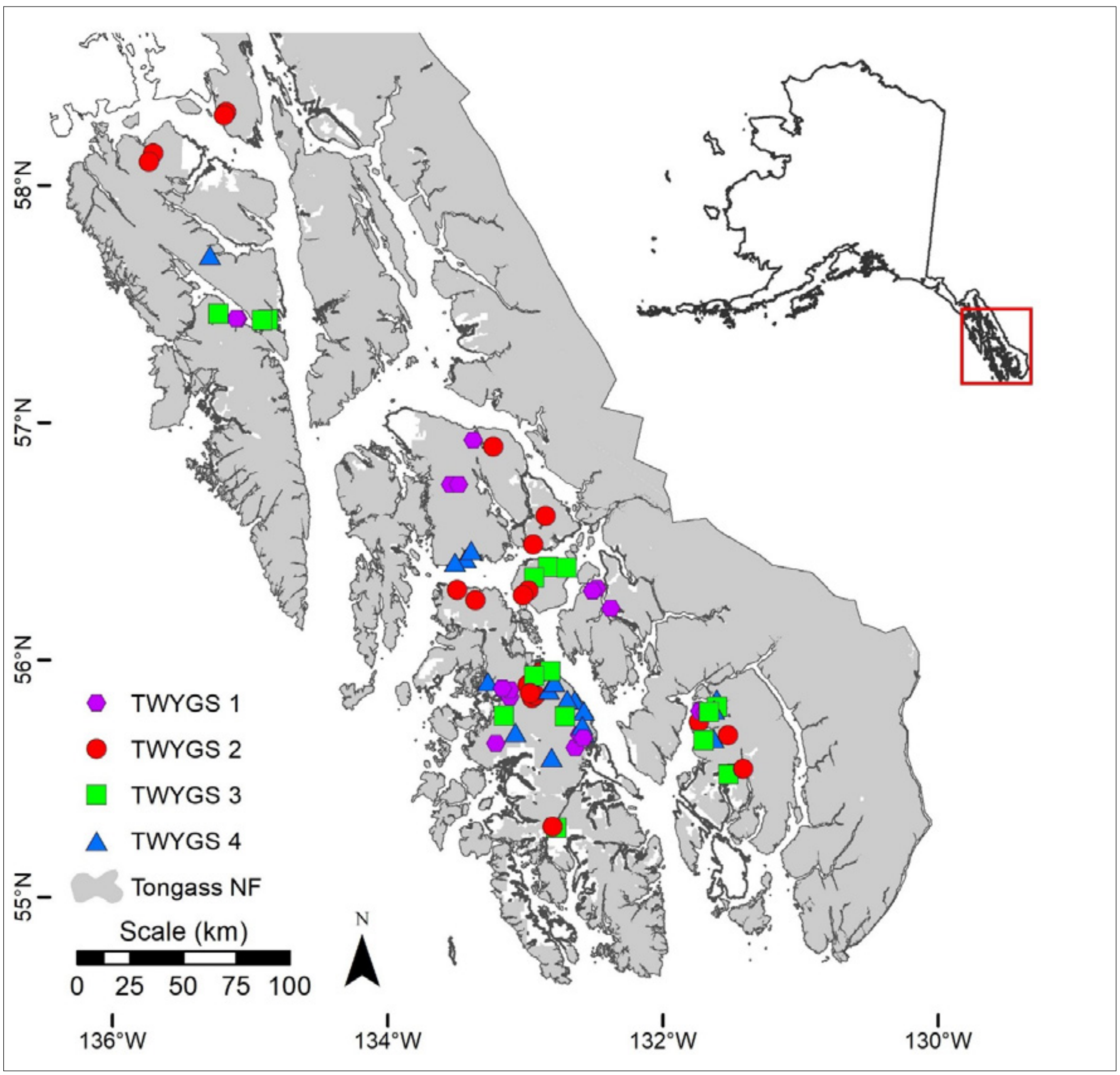

Figure 1.—Tongass National Forest, with installation locations from each of the four experiments in the Tongass-Wide Young-Growth Studies (TWYGS).

Experimental units were delineated to minimize edge effects, and 30- to 46-m untreated buffers were left between experimental units. When possible, buffers coincided with untreated stream buffers. To conduct the studies at an operational scale and to incorporate typical levels of within-stand heterogeneity, the desired minimum size of the experimental units was set at 4 ha. The total area per block and the average experimental unit area varied widely among the four experiments (Table 1). Treatments were randomly assigned to experimental units (Fig 2).

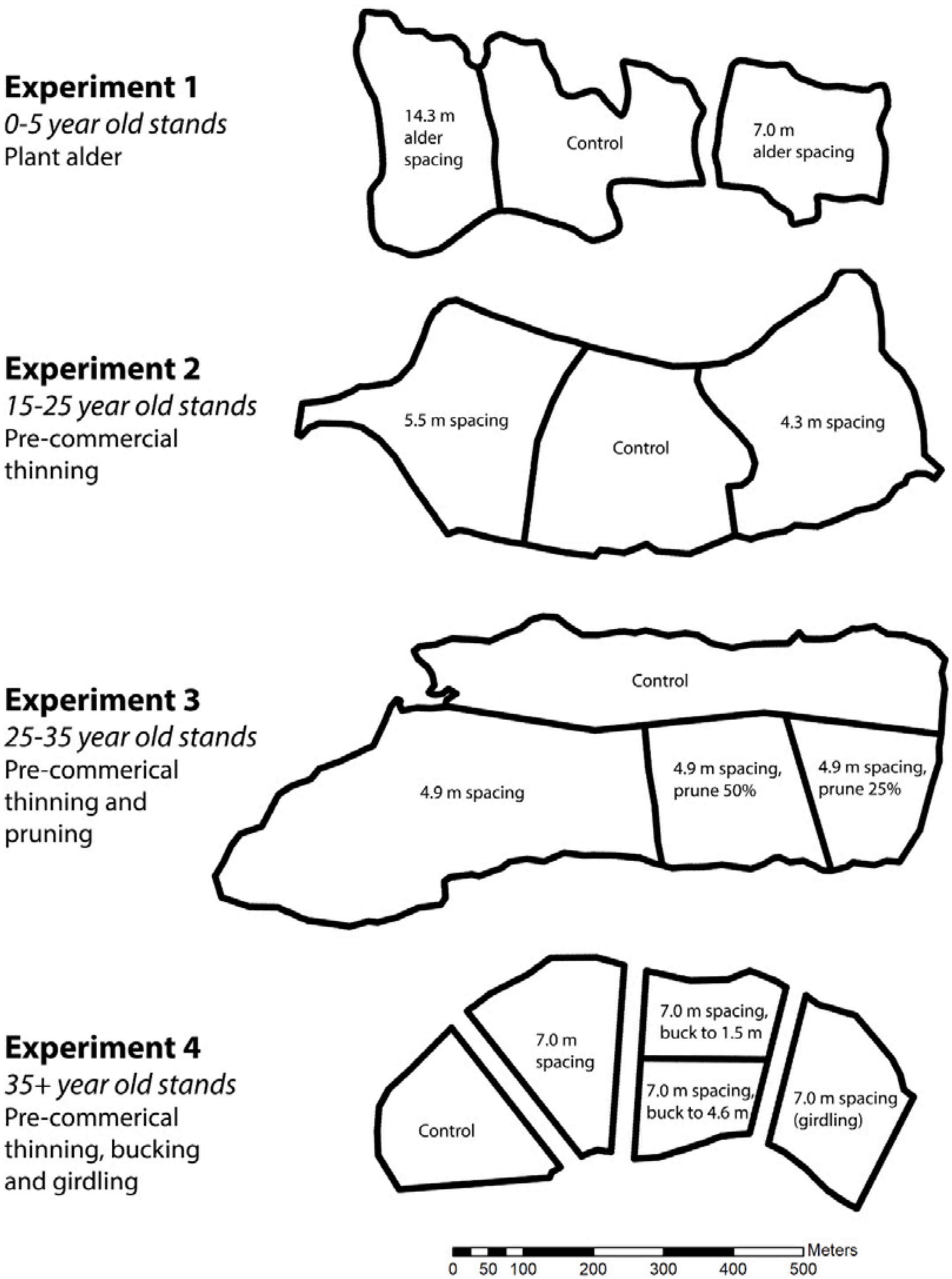

Figure 2.—Conceptual diagram of treatments within installations for each of the four Tongass-Wide Young-Growth Studies experiments.

Experiment 1: Planting red alder in 0- to 5-year-old conifer stands

Three treatments were included in Experiment 1:

1. A control, where no red alder were planted.
2. Red alder planted at low density (49 trees per hectare, 14.3-m spacing).
3. Red alder planted at moderate density (198 trees per hectare, 7.0-m spacing).

Complete sets of treatments were replicated in 23 blocks. The red alder planting stock was grown from seed collected in southeast Alaska, producing bare-root 1-0 seedlings, 30 to 61 cm tall. Contractors planted alder in the spring and summer of 2003. Seedlings were planted in a 0.1-m^2 scarified area of mineral or mixed organic and mineral soil, at least 1.5 m from any conifer that would compete with it within 5 years.

Experiment 2: Precommercial thinning of 15- to 25-year-old conifer stands

Three treatments were included in Experiment 2:

1. A control, where no thinning was done.
2. Moderate precommercial thinning to 548 conifers per ha (4.3-m spacing), allowing for a spacing variation of plus or minus 50 percent (2.1 to 6.4 m).
3. Heavy precommercial thinning to 333 conifers per ha (5.5-m spacing), allowing for a spacing variation of plus or minus 50 percent (2.7 to 8.2 m).

Complete sets of treatments were replicated in 20 blocks. Red alder was not removed, but western hemlock and Sitka spruce were removed with equal preference. Red cedar (*Thuja plicata* Donn ex. D. Don) and Alaska yellow cedar (*Callitropsis nootkatensis* (D. Don) Oerst. ex D.P. Little) presence are variable across the forest, so preference for these species (hereafter, cedar) was considered at the site level. Where cedar was common, it was treated as other conifers and considered for removal; in areas where cedar was uncommon, it was retained. Retained conifers were selected based on height, form, vigor, and freedom from disease. Thinning was performed by chainsaw. A 3.0- to 6.1-m buffer was retained on either side of streams and an effort was made to avoid depositing slash into streams.

Experiment 3: Precommercial thinning and pruning of 25- to 35-year-old conifer stands

Four treatments were included in Experiment 3:

1. A control, where no thinning or pruning was done.
2. Moderately heavy precommercial thinning to 420 conifers per ha (4.9-m spacing), allowing for a spacing variation of plus or minus 50 percent (2.4 to 7.3 m). Stands were thinned but not pruned.
3. Precommercial thinning, as (2) above. In addition, 25 percent of the conifers on an area basis were pruned (106 trees per ha) up to no more than one-half of the total tree height in 2.7 to 5.2-m lifts. Trees selected for pruning were distributed as evenly as possible across the unit while selecting for the largest diameter trees.
4. Precommercial thinning, as (2) above. In addition, 50 percent of the conifers (212 trees per ha) were pruned, as (3) above.

Complete sets of treatments were replicated in 19 blocks. Species retention preferences were the same as Experiment 2. Retained trees were selected based on height, form, vigor, and freedom from disease. Conifers selected for thinning were girdled with a double chainsaw cut if they were greater than 18 cm in diameter; smaller trees were cut down completely by chainsaw. A 3.0- to 6.1-m buffer was retained on either side of streams, and an effort was made to avoid depositing slash into streams.

Experiment 4: Precommercial thinning of conifer stands 35 years old or older

Five treatments were included in Experiment 4:

1. A control, where no thinning or slashing was done.
2. Heavy precommercial thinning to 198 conifers per ha (7.0-m spacing). Thinning was accomplished by conventional methods, i.e., felling the tree with a chainsaw. Thinning slash was not treated.
3. Precommercial thinning, as (2) above. Thinning slash was treated by cutting downed boles into 4.6-m lengths.
4. Precommercial thinning, as (2) above. Thinning slash was treated by cutting downed boles into 1.5-m lengths.
5. Precommercial thinning, as (2) above, but thinning was accomplished by girdling the tree with a chainsaw (not felling). Thinning slash was not treated.

Complete sets of treatments were replicated in 17 blocks. Species retention preferences were the same as Experiment 2 and 3. Retained trees were selected based on height, form, vigor, and freedom from disease. A 3.0- to 6.1-m buffer was retained on either side of streams, and an effort was made to avoid depositing slash into streams.

VEGETATION RESPONSE TO EXPERIMENT 2: 16-YEAR DYNAMICS

Methods

Data collection

A grid of five systematically located, 0.05-ha permanent plots were installed in each experimental unit (see above text). Plots were established at least 25 m from the treatment boundary to reduce edge effects. Overstory and understory data were collected in 2007, 2012, and 2018 (5, 10, and 16 years after treatment, respectively).

We assessed unit overstories by recording status (live or dead), species, and diameter at breast height (d.b.h.; 1.37 m) for all standing trees >2.5 cm d.b.h. within each thinned plot. In most control plots, it was impractical to measure all trees because of high density (>3000 trees ha^{-1}) and a grid of nine, 9-m^2 subplots was established to sample overstory attributes. We measured canopy cover on each plot by taking canopy photos at plot center using a fisheye lens on a Nikon D5000 digital camera; cover was estimated using Gap Light Analyzer (in 2007) (Frazer et al. 1999) or HemiView (2012 and 2018) (Rich et al. 1999). Canopy cover estimates by these two programs are comparable in these young-growth stands (pers. obs., J. Crotteau).

Field crews visually identified and estimated areal cover of each vascular understory species (≤1.3 m tall) in sixty, 1-m^2 quadrats per unit, which were distributed evenly and systematically across permanent plots, at least 6 m from plot centers to avoid trampling. Nonwoody understory biomass (hereafter, just "understory biomass"; kg ha^{-1}) was estimated for these quadrats using cover-to-biomass regressions that we developed. We destructively sampled understory biomass (i.e., dry weight) for each species by clipping and weighing plants across a range of targeted cover values (from 1 to 100 percent cover, by ~10 percent increments).

Biomass samples were located within the treatment units but outside the permanent plots, and only at installations connected to the Prince of Wales road system for access to drying ovens. After oven-drying plant materials at 100 °C for at least 24 hours as weight stabilized, we developed cover-to-biomass regressions for current annual growth of each forage type (i.e., leaves and twigs, not woody growth). Separate regressions were fit for each measurement year because relationships may vary based on environmental factors. For uncommon species that lacked sufficient observations, we used local regression equations (Hanley, unpublished data[4]). Canopy and biomass data were collected from mid-June through mid-August to coincide with peak understory development (per Hanley et al. 2012).

Analytical methods

We calculated stand density (trees ha^{-1}) and stand density index (SDI) (Reineke 1933) for each treatment unit to evaluate the effects of the treatments on the stand structure and understory dynamics. All cover and biomass data were analyzed at the unit level. Understory biomass (kg ha^{-1}) for each species was calculated using cover-to-biomass regressions, then summed by functional class in each unit, where functional classes were ferns, forbs, graminoids, shrubs, and understory trees.

We fit linear mixed-effects models to square-root-transformed understory biomass using lme4 (Bates et al. 2015) and lmerTest (Kuznetsova et al. 2017) in R (R Core Team 2016). We assessed biomass by understory functional class to understand how treatment affects understory structure and functional composition over time. Model fixed-effects included two *a priori* orthogonal contrasts and their interaction with sampling event (three levels: visit 1, 2, and 3 in 2007, 2012, and 2018, respectively). Orthogonal contrasts were defined as the thinning effect, where treatment units were pooled and contrasted with the untreated control, and the thinning intensity effect, where the heavy thinning was contrasted with the moderate-intensity thinning. We established visit 2 (2012) instead of visit 1 as the baseline sampling event to have the model calculate the temporal contrasts we were interested in. We considered this a more efficient statistical means to interpret the changes over time, especially because none of our visits represent an immediately pretreatment or post-treatment "baseline." Installation ("site" or "block") was treated as a random-effect.

Additionally, we calculated the ratio of biomass in thinned units to control units to further evaluate understory response to thinning.

Species composition is an important ecological attribute of understory development. To supplement our analysis of biomass by functional class, we isolated and summarized the species with >10 percent relative cover in each treatment type to evaluate how treatment affects dominant understory species.

We used the Forage Resource Evaluation System for Habitat (FRESH)-Deer model (Hanley et al. 2012) to quantify the habitat value for Sitka black-tailed deer. FRESH-Deer integrates substantial field and laboratory studies of the nutritional characteristics of forages in southeast Alaska and studies of deer metabolic requirements (Hanley et al. 2012). This model calculates "deer days" per hectare, where 1 deer day is defined as the food resources necessary to sustain one adult female deer for 1 day. FRESH-Deer does not consider herbivore-plant interactions, deer population dynamics, or physical accessibility through stands, so the model output should be interpreted as the potential forage at a single point in time. FRESH-deer provides an upper bound on the number of deer a habitat can support with currently available forage

[4] Data on file at the USDA Forest Service Pacific, Northwest Research Station, Juneau Forestry Science Laboratory.

Table 2.—Mean overstory characteristics (and standard error) following treatment in the Tongass-Wide Young-Growth Studies Experiment 2 (TWYGS 2). Stands were precommercially thinned to 4.3-m or 5.5-m spacing in 2002, then measured in 2007, 2012, and 2018. Density and relative density refer to trees with diameter at breast height ≥2.5 cm. Stand density index (SDI) is the metric equivalent (25.4 cm diameter at breast height trees ha^{-1}) of Reineke's (1933) SDI.

	Canopy cover (percent)			Density (trees ha^{-1})			Stand density index		
	Control	4.3 m	5.5 m	Control	4.3 m	5.5 m	Control	4.3 m	5.5 m
2007	88 (1.7)	68.4 (3)	61.8 (2.4)	5223 (88)	514 (22)	394 (12)	759 (88)	208 (22)	159 (12)
2012	84.1 (1.8)	72.3 (2.5)	65.7 (2.9)	5638 (111)	560 (25)	452 (18)	1117 (111)	371 (25)	286 (18)
2018	92.2 (1.2)	84.2 (2.7)	83.2 (2)	6282 (225)	818 (34)	929 (28)	1745 (225)	505 (34)	453 (28)

as the limiting factor. These results provide a quantitative forage value to compare between treatment alternatives, and should not be interpreted as an absolute representation of how many deer a stand supports (Hanley et al. 2012).

We used the FRESH-Deer model to calculate deer days for all units in two summer and six winter scenarios. In the summer scenarios, the model uses all available understory biomass but different metabolic requirements, with one assuming a solo female (maintenance) and the other assuming a mother with a fawn (maintenance + lactation). In the winter scenarios, forage nutritional values reflect only the plant biomass that persists through the winter and that remains unburied by snow, and the metabolic requirements are changed to represent deer winter needs. FRESH-deer uses a nonlinear relationship between canopy cover and forest floor snow depth to determine forage availability; we modeled six snowfall scenarios ranging from 0 to 100 cm to demonstrate a range of winter forage conditions based on snowfall. We use "deer forage" as the integration of edible understory biomass and nutritional content, as represented by FRESH deer days ha^{-1}. Treatment effect on deer forage in each scenario was assessed using the mixed-effects modeling procedure described above.

Results

Overstory context

Treated units were thinned to 4.3-m and 5.5-m spacing (549 and 332 trees ha^{-1}, respectively). Five years after treatment (in 2007), treated units were still within 20 percent of target tree densities (Table 2); by 16 years after treatment (in 2018), units increased to 49 percent and 180 percent more trees than initial prescriptions in the 4.3-m and 5.5-m treatments, respectively. Despite the large difference in tree density growth between the 4.3-m and 5.5-m treatments, mean SDI growth from year 5 to 16 was nearly identical (increased by 300). The misalignment between density growth and SDI growth across treatments shows that the 5.5-m treatment was inundated with ingrowth (primarily western hemlock), which was less present in the 4.3-m treatment. Ingrowth also occurred in the control treatment, where the increase in SDI was 3.3 times what we observed in treated units because of the large number of saplings already present. Overall, large changes in tree densities resulted in minor increases to the already high canopy cover in the control. The slight canopy cover differences between 4.3-m and 5.5-m treatments in 2007 disappeared by 2018 owing to growth that increased with treatment intensity, but both treatments still had noticeably more open canopies than the controls in the final measurement.

Understory biomass and composition

Total understory biomass varied by treatment and year (Fig. 3). Biomass in thinned units was approximately 1 metric ton ha^{-1} in 2007, with less in subsequent years, but lowest in 2012 (10 years after treatment; Table 3; $p < 0.001$). Crotteau et al. (2020) identified that annual states of understory biomass in southeast Alaska are sensitive to both exogenous (climatic) and endogenous (stand density) influences, which explains some of the variation along the y-axis in Figure 3. In this analysis, we found that total understory biomass was consistently three to six times greater in the thinned units than the controls ($p < 0.001$). Total biomass varied by thinning treatment intensity (i.e., was greater in 5.5-m than 4.3-m treatment) in 2007, but not in 2012 or 2018 ($p < 0.01$).

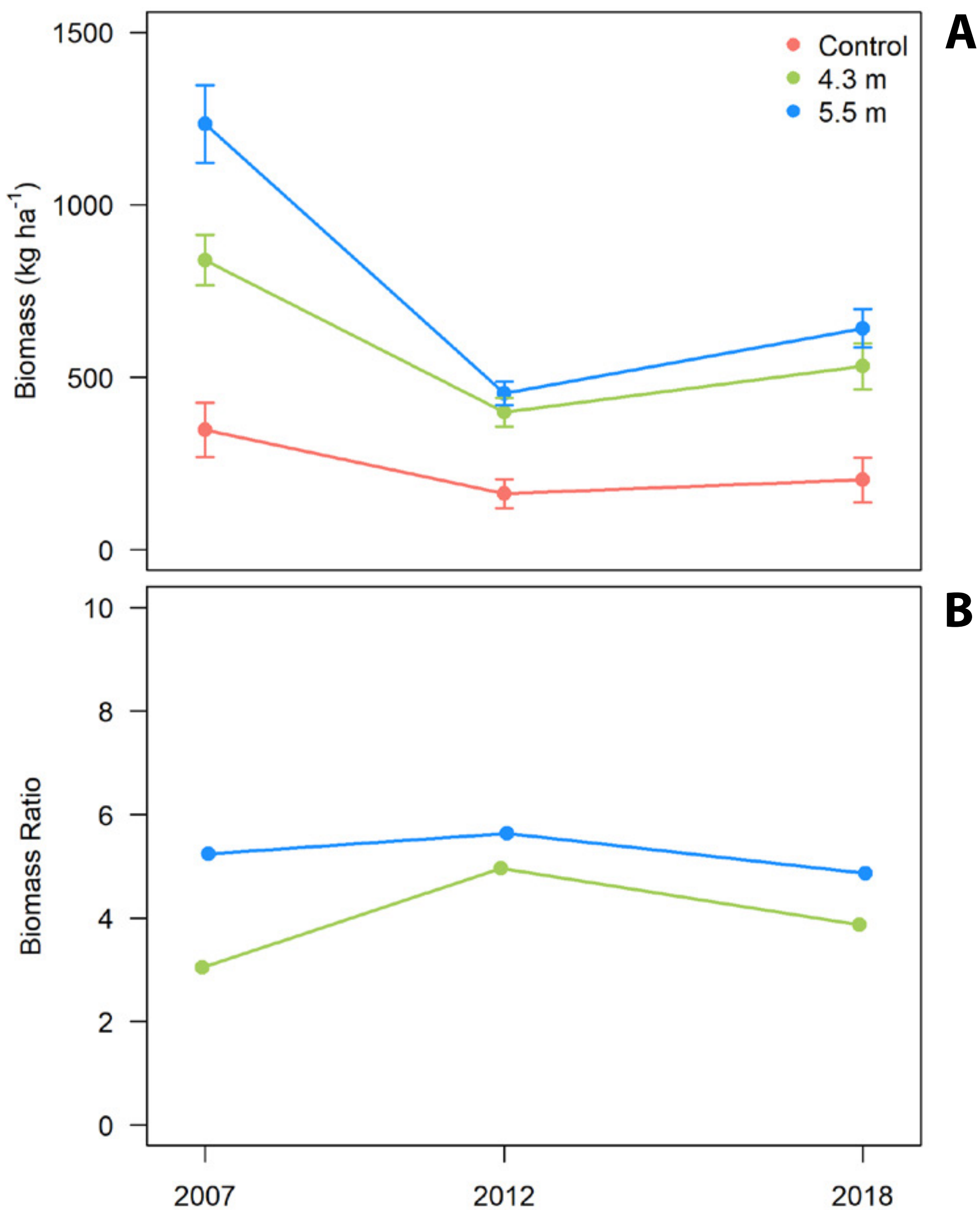

Figure 3.—Total nonwoody understory biomass dynamics in the TWYGS Experiment 2. Stands were precommercially thinned to 4.3-m or 5.5-m in 2002. Fig. 3A shows the total (nonwoody) understory biomass (kg ha^{-1}) from each of three treatments, including the control; Fig. 3B shows the median ratios of biomass in the thinned units relative to the control unit.

Table 3.—Treatment effects on understory biomass by functional class in the Tongass-Wide Young-Growth Studies Experiment 2 (TWYGS 2). Stands were treated in 2002 then measured in 2007 (visit 1), 2012 (visit 2), and 2018 (visit 3). Contrasts were defined as a priori orthogonal linear contrasts within fitted mixed-effects linear models of treatment on square-root transformed understory biomass. Statistical effects are displayed by direction ("+" for positive, "-" for negative) and strength of effect ("+++" = P ≤ 0.01, "++" = 0.01 < P-value ≤ 0.05, "+" = 0.05 < P-value ≤ 0.10, and [blank] for P-value > 0.10).

Contrast	Group mean tested (+)	Group mean tested against (-)	Total	Graminoid	Forb	Fern	Shrub	Tree
Early effect	visit 1	visit 2	+++	+	+++	+++	+++	+++
Late effect	visit 3	visit 2	+++					+++
Overall thinning	Treated (4.3 and 5.5 m)	Control	+++	+++	+++	+++	+++	+++
Overall thinning × early effect	Treated vs. control, in visit 1	Treated vs. control, in visit 2	+++				+++	
Overall thinning × late effect	Treated vs. control, in visit 3	Treated vs. control, in visit 2						++
Thinning intensity	5.5 m	4.3 m		+++				++
Thinning intensity × early effect	5.5 vs. 4.3 m, in visit 1	5.5 vs. 4.3 m, in visit 2	++		++			
Thinning intensity × late effect	5.5 vs. 4.3 m, in visit 3	5.5 vs. 4.3 m, in visit 2				+		

Table 4.—Percentage cover of dominant understory species in the Tongass-Wide Young-Growth Studies Experiment 2 (TWYGS 2). Stands were treated in 2002. "Dominant" refers to species that comprise at least 10 percent of the total understory composition within each treatment (Control, 4.3 m overstory spacing, and 5.5 m overstory spacing) and measurement year (2007, 2012, and 2018).

	Control			4.3 m			5.5 m		
	2007	2012	2018	2007	2012	2018	2007	2012	2018
Cornus canadensis							9.9		
Vaccinium ovalifolium	9.2	4.3		18.6	13.8	23.7	20.6	14.3	21.5
Menziesia ferruginea	5.2		3.7	7.4	7.9	17.3		8.0	16.6
Rubus spectabilis		3.1		12.1	7.6		13.6	10.8	12.2
Vaccinium parvifolium			2.5						
Tsuga heterophylla	4.9								

Understory biomass by plant functional type exhibited only minor variations from the observed total understory biomass trends (Table 3). Just as with total biomass, all functional classes had greater biomass in thinned units than controls ($p < 0.001$), and all classes had more biomass in 2007 than 2012 ($p < 0.05$). Like total biomass, forbs responded positively to treatment intensity in 2007, the positive treatment effect was greater on shrubs in 2007 than 2012, and trees had more biomass in 2018 than 2012 ($p < 0.01$). Unlike the trends we observed in total biomass, however, there were positive thinning intensity effects on graminoid and tree biomass throughout, as well as on ferns in 2018, and 2018 thinning intensity effect on trees was greater than 2012 ($p < 0.05$).

Typical dominant species in thinned units were *Vaccinium ovalifolium*, *Menziesii feruginea*, and *Rubus spectabilis* (Table 4). *V. ovalifolium*, which reached upwards of 20 percent cover by 2018, is an especially important understory plant as it provides both palatable leaves and twigs as well as carbohydrate-rich berries eaten by nearly all local wildlife. Dominant vegetation was very similar across thinned treatments, though the evergreen *Cornus canadensis* comprised a notable portion of the 5.5-m treatment understory in 2007, 5 years following treatment. The control treatment was sometimes characterized by other dominant understory species, such as *V. parvifolium* and *Tsuga heterophylla*, but no dominant species ever had greater than 10 percent cover in any measurement year.

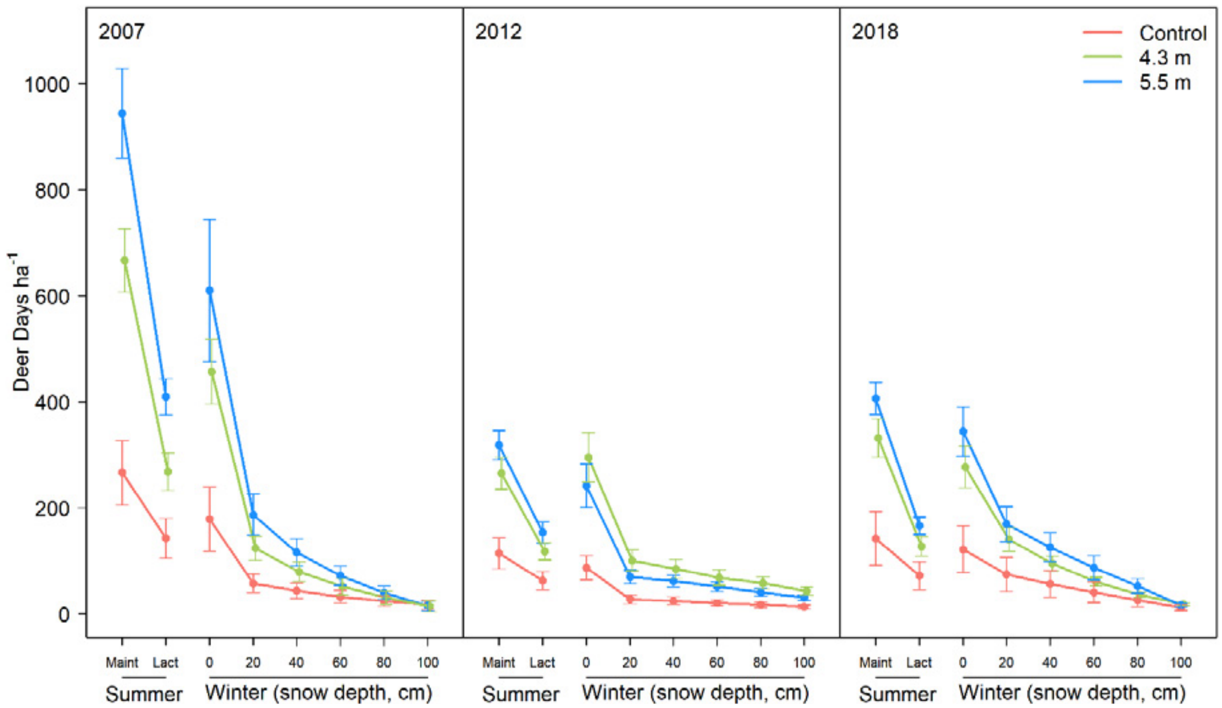

Figure 4.—Deer forage (i.e., deer days ha^{-1}, as defined by Hanley et al.'s (2012) FRESH-deer model) for two summer and six winter scenarios in the Tongass-Wide Young-Growth Studies Experiment 2. Stands were precommercially thinned to 4.3-m and 5.5-m in 2002 then measured in 2007 (visit 1), 2012 (visit 2), and 2018 (visit 3). Summer scenarios include single doe maintenance (Maint), and lactating doe (Lact); winter scenarios include maintenance given snow depths of 0 cm, 20 cm, 40 cm, 60 cm, 80 cm, and 100 cm.

Deer forage

Deer forage exhibited substantial variability across the combinations of treatment, measurement year, and FRESH-deer scenario, ranging from 944.5 deer days ha^{-1} in the 5.5-m treatment in 2007 to only 12.3 deer days ha^{-1} in the control in 2018 (Fig. 4). Deer forage in lactation scenarios was on average 56 percent lower than single fawn maintenance scenarios, according to increased nutritional needs. Additionally, available deer forage declined rapidly with snowfall; 100 cm of snowfall left just 7 percent of winter forage accessible to deer. Yet, available deer forage in thinned units was always significantly greater than the controls ($p \leq 0.001$), except for in the 80- and 100-cm scenarios in 2007 (Table 5). There were some variations in deer forage over time, likely as a result of the climatological factors that caused 2012 plant biomass to be low (i.e., cool temperatures or low precipitation). This resulted in a greater effect of thinning in 2007 than 2012 on summer forage ($p < 0.01$), and greater effect of thinning in 2018 than 2012 for half of the winter scenarios and the summer lactation scenario ($p < 0.05$). Although we observed differences in understory biomass owing to thinning intensity, the deer forage data show no evidence of significant differences between the 5.5-m and 4.3-m thinning treatments (Table 5).

Discussion

This study reveals long-term understory dynamics following treatments designed to simultaneously develop timber and deer forage, and notably demonstrates the long-lasting, biologically significant benefits of thinning on understory development. Our 16-year analysis of TWYGS Experiment 2, precommercial thinning in 15- to 25-year-old stands, revealed that understories behaved dynamically following treatment, but generally followed a predictable pattern, and differences between treatments were relatively stable over time. Overall,

Table 5.—Treatment effects on deer forage for two summer and six winter scenarios in the Tongass-Wide Young-Growth Studies Experiment 2 (TWYGS 2). Stands were treated in 2002 then measured in 2007 (visit 1), 2012 (visit 2), and 2018 (visit 3). Contrasts were defined as a priori orthogonal linear contrasts within fitted mixed-effects linear models of treatment on deer forage (i.e., deer days ha^{-1}, as defined by the FRESH-deer model (Hanley et al. 2012). Statistical effects are displayed by direction ("+" for positive, "-" for negative) and strength of effect ("+++" = P ≤ 0.01, "++" = 0.01 < P-value ≤ 0.05, "+" = 0.05 < P-value ≤ 0.10, and [blank] for P-value > 0.10).

			Summer		Winter					
Contrast	Group mean tested (+)	Group mean tested against (-)	Maintenance	Lactation	No Snow	20cm	40cm	60cm	80cm	100cm
Early effect	visit 1	visit 2		+++	+++	+++			---	---
Late effect	visit 3	visit 2	++			+++	+++			---
Overall thinning	Treated (4.3 and 5.5 m)	Control	+++	+++	+++	+++	+++	+++	+++	+++
Overall thinning × early effect	Treated vs. control, in visit 1	Treated vs. control, in visit 2	+++	++					--	---
Overall thinning × late effect	Treated vs. control, in visit 3	Treated vs. control, in visit 2		+		++	+		+	
Thinning intensity	5.5 m	4.3 m								
Thinning intensity × early effect	5.5 vs. 4.3 m, in visit 1	5.5 vs. 4.3 m, in visit 2								
Thinning intensity × late effect	5.5 vs. 4.3 m, in visit 3	5.5 vs. 4.3 m, in visit 2								

understory biomass and deer forage decreased with time since thinning, with some variation likely owing to regional climatological drivers (Anderson et al. 1969, Crotteau et al. 2020). This decrease was expected because overstories have become denser as crowns expand upward and outward, and resources once available to the understory were increasingly used up by the more dominant overstory (Alaback, 1982a, Oliver and Larson 1996). Understory biomass in the untreated control was an order of magnitude less than expected for this stand age range given Alaback's research (1982a), which included woody understory biomass, but was similar to nonwoody biomass in untreated 38- to 42-year-old mixed alder-conifer stands in southeast Alaska (Hanley et al. 2006). As the canopy continues to close with overstory growth, we expect the understory in untreated controls to be further excluded in the next decade according to the competitive stand development trends identified by these studies.

The principal research question in this study was, what is the effect of thinning on the forest understory, and how long does that effect last? Our analysis revealed that thinning (1) increased understory biomass three to six times more in thinned than unthinned treatments; (2) changed species composition (higher cover by *V. ovalifolium*, especially); and (3) increased forage available to Sitka black-tailed deer (except for in the 80- and 100-cm snowfall scenarios at the first visit, 2007). Although 5-year results for this study were published, it was unclear if these trends would continue over the next decade (Hanley et al. 2013). In 16- to 17- year-old stands that were treated on nearby tribal land, Cole et al. (2010) found that post-thinning understory production exceeded baseline conditions for 7 years, after which understory biomass in thinned stands was still significantly greater than in unthinned stands. This study extended the findings from Hanley et al. (2013) and Cole et al. (2010), providing evidence for the longevity of precommercial thinning to produce and maintain understory biomass. We found that the proportion of biomass in thinned versus unthinned units has been stable across all three measurements. In this respect, treatment effectiveness has not diminished in 16 years. However, understory biomass composition is very important for biodiversity and forage mixing. Key understory species for deer forage include *Coptis aspleniifolia*, *Cornus canadensis*, *Rubus pedatus*, *Tiarella trifoliata*, and *Vaccinium ovalifolium*. Of these species, only

C. canadensis and *V. ovalifolium* attained at least 10 percent of total species composition, the former only breaching this threshold early in the 5.5-m treatment and the latter notably more abundant in the thinned units. FRESH-deer integrated cover with composition for deer forage. Although species assemblages within each of the TWYGS stands were far more complex than the simple dominant species listed in Table 4, our model analysis of forage suggested that assessment by dominant species was sufficient to identify the key differences amongst the treatments: namely, that there was much greater cover of one or two very important deer forage species in thinned treatments than unthinned treatments. Thus, abundance of *V. ovalifolium*, especially, may be a reliable indicator of deer forage habitat suitability in these young-growth stands.

This study also sought to examine whether residual tree spacing has an appreciable impact on understory vegetation. We identified some limited differences in understory between 4.3-m and 5.5-m spacing, and they changed with time. The 5.5-m spacing treatment had greater graminoid and tree biomass throughout the measurements, but by 16 years also had greater fern biomass. Yet, shrubs dominated composition in both treatments, which led to the lack of significant difference in deer forage between thinning treatments. It is not surprising that we found no significant difference in deer forage between active thinning treatments given the similar spacing prescriptions. Post-treatment overstories in these treatments were strikingly similar compared to the control—9.8 percent (4.3-m treatment) and 7.5 percent (5.5-m treatment) of control tree density (overstory trees ha^{-1}) in 2007. Other studies have similarly found minor thinning variations do not make as much of a difference as thinning itself, or stand age at treatment (Cole et al. 2010, Zhang et al. 2013). One of the management implications for this finding is that the wider 5.5-m spacing is not recommended for future treatment, as it is more expensive to implement, detrimental to timber quality because it promotes larger knots and more juvenile wood, and produces no detectable benefits to deer forage. The 4.3-m spacing accomplishes as much understory benefit for reduced investment and greater yield.

SCIENCE-MANAGEMENT PARTNERSHIP

Long-term silvicultural experiments like this require committed collaboration between managers and scientists. The multi-decade TWYGS partnership between the Tongass NF and the Pacific Northwest Research Station enabled stakeholder-driven problem identification, rigorous experimental design, regular monitoring and upkeep, scientific analysis, and an open channel for communication of results and future needs. The longevity of the program grew, in part, from the research-management partnership. This co-production model of science supports land management decisions and brings together specialists with complementary skills to answer questions neither could answer alone, ultimately producing knowledge critical for complex land management decisionmaking (Enquist et al. 2017).

The TWYGS partnership was established as a vehicle for adaptive forest management to examine a dominant uncertainty facing the Tongass NF, namely, balancing multiple uses in developing young-growth forests. The partnership acknowledges differing skills and interests between personnel in research and management, uniting them to examine long-term questions of interest to both parties. As the partners monitor and learn from varied young-growth strategies, the growing body of knowledge will facilitate adjustments to future silvicultural prescriptions to yield both timber and wildlife habitat, while contributing to the broader knowledge of coastal rainforest dynamics. The focus on a dominant uncertainty—a difficult science and management conundrum—is a key element of adaptive management, which includes the iterative cycle that begins with assessing the uncertainty, designing a treatment focused on the specifics of that uncertainty, implementing an experimental design, monitoring outcomes, evaluating results, adjusting management treatments, and repeating (Nyberg 1999). In fact, the personal observations from the TWYGS experiments recently contributed to significant land management decisions. Managers on the Tongass NF used evidence from TWYGS to adjust precommercial treatments in at least three ways. First, Experiment 3 suggested that pruning may be valuable for both wildlife and wood quality, so pruning has been implemented more rigorously in subsequent treatments. Second, the implementation of Experiment 4 revealed that slash treatment (i.e., bucking felled trees to be left on site) was too expensive to put into practice. And third, many trees girdled in Experiment 4 quickly snapped at the girdle point because of the double-cut chainsaw technique used. Managers continue to prescribe girdling, but now specify a technique that shaves off the bark rather than cuts into the wood to improve snag stability. As the TWYGS experiments mature, we expect the research-management partnership will continue to provide practical insights that refine forest practices according to the adaptive management cycle on the Tongass NF.

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Effects of Thinning and Prescribed Fire in the Goosenest Adaptive Management Area in Northeastern California

Martin W. Ritchie[1]

ABSTRACT.—The Goosenest Adaptive Management Area was established in 1994 on the Klamath National Forest with the intent of evaluating late-successional forest characteristics. A large-scale experiment was established in the late 1990s to evaluate a range of management strategies. Treatments include combinations of mechanical thinning and prescribed fire. Observations 6 and 14 years after establishment were analyzed to evaluate effects on large tree component of the stand as well as species distribution and coarse woody debris. Thinning treatments accelerated growth of retained trees and modified proportion of ponderosa pine due to two factors: high levels of ponderosa pine mortality in control treatments, and the effects of group-selection plantations. Two applications of prescribed fire had little effect on stand structure and species distribution but did influence surface fuels >3 inches in size. Current rates of growth suggest that longevity of these treatments is on the order of 20 years.

INTRODUCTION

In response to difficulties encountered managing forests of the Pacific Northwest, a large scale assessment effort was conducted in the early 1990s by the Forest Ecosystem Management Assessment Team (FEMAT) with a focus on lands managed by the USDA Forest Service and U.S. Bureau of Land Management (USDA and USDI 1993). The resulting Record of Decision for the Northwest Forest Plan (USDA and USDI 1994) relied on adaptive management as one key facet of a comprehensive plan for this region. A network of 10 adaptive management areas (AMA) in forests within the range of the northern spotted owl (*Strix occidentalis caurina*) were established with the intent of providing an opportunity to learn how to improve ecosystem management in forests managed by the Forest Service and the Bureau of Land Management. Among these is the 173,000-acre Goosenest Adaptive Management Area (GAMA) on the Klamath National Forest in northeastern California. The stated emphasis for GAMA was: *"Development of ecosystem management approaches, including the use of prescribed burning and other silvicultural techniques, for management of pine forests, including objectives related to forest health, production and maintenance of late-successional forest and riparian habitat and commercial timber production"* (USDA and USDI 1994, page D-14).

A study was implemented with a range of treatment intensities to address the overall goals of the AMA designation in the late 1990s. The purpose of this paper is to evaluate the results of this study as they relate to conifer species distribution, recruitment of large trees, and surface fuel accumulation 14 years after treatment.

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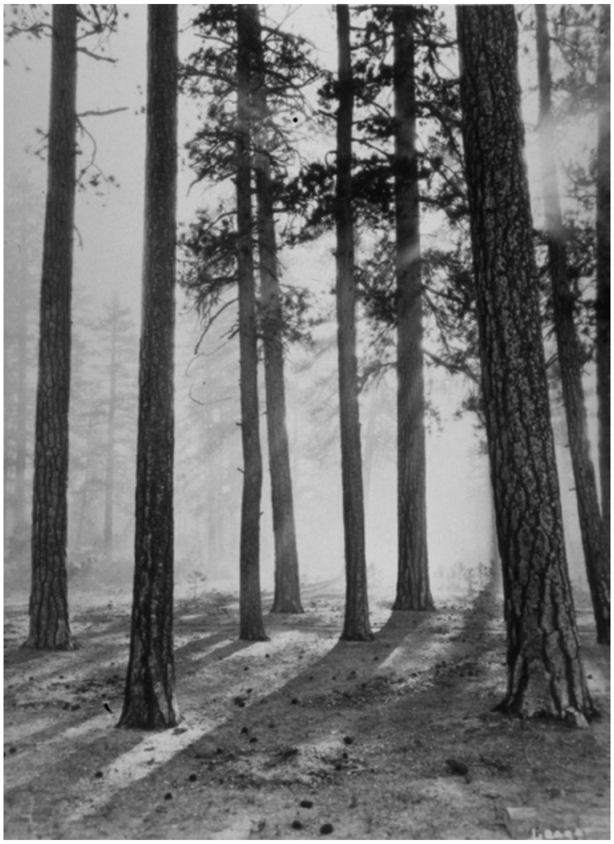

Figure 1. —Photo of stand in the Goosenest region ca. 1920 prior to harvest. Photo by USDA Forest Service.

STUDY AREA

Prior to European settlement, conditions for this region of northern California were influenced by the presence of frequent low-intensity wildfire (Skinner and Taylor 2006). This tended to produce open stands (Fig. 1) with many large diameter ponderosa pine (*Pinus ponderosa*) trees (Laudenslayer and Darr 1990). The forests of GAMA were harvested by Long-Bell Lumber Company in the 1920s and 1930s, removing much of the ponderosa pine while leaving behind sub-merchantable and cull pine and other less favorable trees, primarily white fir (*Abies concolor*). The Forest Service subsequently acquired these cut-over lands.

In the decades since first harvest, these formerly pine-dominated forests regenerated with stands heavy to white fir—about 60 percent by basal area. The next most common species is ponderosa pine. Other species encountered occasionally throughout the study area are incense-cedar (*Calocedrus decurrens*) and, at higher elevations, red fir (*Abies magnifica*), sugar pine (*Pinus lambertiana*), and lodgepole pine (*P. contorta*). But in general, these stands can be considered a two-species mix, white fir and ponderosa pine, with a minor component of other conifers.

By the time Northwest Forest Plan (USDA and USDI 1994) was enacted, stand conditions could be described as overstocked second growth with a median relative density of 0.70 (range 0.5 to1.1) with an assumed limiting stand density index[2] (SDI) for ponderosa pine of 400 (Ritchie 2005). Limiting SDI is an average upper bound for this metric; published research on

[2] Stand Density Index (SDI) – An expression of relative stand density based on the predictable relationship between average tree size and trees per unit area in dense stands. This relationship, independent of both stand age and site quality, provides an excellent basis from which to develop an understanding of the competitive interactions between individuals in a population.

this maximum ranges from 365 in the presence of *Dendroctonus* bark beetles (Oliver 1995) to 450 (Long and Shaw 2005). Quadratic mean diameters ranged from 9.7 to 16.2 inches (for trees greater than 4.0 inches diameter at breast height (d.b.h.; measured 4.5 ft above ground). Large trees were observed to be sparse or non-existent and the diameter distribution exhibited large numbers of small trees (Ritchie 2005).

With the establishment of the AMAs, several management issues were defined for GAMA. Among these were (1) declining forest health due to high stand density and fir encroachment, (2) potential for extreme fire behavior due to high mortality and fuels accumulations and a past history of fire exclusion, (3) lack of late-successional conditions due to past harvest activity, and (4) a need to achieve sale quantity goals in the forest plan (USDA Forest Service, Klamath National Forest 1996).

In 1995, an interdisciplinary team of researchers from the Pacific Southwest Research Station and Humboldt State University, working with personnel from the Klamath National Forest, began designing a study at GAMA to investigate the effects of mechanical thinning and prescribed fire on an array of late-successional forest attributes related to late-successional forests (Oliver 2001, Ritchie 2005). Among these are: conifer species distribution, recruitment and retention of large diameter trees, and surface fuel levels. The research team considered potential for research was best in an area of mid-elevation with a potential for developing a commercial timber harvest. The study area selected is near Tenant, CA (41.563°, -121.858°) with elevation ranging from 4800 to 5800 ft. Slopes are gentle, generally <15 percent, with a northeasterly aspect.

METHODS

In order to foster evaluation across a number of disciplines, the team elected to implement large-scale treatments, 100 acres each plus a buffer. The buffer target was ~100 m but occasionally was less when other features like roads were limiting. A 328 ft (100 m) grid of sample points were surveyed, with acceptable error of 6 inches, into each 100-acre treatment unit with each grid point having a Universal Transverse Mercator (UTM) reference stamped on the monument. Cross-disciplinary data to be collected in the study could thus be spatially referenced. Treatment unit boundaries and grid points were established in 1995 and 1996 (Fig. 2). NEPA analysis and presale work was conducted in 1997.

Experimental Treatments

The research team developed a completely randomized design of four treatments including a control, with all treatments replicated five times: 20 total treatment units. The treatments were described in detail by Ritchie (2005) and are summarized here.

Treatment 1: Control

The Control treatment dictated that no active management (including salvage, sanitation, or fuelwood cutting) would take place within the treatment unit boundary. This is a treatment consistent with a passive management strategy allowing stand development to be dictated by current conditions and future disturbance events. Since this is a completely randomized design, the expectation is that the Control treatments should be consistent with the pretreatment conditions of the other treatments and this appears to be the case. For example, tests of pretreatment estimates of trees per acre and quadratic mean diameter were found to be consistent across treatments.

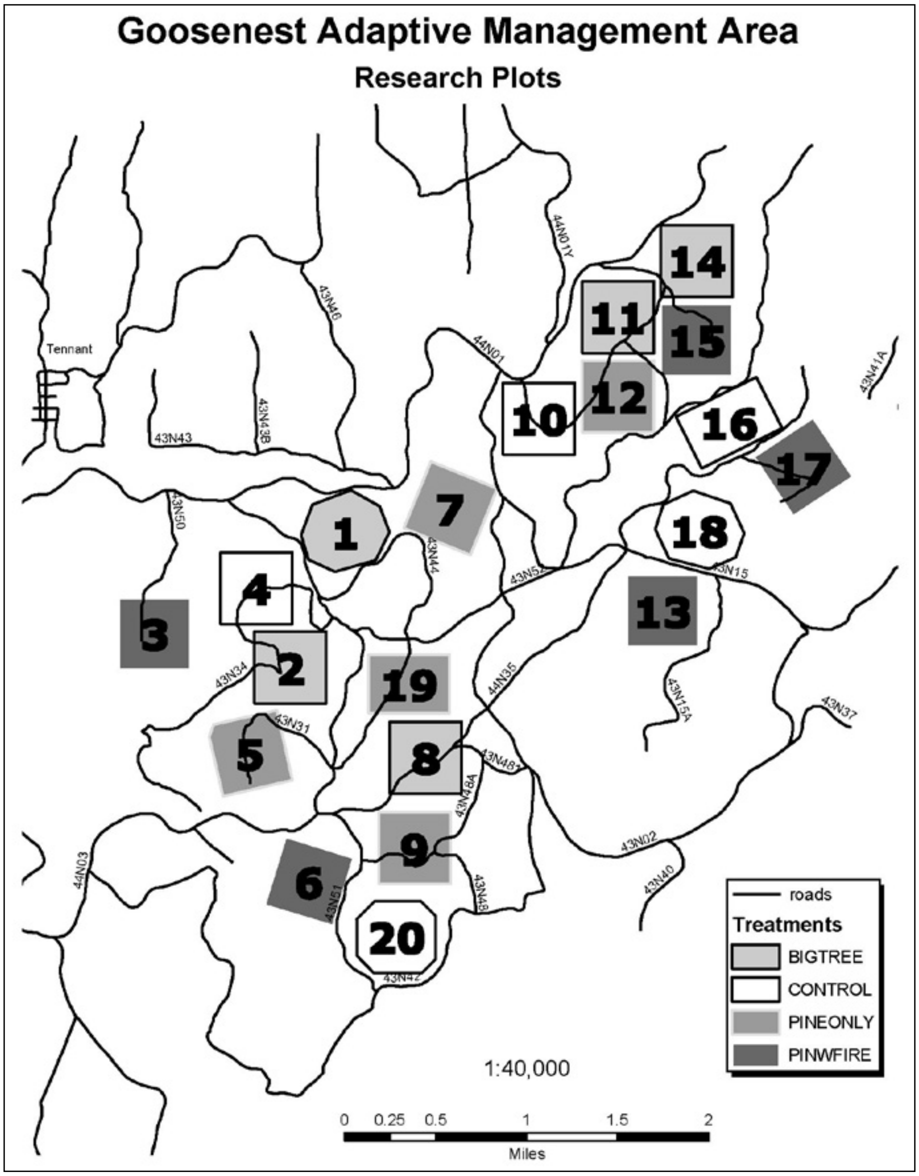

Figure 2.—Goosenest Adaptive Management Area treatment map. In the map legend, BIGTREE = Large Tree Emphasis treatment; PINE ONLY = Pine Emphasis treatment; PINWFIRE = Pine Emphasis with Fire treatment.

Treatment 2: Large Tree Emphasis

The Large Tree Emphasis treatment called for a thin from below with 18 to 25 foot spacing for dominant and codominant trees with no species preference. Whole-tree harvest was employed to reduce surface fuels. After harvest, all remaining trees <4.0 inches in d.b.h. were hand-felled with buck, lop, and scatter of tops and limbs. Treatment 2 should produce accelerated growth rate for trees and reduce tree mortality rates, as well as lower fire hazard due to reduced surface and ladder fuels. This treatment is similar in many respects to fuel reduction prescriptions commonly implemented throughout the Forest Service Region 5 (California) in recent years.

Treatment 3: Pine Emphasis

The Pine Emphasis treatment called for a thin-from-below process with a D+5 rule, subject to a retention guide for all dominant and codominant ponderosa pine >12-inch d.b.h., retention of all sugar pine and all incense-cedar >10-inch d.b.h.. The D+5 rule called for spacing (in feet), around retention trees as equal to d.b.h. + 5 so that a tree with a diameter of 16 inches would have a minimum radial release of 21 feet. After harvest, all trees <4.0 inches d.b.h. were hand-felled with buck, lop, and scatter of tops and limbs. In addition, because pine will not regenerate naturally under cover of fir, 15 percent of each Pine Emphasis area was subjected to group selection harvest with openings from 0.5–3.5 acre. Site preparation consisted of ripping with a winged subsoiler. Openings were then planted at 11-foot spacing with 2-0 bare root ponderosa pine seedlings between 2000 and 2002. In addition to increased growth and survival as well as reduced fire risk, this treatment should also produce the benefit of an increase the proportion of ponderosa pine and increase forest structural heterogeneity by developing a second age cohort.

Treatment 4: Pine Emphasis with Fire

The Pine Emphasis with Fire treatment is the same as Treatment 3, with the addition of the repeated application of prescribed fire. In addition to the anticipated benefits of Treatment 3, the presence of fire should further reduce surface and ladder fuels, increase crown base height, reduce the density of natural regeneration, and may also contribute to an increase in structural heterogeneity. Prescribed fire was applied in the fall of 2001 and then again 2010. During the first application of prescribed fire, the subsoil treatment effectively precluded fire damage to seedlings due to the lack of surface fuels. During the second prescribed fire entry, crews were directed to avoid entering the openings and generally the fuels were not sufficient to carry fire through the plantations.

Because of the scale of the project, mechanical treatments were implemented over a period of 3 years (1998-2000). Harvests removed a total of 68,000 green tons of biomass and 18 million board feet (MMBF) of saw logs for sale revenue of $5.5 million. The first post-treatment observations were made in 2002. The most recent observations were conducted in 2005 and again in 2013; these last two observations are evaluated in this paper.

Standing Trees

The sampling protocol for trees and snags employed a nested circular plot design centered on grid points at a spacing of 464 feet (every other grid point). Trees and snags >11.5 inches d.b.h. were measured on a 0.2-acre plot. Trees and snags >4.5 inches and ≤11.5 inches d.b.h. were measured on a 0.05-acre plot. All live seedlings (trees <4.5 feet in height) and saplings (trees with d.b.h. 0.0 to 4.5 inches) were tallied by species on a 0.01-acre plot.

In 2005, a total of 5,077 live trees were sampled along with 552 snags, 349 of which were in Control treatment areas. In 2013 a total of 5,310 live trees were sampled along with 551 snags, 351 of which were in Control treatment areas. There were a total of 360 plot measurements in both 2005 and 2013. The increase in number of sampled live trees is due to ingrowth.

Because one of the key questions is the longevity of treatments, stand density index (SDI) (Reineke 1933) was used to evaluate the trajectory of stands and the need for retreatment assuming a SDI upper limit of 400 with a management zone between 120 and 220 (relative density 0.30 to 0.55).

To evaluate change in the large tree component of these stands, we calculated the net change in number of large (>24 inch d.b.h.) trees. This analysis was augmented by fitting a peaking growth function for squared diameter increment on 4,566 repeat observations of ponderosa pine and fir trees >4.5 inches:

$$ln(bagrow) = \left(\beta_{00} + \beta_{01}I_s + \beta_{02}I_t\right) + \left(\beta_{10} + \beta_{11}I_s + \beta_{12}I_t\right)ln(DBH) + \left(\beta_{2i} + \beta_{2i}I_s\right)DBH^2 + \varepsilon$$

Where,

$ln(bagrow)$= natural log of basal area increment (square inches),

β_{ij} = parameters to be estimated,

I_s = Indicator for species, 1 for pine, 0 otherwise,

I_t = Indicator treatment, 1 for treated, 0 for control,

ε = model error term

This function is similar in form to that originally employed in the Forest Vegetation Simulator (Cole and Stage 1972, Stage 1973).

The contribution of ponderosa pine was calculated by basal area of pine expressed as a percentage of the total basal area.

Woody Debris

A 328 ft line-intercept transect was centered on each measured grid point (approximately 18 per treatment unit). Woody debris were sampled following the protocol of Brown (1971). Fuel pieces between 1 and 3 inches in diameter were sampled in a 12-foot section randomly located along the transect. Biomass of woody surface fuels >3 inches in diameter was calculated and compared among treatments. Sampled wood was characterized by decay class as an ordinal variable. Decay class 1 is primarily sound wood with little evidence of decay. Decay class 2 is wood with significant evidence of decay but still structurally sound. Decay class 3 is wood which has lost all structural integrity.

RESULTS

The focus of this analysis is the 8-year period (2005 to 2013). For convenience, these will be referred to as year 6 and year 14 since treatment establishment. Analysis of variance for a balanced design with five replicates of four treatments are presented.

Contrast in stand structure across treatments at year 14 shows the large differences in density among smaller trees, with much lower density among trees less than about 18 inches d.b.h. and a higher proportion of ponderosa pine, particularly in the pine emphasis treatments. Also evident is the early stages of ingrowth from the planted group selection openings in the Pine Emphasis and Pine Emphasis with Fire treatments (Fig. 3). At this age, the planted seedlings were just beginning to cross the 3.5-inch threshold for our larger plot samples. In the 2005 measurement, many of the planted trees were still below breast height (<4.5 inches in height).

SDI at age 14 shows that some treated stands are at or above the upper limit of the management zone (Fig. 4). Untreated stands remain clustered near the assumed maximum of 400 for pine. Ponderosa pine at SDI above the upper management zone of 220 are at high risk of bark beetle-induced mortality (Fettig 2012, Oliver 1995).

One of the objectives of the research was to evaluate the recruitment of large trees over time. An evaluation of the number of trees >24 inches d.b.h. reveals no difference among treatments in this metric (P=0.42) in the growth period between year 6 and 14 (Fig. 5), although there is evidence of a slight increase in the treated units.

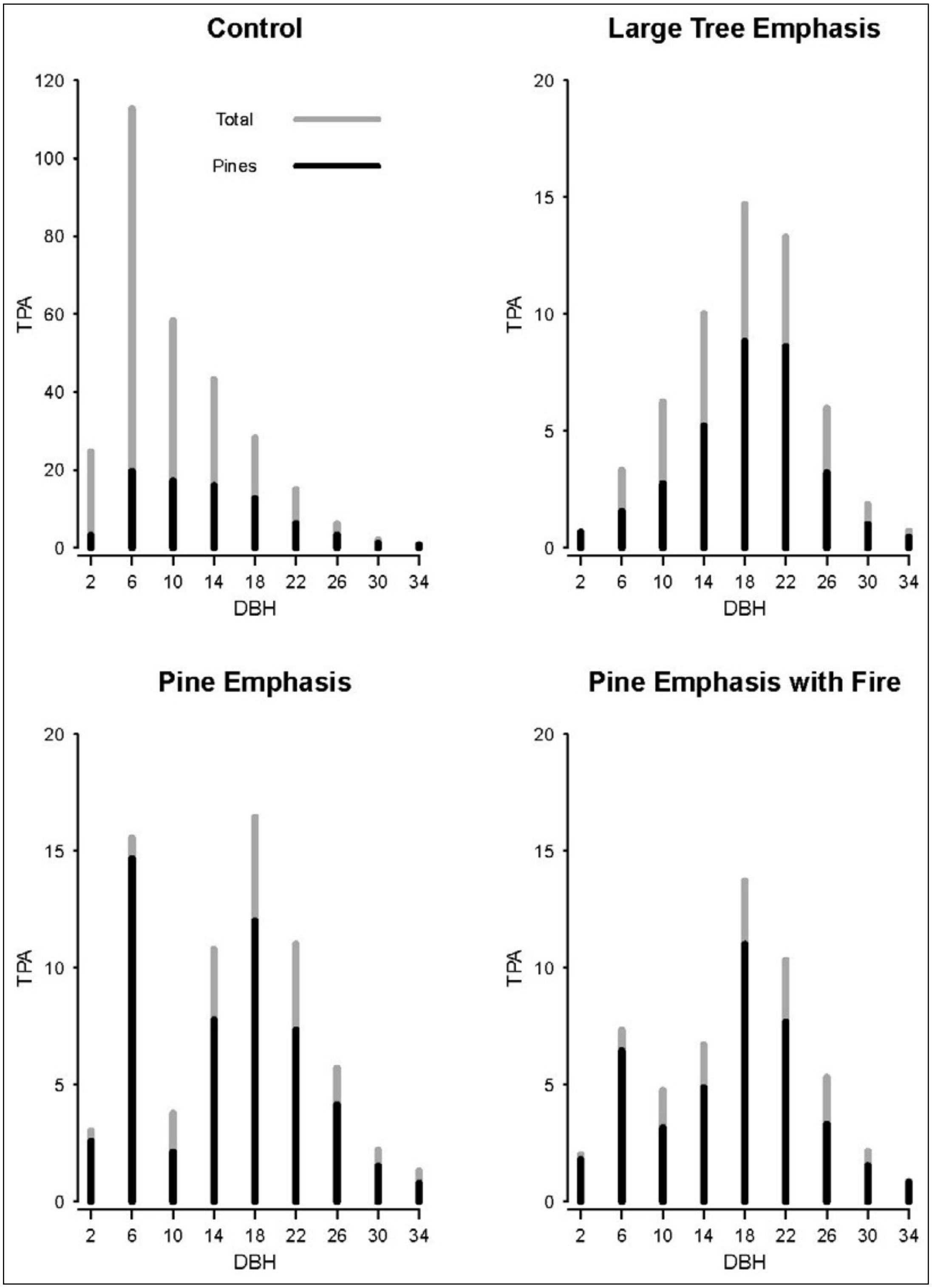

Figure 3. —Composite diameter (DBH) and density (TPA) distributions by treatment in 2013, approximately 14 years since treatment installation. DBH = diameter at breast height, in inches, and TPA = trees per acre. Pine group (darker portion of each bar) includes all pines and incense-cedar.

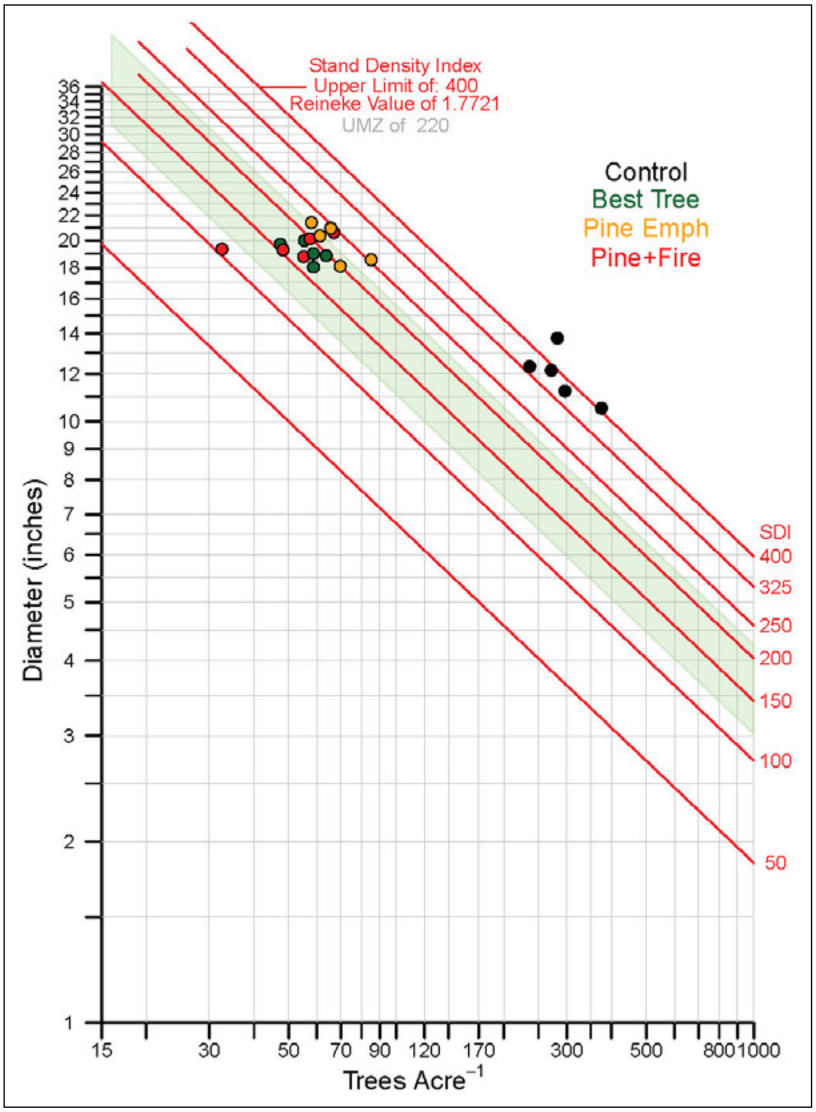

Figure 4. — Density management diagram (assume limiting SDI=400) with treatment plots at approximately 14 years post-treatment in the Goosenest Adaptive Management Area. UMZ = upper management zone. Green shaded area indicates the management zone between SDI=120 and 220.

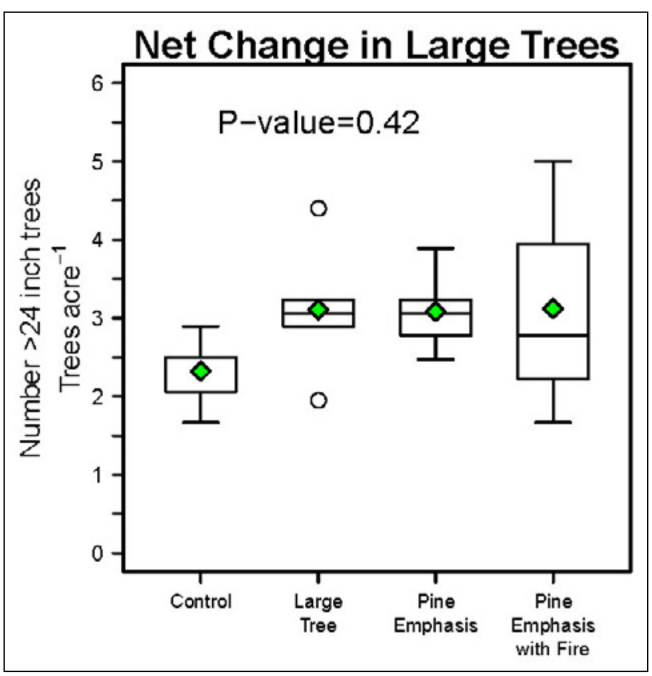

Figure 5. — The change in the density (trees per acre) of large trees (>24 inches d.b.h.) by treatment in the period between 6 and 14 years post-treatment. There is no apparent difference in number of large trees in any of the treatment areas.

Table 1.—Parameter estimates for 8-year basal area increment model for ponderosa pine and fir trees at the Goosenest Adaptive Management Area , where Y=ln(bagrow), and bagrow is individual tree basal area growth in square inches. Note the model is parameterized such that indicator variables are added for pine parameter differential and treatment parameter differential and intercept estimate is not corrected for log bias.

Term	Parameter	Estimate	S.E.	P value
Intercept	β_{00}	-1.34853	0.0805	<0.0001
	β_{01} (species=pine)	-0.81656	0.172	<0.0001
	β_{02} (treated)	2.17540	0.143	<0.0001
ln(DBH)	β_{10}	1.84531	0.0401	<0.0001
	β_{11} (species=pine)	0.15325	0.0757	0.0430
	β_{12} (treated)	-0.58110	0.0510	<0.0001
DBH^2	β_{20}	-0.0008926	0.000111	<0.0001
	β_{21} (species=pine)	0.00005797	0.000149	0.6974
RMSE		0.516		

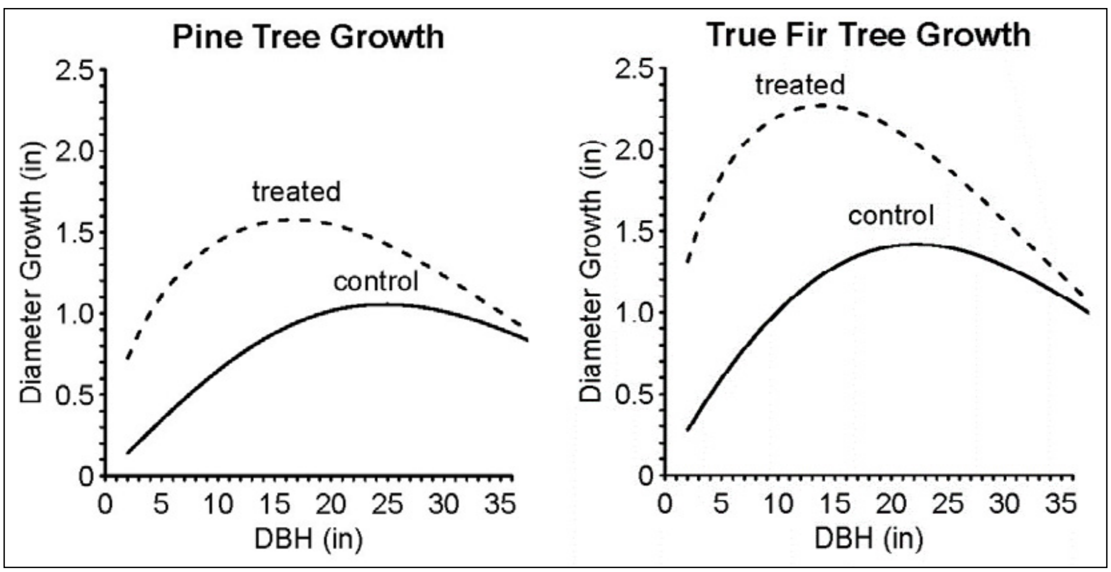

Figure 6. —Tree diameter growth model for ponderosa pine (A) and true fir (B) for the period 6 to 14 years post-treatment, at the Goosenest Adaptive Management Area. The two lines in each graph contrast the five control plots with the treated units.

The fitted individual-tree growth model reveals that fir trees are growing faster than pine trees at GAMA (Table 1), and that treated units had greater growth than controls (Fig. 6). Eight-year increment for white fir peaked at 2.3 inches (0.29 inches yr^{-1}) in treated stands versus 1.4 inches (0.18 inches yr^{-1}) in untreated stands. In similar fashion, pine increment in treated areas peaked at about 1.6 inches (0.20 inches yr^{-1}) while untreated pine peaked at approximately 1.0 inch (0.13 inches yr^{-1}). When a term was added for the effect of fire on the intercept and log of diameter, the influence was minimal (P=0.48 and 0.42, respectively).

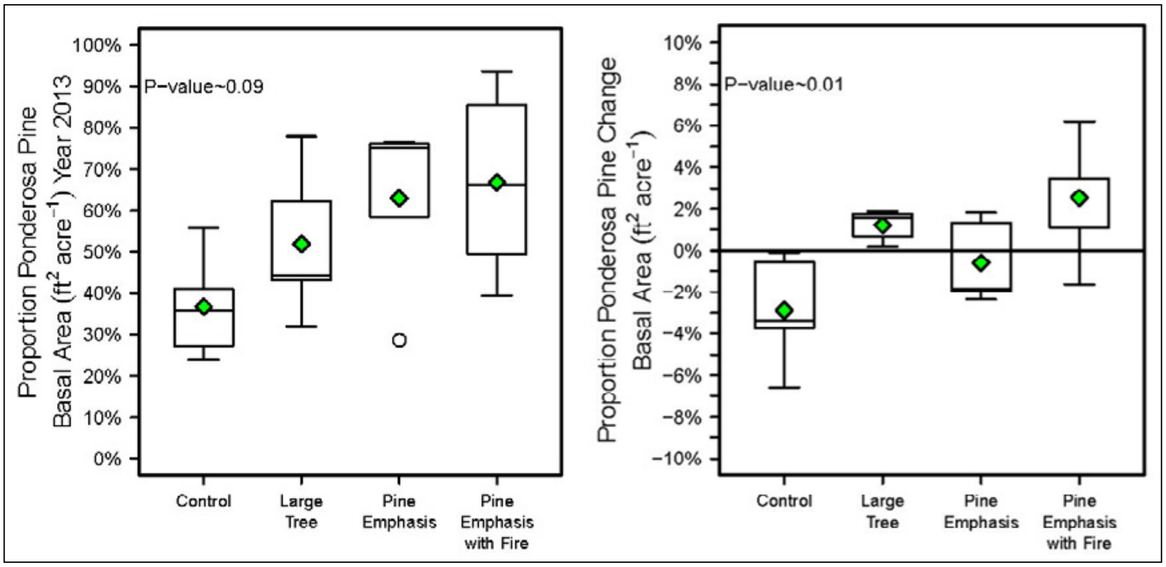

Figure 7. —Proportion of ponderosa pine (A) and the change in ponderosa pine proportion (B) for the period 6 to 14 years post-treatment, Goosenest Adaptive Management Area.

The most recent observation shows a marginal difference (*P*=0.09) in proportion of ponderosa pine by basal area. However there is strong evidence of a treatment effect on the periodic change in species proportion with the control units appearing to lose proportion of pine over the previous 8 years (Fig. 7). This is due primarily to accelerated rates of pine mortality in the controls. As shown in Figure 4, the controls are at or near the limiting SDI for pine and these units lost, on average about 28 trees acre^{-1} in 8 years while the Large Tree Emphasis treatment held steady. In contrast, the Pine Emphasis and Pine Emphasis with Fire treatments both gained trees (19 acre^{-1} for Pine Emphasis and 12 acre^{-1} for Pine Emphasis with Fire) and this gain is in evidence in Figure 3; it appears to be primarily in the smaller diameter classes, which at this time have little in terms of basal area but high numbers of stems in the plantations. The group selection plantations are beginning to be picked up by our sampling methods more efficiently as trees cross the 3.5-inch threshold and have a higher probability of sampling.

Analysis of variance of coarse woody debris by decay class (Fig. 8) demonstrates there is little influence of any treatments on sound wood (decay class 1) at GAMA (*P*=0.42). However there is an impact of our treatments on wood with a more advanced state of decay. Thus prescribed fire was effective in reducing some fuels in the short term, but it may take repeated entries to have a more profound effect on accumulations of sound wood. There is also some evidence of a reduction in decay class 3 in Pine Emphasis Treatments, where prescribed fire was not implemented.

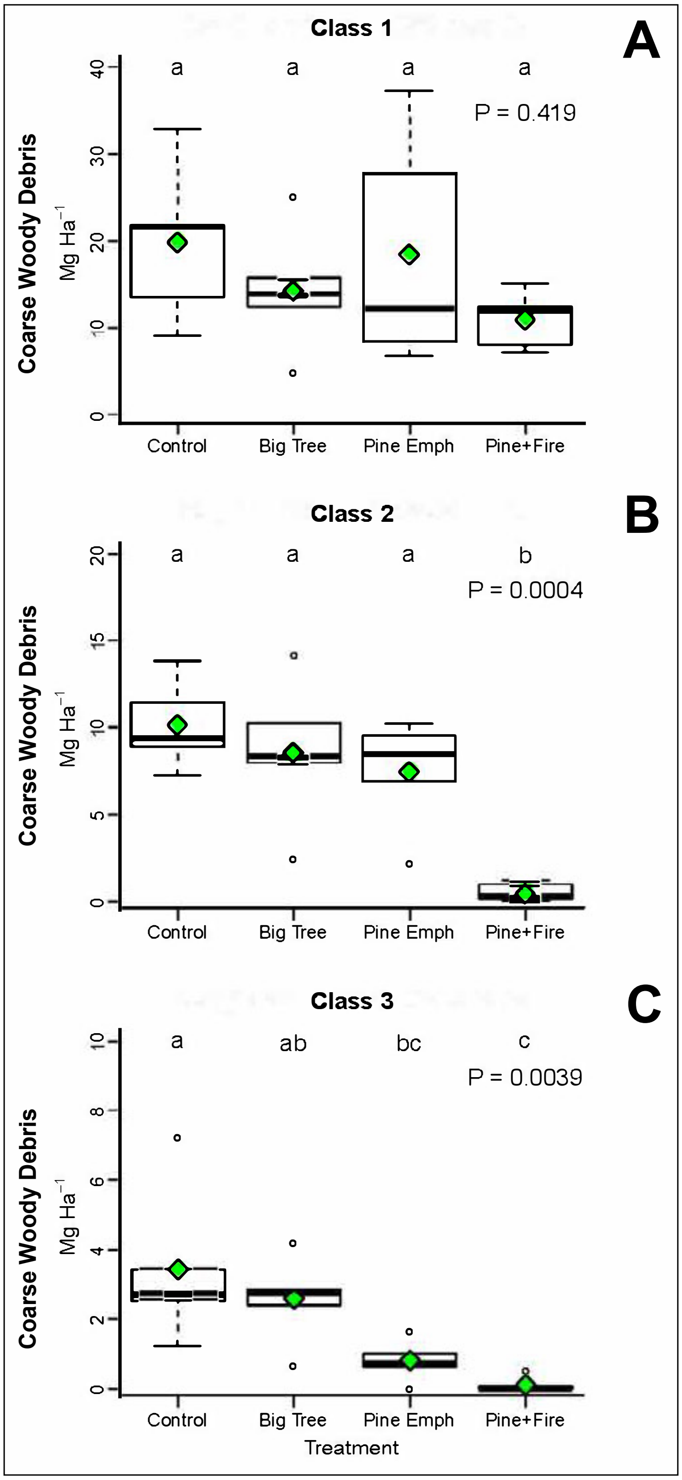

Figure 8. —Coarse woody debris (>3 inch) by decay classes 1 (A), 2 (B), and 3 (C), 14 years post-treatment, Goosenest Adaptive Management Area. Different letters that appear at the top of the graph, above the bars, indicate significant differences.

DISCUSSION

The evaluation of the stands in the Goosenest AMA research project 14 years after treatment shows some evidence of development of the late-successional attributes. Trees have accelerated growth rates and ponderosa pine mortality has been greatly reduced in treated areas. Also, introduction of prescribed fire has reduced surface fuels, which should aid in fire resilience. Despite the increase in growth rates, the recruitment of large trees (>24 inches d.b.h.) has not yet occurred. Developing a greater number of large trees is a long-term problem in second growth stands, there is no quick fix. Given the age of the stands (about 80 years old) this is not all that surprising. Given the diameter distribution and current growth rates, it is likely that we will see evidence of an increase in number of trees >24 inches 20–25 years post-treatment. The growth advantage of white fir over pine is one other factor contributing to the ability of fir to dominate these sites. The growth rate difference between species suggests a competitive advantage for fir at this site. To the degree that prescribed fire can disproportionately remove white fir regeneration, it will provide a long-term advantage for ponderosa pine.

The Pine Emphasis treatments, both with and without fire, have influenced the species distribution and this will continue due to the rapid development of the planted group selection openings. Advanced rates of pine mortality continue unabated in the controls due to the elevated density in these units which favors the continued dominance of fir. In contrast to elevated mortality in ponderosa pine, fir in the control units is surviving well. The control units have an SDI of about 400, a comfortable density for fir, which has a limiting density of about 800. But this is well above the zone of imminent mortality for ponderosa pine.

Unfortunately our sampling methods in the early stages of this study have a fixed-plot spacing of one plot every 5 acres and this is inadequate to really capture what is going on in the group selection units as most of the groups are not sampled. We will need to augment sampling by stratifying the plantations and sampling more intensively in future measurement cycles. The sector sampling method of Iles and Smith (2006) seems like a promising approach to this problem. Sector sampling is an innovative approach to sampling small areas that is free from the liability of edge-effect sampling bias. We have initiated sector sampling in the 2019 measurement of the group selection units. We hope this allows for a more detailed and precise description of the changes in structure over time.

At the time of the most recent observations, there was little evidence of a prescribed fire effect on either rates of growth or species distribution of living trees. One area where the effects of prescribed fire can be seen is on the distribution of coarse woody debris. Prescribed fire has reduced the amount of surface fuels, particularly in the fuel with a more advanced state of decay. Stage 3 material is essentially at zero in areas with prescribed fire. This is consistent with the findings of other studies (e.g., Uzoh and Skinner 2009). Since much of the decay class 1 wood dates to a recent windthrow event, this material is at this time more impervious to the effects of prescribed fire because there hasn't been enough time for it to break down. With repeated applications of prescribed fire, we would expect even more effective fuel reduction in the future as much of this material reaches a more advanced state of decay. Anecdotally, it also appears that prescribed fire has had little impact on development of the shrubs, and this is likely due to the time of year that burning is conducted and the prescriptions that call for a cool burn. We might obtain a better result with a more consumptive prescription.

The elevated rates of pine mortality in the untreated units along with the superior observed growth of fir in all treatments underscores the challenge in managing for pine at GAMA. Historically ponderosa pine was able to overcome these disadvantages because of the influence of fire; a fire regime with frequent low to mid severity burns discriminated against fir. In the absence of this natural disturbance the ponderosa pine component will need assistance if managers wish to feature pine with the desired goal of creating stands with greater resilience to wildfire. Our current fire regime is one in which wildfire occurs more infrequently but with greater intensity. Prescribed fire may work well but it may be worth considering changing the prescriptions to allow for a hotter fire. This could produce a more effective reduction of fuels, fir regeneration, and the understory shrub component.

Our observed densities in the treated units 14 years after thinning suggest that we need to consider rethinning of these stands at the 20 year mark followed by a third prescribed fire application in the Pine Emphasis with Fire treatment. Given the current diameter distributions, we could consider a proportional thinning followed by another hand thinning of white fir saplings <4 inches d.b.h.. The Adaptive Management Area has approximately 111,000 acres of commercially viable timberland (USDA Forest Service, Klamath National Forest 1996). If this area were to be managed with a goal of achieving more fire resilient stands using treatments similar to those employed in this study with a 20 year re-entry schedule, it would require a management intensity of approximately 5,500 acres year^{-1} just to get these areas into a more resilient condition. If a similar volume recovery rate applied, this would produce 65 MMBF annually removed from the forests of the Goosenest Adaptive Management Area, just to maintain a resilient condition on these productive acres of the AMA.

A 20-year remeasurement of this study is underway in 2019 and this will help guide any decisions on future mechanical treatments and prescribed fire. Researchers hope to once again work with Klamath National Forest staff to develop prescriptions that will allow for the continuation of this study.

ACKNOWLEDGMENT

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CAPSTONE

Forest Management and Research Collaboration Today and in the Future: A Panel Discussion

Thomas M. Schuler and David Gwaze[1]

Co-Moderators

Thomas Schuler, National Program Leader for Silviculture Research, USDA Forest Service, Washington Office, Research and Development; and David Gwaze, National Silviculturist, USDA Forest Service, Washington Office, National Forest System.

Panelists:

- Nehalem Clark, Science Delivery Specialist, USDA Forest Service, Rocky Mountain Research Station
- Mark Bethke, Planning Director, USDA Forest Service, Intermountain Region
- Elizabeth Larry, Research Assistant Director, USDA Forest Service, Northern Research Station
- Jarel Bartig, Ohio Interagency Liaison, USDA Forest Service, Wayne National Forest
- Toral Patel-Weynand, Director of Sustainable Forest Management Research, USDA Forest Service, Washington Office, Research and Development
- Eric Davis, Assistant Director of Forest Management, USDA Forest Service, Washington Office, National Forest System

PANEL SUMMARY

Research and management collaboration is essential to address changing forest conditions across the United States and to deliver expected benefits of healthy forests to the public. Collaboration across the research and management mission areas in the USDA Forest Service occurs at the project, regional, and national levels, and addresses multiple challenges such as specific management needs, resource allocation, and strategic planning. An increase in collaboration internally and externally was recently called for in "Toward Shared Stewardship across Landscapes: An Outcome-Based Investment Strategy[2]" introduced by Forest Service Chief Vicki Christiansen and Secretary of Agriculture Sonny Perdue in 2018.

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[2] USDA Forest Service. 2018. Toward shared stewardship across landscapes: An outcome-based investment strategy. FS-1118. https://www.fs.usda.gov/sites/default/files/toward-shared-stewardship.pdf

Panelists were asked to share their insights about ongoing collaborations, with a focus on the science partner program from the intermountain west, leadership and project level successes in the eastern area, and national level projects. Two questions were asked of the panelists as follows:

Question 1: Please describe a successful research and management partnership that you were or are involved in and what contributed to the success? What were the challenges and what were the lessons learned?

There are many examples of Forest Service research scientists, managers, and program staff collaborating across the Eastern Region (R9) and Northern Research Station (NRS), shared by panelists representing the region. Panelists noted that the best projects are those where researchers and managers come together with shared context and purpose, and where they both take part in project design, implementation, analysis, and learning. This more naturally occurs when researchers are co-located with or near National Forests, when scientists and mangers are approachable and engaging, and/or when relationships engender respect and trust. However, place-based collaborations have limitations. Retirement projections are a concern and strategies are needed to mitigate the impact that anticipated retirements will have on long-term relationships. Another issue is that research scientists tend to remain in place for their career, whereas land managers tend to move to positions in new locations to advance professionally. This puts the onus of maintaining contacts in the hands of the research scientist, who must learn to value how building that relationship promotes not just the conduct of research but also the application of research in active land management decisions. In a long-term Ohio-based eco-mapping project, it took time to build relationships and find the most effective way to communicate. Lessons learned included using the relationship building as a time to learn about each other and to think more strategically.

To overcome the place-based model of success when potential partners are not located near each other, the science partner program in Rocky Mountain Research Station (RMRS) and the Intermountain Region (R4) actively pairs up scientists and managers to work on specific management-driven projects. Action plans are developed, meetings are facilitated, and travel funds are provided so that new partners can meet in the field or convene as a group. Annual workshops are held to share lessons learned, new knowledge, and form new partnerships. Leadership support for the science and management partnerships in R4 has been a critical part of the success. This new initiative benefited from modest funding to bring people together in person. There was also a willingness to try something different in R4 and RMRS. The result is better products from research and more effective management of National Forest System lands. The challenge is to sustain existing networks and continue to bring in new people to the collaborative groups. Another challenge is to be nimble enough to respond to management needs but to resist a significant change in focus without careful consideration (i.e., “the shiny object syndrome”).

The introduction of the California condor was presented as a model of a successful research and management collaboration, especially with respect to bringing in external partners to work with agency research scientists and land managers. Challenges included aligning different agencies and cultures, different federal and state legal requirements, and creating and maintaining a joint timeline for the project. The lessons learned included using each partner’s skills and abilities to supplement the strength of the team and to achieve the desired outcome. Another noteworthy national collaboration includes this forum, the National Silviculture Workshop, which brings together researchers and managers from national, regional, and forest-level offices across the nation. Lessons learned include the importance of a long-term approach to information exchange relevant to evolving high-priority forest management issues and the need to nurture the forest management and research partnership over time. The evolution of workshop themes over the last four decades outlines the changing priorities nationally. Current concerns include overcoming logistical hurdles and the time required to plan and implement a large national gathering.

Question 2: It is a given that strong relationships are needed to promote collaboration but what else is needed? What one or two changes do you recommend that can be implemented in the next two years and in the long-term to promote collaboration and change outcomes.

Panelists noted that there are often significant examples of science and management collaboration in each Region and Station despite the administrative, budget, organizational, and cultural differences between Forest Service mission areas. Supportive leadership is critical for facilitating how researchers and managers work together. Hiring, planning, budgeting, chartering new groups, and balancing the centralized versus the regionally autonomous nature of the agency are largely leadership dependent and are key to facilitating collaboration.

Specific suggestions by the panel to promote collaboration included:

1. Leadership must validate the investment needed to maintain and form collaborative efforts. Strategic communication, charters, and support for intra-agency personnel exchanges are some of the ways leadership can promote collaboration in the near term.

2. Utilize competitive funding models to encourage co-production of knowledge that is deemed a high priority by leadership such as the BeSmart program used in the Intermountain Region, a micro-grant program that that accepts proposals from scientists and managers working together and sets the stage for longer-term investments.

3. Continue the Regional Science Advisory Teams being piloted in Regions 1, 2, 3, and 4 with the Rocky Mountain Research Station. Science Advisory Teams include both scientists and regional staff, and report out to both Regional and Station leadership teams. These teams are envisioned as stable science consulting networks at a regional-level scale.

4. Hire and train with the intention to foster a culture of research and management collaboration. Identify candidates that will be more likely to embrace joint research and management problem solving. Train and inspire new line officers and scientists to look outside of their mission area for solutions and potential partners.

5. Recognize that collaboration takes place at local, regional, and national levels and take steps to enhance each platform and encourage networks amongst them. Add more bridge-building positions, liaison assignments, and temporary work details to help connect across Deputy Areas within the Forest Service and serve as points of contact with other external partners.

6. Identify collaboration success stories and feature them to share lessons learned at Region/Station meetings, Washington Office presentations, Capitol Hill visits, leadership training and forums, and training for new scientists and line officers.

7. Use subregional workshops as a feasible opportunity to learn from success stories, share new insights, identify problems, and build relationships. Participating in existing forest collaboratives can provide an effective pathway to better understanding the needs of diverse stakeholders and sharing relevant science. Use strategic planning to codify team charters, if needed, and use multi-year business plans to support them.

8. Fully credit researchers in their performance evaluations and panel reviews for management-oriented research to encourage them to collaborate with managers on research projects that directly influence land management. Re-introduce managers on scientist's performance evaluation panels.

9. Improve technical transfer of research results to managers. This may require science synthesis (short briefs for decisionmakers and managers), internal data sharing platforms, and pre-publication information.

CONCLUSION

It was clear in the panel that relationships built on trust and a common purpose are the foundation of successful and sustained research and management collaboration. Engaged leadership is essential for working through the associated challenges and supporting collaboration at national, regional, and local levels. The panel's recommendations should serve as a catalyst for further discussion in other venues about enhancing research and management collaboration. Our Agency's values remind us that our mission transcends fidelity to individual programs and directs us to find solutions that embrace collaboration with each other and the communities we serve. Our charge is to serve our conservation mission by always striving to be more inclusive in our approach and the service we provide to society.

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2017 WORKSHOP PAPERS

Connecting the Dots: Moving Frameworks for Ecosystem Services from USDA Forest Service National Programs to Forest and Project Scales

Robert L. Deal, Nikola Smith, and Joe Gates[1]

ABSTRACT.—The USDA Forest Service has been developing an ecosystem services framework to highlight forest values provided by public lands and to build partnerships with stakeholders to implement projects. In addition to describing ecosystem services provided by forest landscapes, this framework examines the potential tradeoffs among services associated with proposed management activities. This paper briefly describes results ranging from national programs to forest plan assessments to project scale applications that enhance the provision of ecosystem services and sustainable forest management at national to local scales.

OVERVIEW

Ecosystem services are increasingly recognized as a way of framing and describing the broad suite of benefits that people receive from forests. The USDA Forest Service has been exploring use of an ecosystem services framework to describe forest values provided by federal lands and to attract and build partnerships with stakeholders to implement projects. Recently, the agency has sought place-based applications of the ecosystem services framework to national forest managers to better illustrate the concept for policymakers, managers, and forest stakeholders. This framework includes describing the ecosystem services provided by forest landscapes, examining the potential tradeoffs among services associated with proposed management activities, and attracting and building partnerships with stakeholders who benefit from particular services forests provide. Projects that describe objectives and outcomes using an ecosystem services framework are quickly gaining support and could provide an optimal method of managing forests to better serve the needs of people while sustaining the integrity of ecosystems. We describe how project-scale guidelines can be designed to address commonly recognized products such as timber and clean water, as well as critical regulating, supporting, and cultural services. We present results from national programs, to forest plan assessments, to project-scale applications that enhance the provision of ecosystem services and sustainable forest management at broad to local scales.

NATIONAL PROGRAMS

Federal natural resource agencies are now required to address ecosystem services in planning and operations. The USDA Forest Service 2012 Forest Planning Rule now requires the agency to include ecosystem services in assessments and forest plan revisions. A 2015 Presidential memorandum directs all federal agencies in the USA to develop and institutionalize policies to promote consideration of ecosystems services in planning, investments, and regulatory

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policy. There is now a need to apply national policies and programs that integrate ecosystem services into local project implementation. We provide three examples that illustrate how ecosystem services can be integrated into current forest management and policy.

An example: How ecosystem services are incorporated into national USFS policy and operations was from the National Ecosystem Services Strategy Team (NESST). NESST was chartered by the Forest Service leadership to collaboratively develop national strategy and policy around ecosystem services and integrate them into Forest Service programs and operations. Major NESST objectives included articulating and demonstrating the relevance of an ecosystem services framework across the agency; developing formal policy and informal guidance to support an ecosystem services framework for federal, state, private, and tribal forest lands; building capacity and infrastructure across Forest Service Deputy Areas to manage forests for the enhancement of ecosystem service benefits; designing inventory methodologies and data management solutions to improve reporting and evaluating ecosystem service benefits; and fostering two-way communication inside and outside the Forest Service regarding how an ecosystem services framework can better support management objectives and improve outcomes.

NATIONAL FOREST PLANNING

A second example highlights how national forest plans can use an ecosystem services framework to both meet the requirements of the Forest Service planning rule and help the agency identify and clarify relationships between the conditions of forest ecosystems and the quality of services they provide. The Marsh and Drink project areas on the Deschutes National Forest (Oregon) and the Cool Soda Project on the Willamette National Forest (Oregon) are examples where an ecosystem services framework was used to consider a broad suite of values as well as tradeoffs resulting from management decisions. Silvicultural prescriptions are site-specific plans that describe a series of treatments in forested stands that are designed to meet specified management objectives. Prescriptions provide direction as how to move the current stand condition to some desired future condition which meets a predefined set of objectives, conditions, or outcomes. The ecosystem services framework could incorporate stand-level management prescriptions and may be a highly effective way to demonstrate the provision of important ecosystem services included in forest assessments and plans. We provide examples of a modified approach that integrates this concept with typical silvicultural guidelines.

PROJECT-SCALE IMPLEMENTATION

A third example illustrates how ecosystem services framework could be implemented into stand prescriptions at the project scale and how this framework can help the agency meet its mission at the national, forest, and local levels. The Forest Service has been exploring the use of an ecosystem services framework to describe the ecosystem services provided by forest landscapes, examine the potential tradeoffs among services associated with proposed management activities, and attract and build partnerships with stakeholders who benefit from particular services the forest provides. We describe how an ecosystem services framework can add value to agencies like the Forest Service to support management objectives while better connecting the agency to stakeholders and community members. We summarize applications of an ecosystem services framework from national policy to forest- and project-scale implementation including the modification of silvicultural prescriptions into ecosystem services prescriptions that include key ecosystem services that are a central part of forest plans and assessments. An ecosystem services framework will not only help transform the agency into a more effective and relevant organization, but it will bolster external relationships by strengthening the public's investment in Forest Service activities and articulating a management vision in terms of social values.

For further updates, see "Integrating Ecosystem Services into Sustainable Forest Management of Public Lands" on page 83.

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Restoring Forest Heterogeneity with Thinning and Prescribed Fire: Initial Results from the Central Sierra Nevada, California

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ABSTRACT.—Many fire-adapted forests across the United States where fire has been excluded have in-filled with shade-tolerant species, reducing the characteristic spatial heterogeneity. We used 1929 stem maps of historical forest conditions in the Sierra Nevada to develop a thinning prescription designed to restore a pattern of tree clumps, individual trees, and gaps. This "high variability" (HighV) thinning treatment was evaluated in a replicated experimental design along with a more standard regular "leave" tree spacing "low variability" (LowV) thinning treatment, and an unthinned control, all with or without prescribed fire. Both thinning treatments reduced tree density and basal area equally, but differed in spatial pattern, with the HighV thinning leading to greater variability in canopy closure and stem distribution. While creating small gaps with the HighV treatment required the removal of some larger trees, slightly more board foot (BF) volume was removed with the LowV treatment because larger trees often grow in groups and imposing a regular spacing resulted in the removal of some. Any difference in BF volume removed between treatments would likely be minimal on most Forest Service lands in the Sierra Nevada where a 30-inch diameter limit for cutting applies. Both thinning treatments improved tree survival in a severe drought compared with the untreated control. No difference was observed between thinning treatments indicating that leaving some trees in groups did not increase susceptibility to bark beetle attack at the stand scale. While more trees died in the prescribed burn treatments, secondary mortality in thinned units was relatively minor. The HighV with prescribed fire treatment not only produced a structure more closely approximating that of historical stands, but low surface fuel loads should make treated areas more resilient to future wildfires.

Most western U.S. forests that once experienced frequent fire are considerably denser today than they once were (Collins et al. 2011, Moore et al. 2004, Scholl and Taylor 2010). In the absence of fire, gaps in the forest filled with trees (Lydersen et al. 2013), altering the understory light environment and increasing fuel continuity. Composition of forests has also shifted to a greater dominance of shade-tolerant species (Knapp et al. 2013). Structural changes, including a deficit of larger more fire-resistant trees as a result of past harvest practices, plus greater fuel loading and continuity, have all contributed to a greater vulnerability of stands to uncharacteristically intense fires (Steel et al. 2015). Unnaturally dense stands are also more susceptible to elevated bark beetle mortality, especially during drought conditions (Ferrell et al. 1994, Fettig et al. 2007, Graham et al. 2016, Young et al. 2017).

While the need to thin overstocked forests and reduce the accumulated surface fuels is widely accepted, progress in many areas has been slowed by concern that standard approaches may be at odds with habitat needs of key wildlife species (Lehmkuhl et al. 2007, Scheller et al. 2011). Producing a variety of forest conditions with thinning, which is guided by historical

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reference information, may provide a greater diversity of habitats desired for multi-species management (North and Manley 2012). Heterogeneity may also improve the resilience of stands to wildfire and a changing climate (Stephens et al. 2010), and approaches emphasizing heterogeneity as a central element to forest restoration have been described for many forests historically shaped by frequent fire (Addington et al. 2018, North et al. 2009, Reynolds et al. 2013).

The Variable Density Thinning study at the Stanislaus-Tuolumne Experimental Forest in the central Sierra Nevada, CA, was established in 2009 to test the ecological responses to mechanical thinning designed to restore stand heterogeneity similar to that found in historical prefire suppression forests. This thinning treatment was compared against a more conventional thin-from-below, in which residual trees were relatively evenly spaced such that crown overlap for dominant and co-dominant trees was minimized. Additionally, this study included an untreated control, which along with the two thinning treatments was crossed with a prescribed fire treatment. The objective of the prescribed fire treatment was not only to reduce surface fuels, but to evaluate the capacity of prescribed fire to enhance structural heterogeneity compared to thinning. Recently published results show that thinning generated more within-stand heterogeneity than a single entry prescribed burn (Knapp et al. 2017). In addition, the "high variability" (HighV) treatment increased within-stand heterogeneity more than the "low variability" (LowV) thinning treatment, approaching the historical reference condition at some spatial scales. Analysis of many of the ecological variables being monitored is still underway. Additional lingering questions about the HighV treatment that might discourage wider application include whether the HighV treatment is more difficult to implement, is cost-effective, and whether leaving some trees in denser groups might reduce growth rates while leaving trees more susceptible to mortality caused by bark beetle or self-thinning.

The objectives of this paper are to illustrate differences among treatments, compare the harvested board foot volume and dry tons of biomass removed between a HighV thinning treatment and a LowV thinning treatment, and to report on the initial response of all treatments to a severe drought. The four water years following the thinning treatments (2012-2015) were substantially drier than normal, which led to extensive drought-related tree mortality in the Sierra Nevada (Young et al. 2017), including the area of the study.

STUDY AREA

The Variable Density Thinning study was established across approximately 240 acres of second growth mixed-conifer forest within the Stanislaus-Tuolumne Experimental Forest (Stanislaus National Forest) at elevations ranging from 5700 to 6200 ft. Tree species included white fir (*Abies concolor* (Gordon & Glend.) Hildebr.), sugar pine (*Pinus lambertiana* Douglas), incense cedar (*Calocedrus decurrens* (Torr.) Florin), ponderosa pine (*P. ponderosa* Lawson & C. Lawson), Jeffrey pine (*P. jeffreyi* Grev. & Balf.), and black oak (*Quercus kelloggii* Newb.), in order of abundance.

The study was set up in a split-plot design, with eight blocks of equal size, each randomly assigned a burn treatment (burn or no burn). Blocks were divided into three units and each randomly assigned a logging treatment. Logging treatments were a high variability (HighV) thin, a low variability (LowV) thin, and an unthinned control. The objective of the HighV thinning prescription was to produce a spatial structure, density, species composition, and size distribution consistent with the historical patterns once observed on this site, based on data from nearby forest (Knapp et al. 2013, Lydersen et al. 2013). These historical data and photographs showed the forest consisted of individual large trees, clusters of trees, and gaps—consistent with the individuals, clumps, and openings (ICO) pattern documented in frequent fire forests of the western United States by others (Larson and Churchill 2012).

MATERIALS AND METHODS

The HighV thinning involved cutting trees to produce small (0.1 acre to 0.5 acre) gaps (approximately one per every 2 acres), similar in size and density to those noted on the historical records (Lydersen et al. 2013). The remaining forest was broken up into tree groups of similar size to the gaps, with thinning intensity varying among groups. About a third of groups were thinned more heavily, a third moderately, and a third lightly. Within groups, the best trees (generally the largest trees, trees with the best crown form, or both) were retained, regardless of crown spacing. Additional details of the HighV prescription are found in Knapp et al. (2012). The LowV thinning treatment was marked for cutting by selecting "leave" trees spaced approximately 0.5 crown widths from nearest neighbors. The LowV prescription approximated a standard "thinning from below" treatment at the time the study was planned. Abundance of white fir and incense cedar had increased the most relative to historical conditions (Knapp et al. 2013) and these two species were therefore targeted for cutting over pines. The goal with the two thinning treatments was to produce stands of similar tree density, basal area, size class distribution, and species composition, but with a different spatial arrangement of trees. Most of the smaller trees (<22 inches) were cut with tracked feller bunchers while larger trees were chainsaw felled. All material (whole smaller trees, plus boles and nonmerchantable tops of larger trees) was skidded to landings for processing into logs and other forest products. Small trees (generally <10 inches) and tops of larger trees were chipped and removed as biomass. All logging was completed between July and September 2011. Prescribed burning treatments were carried out in November 2013 using drip torch spot ignition, working fire from higher to lower elevations. This resulted in a mixture of backing, flanking, and short-distance head fire.

Within each unit, trees >4 inches diameter at breast height (d.b.h), within a belt transect 787.4 ft long by 49.2 ft wide, were mapped and measured in 2009, 2 years prior to logging. To fit within the unit, belt transects were broken up into parallel (west to east) segments 98.4 ft apart, with the number of segments depending on the shape of the unit (see Figure 1 in Knapp et al. [2017]). The belt transects represented approximately an 8 percent sample of the study area. After logging, remaining trees within each transect were tagged with an individually numbered metal tag (see Fig. 1 for "before" and "after" cutting comparison). Status (live/cut/dead) was determined, and d.b.h and height of each tree measured in 2012 (year after logging), 2014 (year after prescribed burning), and 2016. Height was estimated using laser rangefinders and/or clinometer and meter tape.

Board foot (BF) volume and biomass removed by logging was estimated from the 2009 (prelogging) tree data together with a list of those which were cut, based on the 2012 (post-logging) survey. Volume for individual cut trees was calculated from d.b.h. and tree height values with the USDA Forest Service national volume estimator library (USDA Forest Service, n.d. b) using individual species equations of Wensel and Olson (1993) with numbers based on the Scribner log rule. Calculations assumed saw logs were processed to a minimum 6-inch top diameter from trees ≥10 in d.b.h. Smaller (<10 inches) trees and the tops of saw log trees were assumed to have been chipped and converted to biomass. Amount of biomass was estimated with the Forest Service national biomass estimator library (USDA Forest Service, n.d. a) using equations of Jenkins et al. (2003). The program's functions "bmAboveGroundTotal" were used to calculate bone dry tons for small (<10 inches) trees and "bmStemTop" was used to calculate bone dry tons for tops of saw log-sized trees.

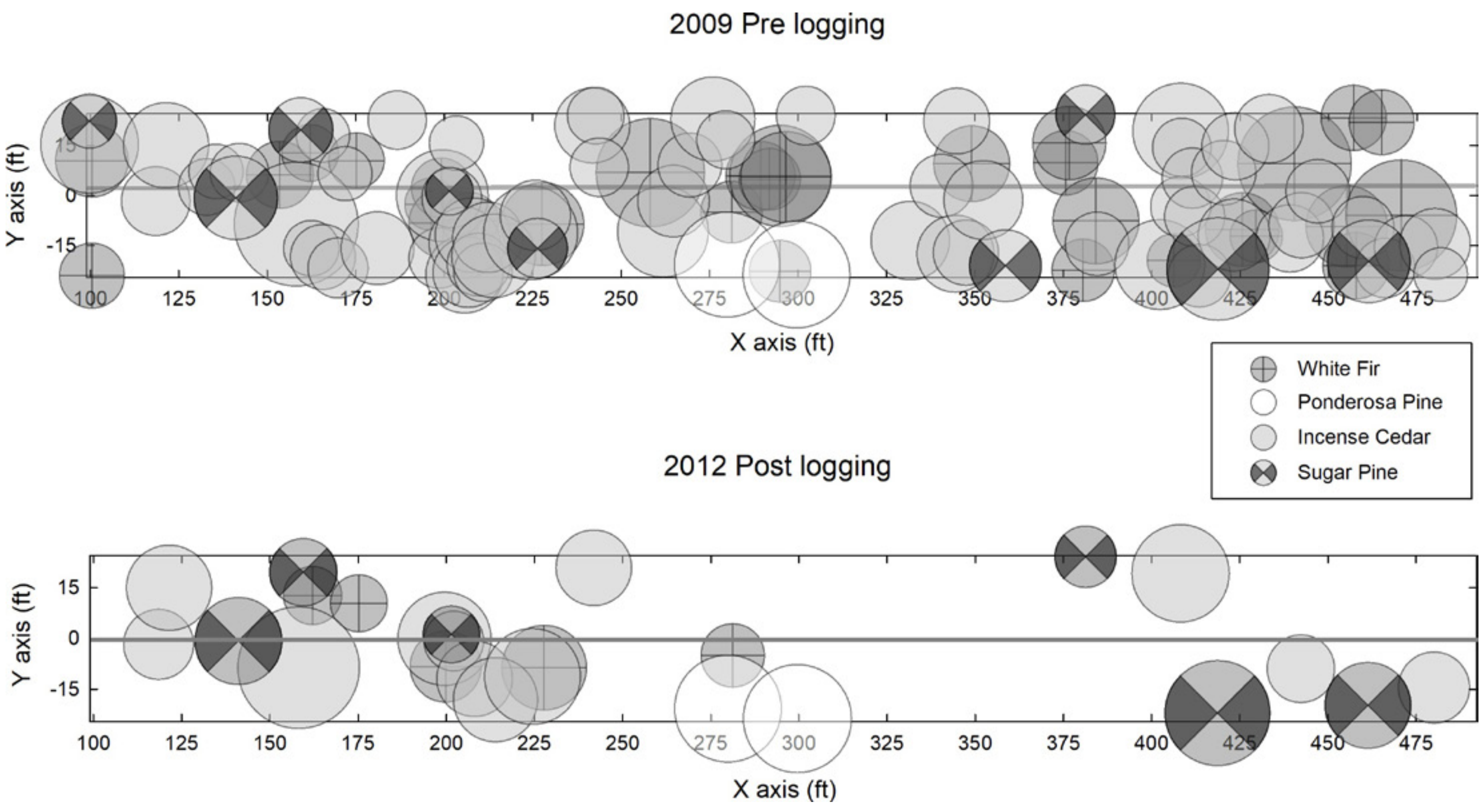

Figure 1.—Illustration of one stand (Unit 15, Transect 1) thinned using a "high variability" (HighV) prescription, showing a 393 ft × 49 ft belt transect through the unit in 2009 (prelogging) and in 2012 (post-logging).

Since tree heights were not measured until after logging, tree heights for cut trees were estimated using post logging (2012) data for all trees without broken tops as determined from field notes. Tree height was estimated for each species using equation 3 of Larsen and Hann (1987) with coefficients b0, b1, and b2 calculated using SAS NLIN in SAS version 9.4, and the coefficients listed in the paper for the tree species as starting values.

$$\text{Height\_ft} = 4.5 + \text{EXP}(b0 + b1{*}\text{DBH\_in}^{b2})$$

Two outliers—the tallest white fir and the tallest sugar pine—were dropped as diameter values were considerably larger than any trees removed by logging. All equations using coefficients (Table 1) derived from 2012 (post-logging) tree diameter data were highly significant (P <0.001), except for Jeffrey pine (PIJE), which had the fewest observations and did not converge. We therefore combined the ponderosa (PIPO) and Jeffrey pine datasets and estimated b0 for each while keeping b1 and b2 constant. The difference between b0(PIPO) and b0(PIJE) was significant.

Significance of differences in prelogging, retained, and removed BF volume between the HighV and LowV treatments was determined using generalized linear mixed effects models (PROC GLIMMIX). Volume was also estimated for hypothetical maximum diameter limits of 30 inches, 24 inches, and 20 inches, and significance of the differences between treatments analyzed using the same method. The three selected diameter limits represent the current upper diameter limit on national forest lands in the Sierra Nevada, the often-used limit resulting from spotted owl guidelines (Verner et al. 1992), and an early 2000s proposed upper limit that was not implemented, respectively. Because pretreatment volume was numerically higher in the LowV treatment, pretreatment volume was used as a covariate in all BF volume removed and retained analyses.

Table 1.—Individual species coefficients for estimating height from diameter at breast height within the Variable Density Thinning study at the Stanislaus-Tuolumne Experimental Forest, using equation 3 of Larsen and Hann (1987)

Species	b0	b1	b2
White fir	5.7418	-7.0241	-0.5806
Incense cedar	6.2967	-6.7234	-0.3904
Sugar pine	5.5006	-8.5938	-0.7291
Ponderosa pine	6.9445	-5.7794	-0.2929
Jeffrey pine	6.7647	-5.7794	-0.2929

Table 2.—Average tree density, basal area, and quadratic mean diameter (QMD), for unthinned control, high variability thin (HighV), and low variability thin (LowV) treatments, all with or without prescribed fire, in 2014, 3 years after logging and 1 year after implementation of prescribed burns. (Standard error in parentheses.) P values (in italics) for main and interaction effects were determined with generalized linear mixed effects models.

		Density (trees ac^{-1})				
Logging Treatment	Burning treatment	Small (4 to 10 in)	Medium (10 to 20 in)	Large (>20 in)	Basal area (ft^2 ac^{-1})	QMD (in)
Control	No Burn	195.3 (39.5)	100.3 (7.2)	32.9 (5.0)	259.4 (17.7)	13.0 (1.1)
Control	Burn	145.3 (21.7)	88.5 (9.1)	41.0 (7.2)	261.1 (30.3)	14.0 (1.1)
HighV thin	No Burn	6.7 (1.6)	26.4 (5.2)	31.5 (2.3)	148.7 (7.8)	22.0 (1.0)
HighV thin	Burn	10.7 (3.6)	25.0 (1.6)	27.2 (4.1)	152.4 (23.0)	22.2 (1.9)
LowV thin	No Burn	13.5 (3.5)	27.0 (7.3)	26.2 (0.5)	139.1 (12.7)	21.0 (1.6)
LowV thin	Burn	5.9 (2.6)	16.9 (6.0)	32.0 (2.4)	157.9 (18.4)	24.7 (2.7)
Logging treatment		*<0.001*	*<0.001*	*0.146*	*<0.001*	*<0.001*
Burning treatment		*0.674*	*0.318*	*0.509*	*0.597*	*0.365*
Logging × Burning		*0.177*	*0.436*	*0.227*	*0.816*	*0.534*

Performance of treatments during a severe drought was evaluated as the change in basal area between 2014 and 2016. Significance of differences among treatments was determined using a generalized linear mixed effects model (PROC GLIMMIX) including main effects (thinning treatment, burning treatment, year) and interaction terms, and block and burning*block as random effects.

RESULTS AND DISCUSSION

Both thinning treatments resulted in a stand with significantly fewer small (4-10 inches) trees, medium (10-20 inches) trees, and basal area, and significantly increased quadratic mean diameter (Table 2). The number of large (>20 inches) trees did not differ significantly among treatments. For all variables where thinning was significant, the HighV and LowV treatments did not differ from each other. Differences between "no burn" and burn treatments were not significant in the year following implementation of the burns. Delayed mortality in the burned units, which was likely exacerbated by the severe drought (Van Mantgem et al. 2013), was substantial, especially in the unthinned control units, but not considered in this analysis. Despite the lack of significant differences among stand-level means, thinning-

Figure 2.—Aerial photograph of a portion of the study area, taken in 2012, 1 year following logging, showing an unthinned control unit (upper left), two high variability thin units (center), and two low variability thin units (right and bottom). Average tree density and basal area did not differ between thinning treatments, only how trees were arranged within units.

produced differences in the forest spatial structure were evident, both visually (Fig. 2) and numerically, thus illustrating the need for new metrics to describe structural heterogeneity. Knapp et al. (2017) found that coefficients of variation for tree density and basal area for the HighV treatment came closer to a historical reference than those produced by the LowV treatment. In addition, HighV thinning led to a broader range of canopy closure values, with more of the treated area in the very low and high canopy closure classes relative to the LowV treatment. The LowV treatment, on the other hand, pushed the majority of the treated area toward the mean value of canopy closure (Knapp et al. 2017). One common concern with thinning designed to meet ecological objectives is that not enough material would be removed for the treatment to pay for itself (i.e., generate revenue). However, data from nearby historical plots illustrate that the current stands are not just overstocked in the smaller diameter tree size classes with low value, but also in intermediate and larger-intermediate sized trees (Knapp et al. 2013).

Using calculated height estimates for the 2009 preharvest stand plus the equation and coefficients described above, no difference in bone dry tons of biomass removed was detected between the two thinning treatments, but total gross BF volume was marginally significantly

Table 3.—Standing volume prior to harvest, residual volume after thinning, and total saw log volume plus biomass removed as chips from units thinned with HighV prescription compared to units thinned with a more even crown spacing treatment (LowV). Saw logs were considered any tree with a d.b.h. ≥10 inches and logs were processed down to a 6-inch top. The actual thinning was done without diameter limits, but saw log volume values are also shown for hypothetical situations using diameter limits of 30 inches, 24 inches, and 20 inches, where no trees larger than the diameter limit are removed. Biomass consists of trees <10 inches and tops. Significance of the difference between logging treatments for BF volume removed and retained were calculated with preharvest volume as a covariate and means are corrected for the covariate. Standard errors are in parentheses and P values are in italics.

				Hypothetical volume removed with diameter limits			
Logging treatment	Preharvest volume	Residual Volume	Volume removed	<30 in d.b.h.	<24 in d.b.h.	<20 in d.b.h.	Biomass removed
	Volume (BF ac^{-1})						Dry tons ac^{-1}
HighV thin	46,651 (4,955)	34,634 (1,435)	12,533 (828)	11,923 (751)	9,210 (623)	6,017 (485)	16.72 (1.69)
LowV thin	51,595 (5,480)	31,190 (1,293)	15,396 (1,017)	12,128 (764)	8,897 (602)	5,410 (444)	13.67 (1.38)
Preharvest covariate	-	*<0.001*	*<0.001*	*0.053*	*0.328*	*0.028*	-
HighV vs. LowV	*0.492*	*0.098*	*0.049*	*0.852*	*0.726*	*0.459*	*0.190*

higher for LowV thinning treatment (P = 0.049), even after correcting for the higher preharvest volume (preharvest covariate P <0.001) (Table 3). We expected that the creation of gaps in the HighV treatment would result in equal, if not more, volume removed. However, because the largest trees in the stand often were growing in groups, cutting of some larger trees was also necessary to enforce the crown spacing guidelines of the LowV prescription. It is possible that this more than balanced out the larger trees that would need to be cut to create small gaps. Much of the difference between the two logging treatments was the result of somewhat greater number of >30 inch trees cut (2.2 ac^{-1} in the LowV treatment vs. 0.3 ac^{-1} in the HighV treatment; mostly white fir with a few incense cedar). The majority of these >30-inch trees were <34 inches, but the average >30 inch cut tree still contained 2,060 BF volume. Under the Sierra Nevada Forest Plan Amendment (USDA Forest Service 2004), if these or similar prescriptions were used on most other (non-Experimental Forest) NFS lands, a 30-inch diameter limit would have applied. The BF volume of trees <30 inches did not differ significantly between the HighV and LowV treatments (P = 0.852) (Table 3). An additional 714 BF ac^{-1} would have been removed in the HighV treatment (618 BF ac^{-1} in the LowV treatment) if logs were processed down to a 4-inch top diameter. Amount of biomass removed would have been correspondingly less. In addition, volume amounts were likely slightly higher than estimated, given that 2 years of additional growth had occurred between the time of tree measurement (2009) and when logging was done.

Volume comparisons between treatments should be interpreted with some caution, given the relatively small sample. Only 8 percent of the harvest area was captured in the tree transects. In addition, the numbers of larger trees cut was relatively low but larger trees contribute disproportionately to volume, thus chance sampling can easily skew results. However, volume estimates were similar to numbers calculated based on a post-marking and preharvest cruise.[2] In addition, the sum of volumes from the two treatments multiplied by the acres treated was very close to the volume that was actually measured when the logs were scaled, giving more

[2] Stanislaus National Forest, unpublished data.

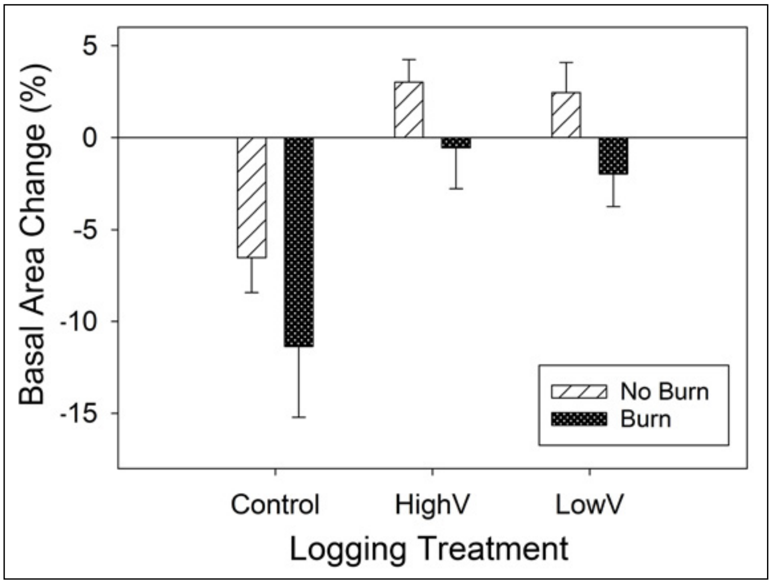

Figure 3.—Percentage basal area change between 2014 and 2016 in unthinned control units, units thinned with a HighV prescription and units thinned more evenly, or LowV, all with or without a follow-up prescribed burn. Thinning was completed in 2011 and prescribed burning in 2013. The study area experienced a severe drought from 2012 to 2015, with high mainly bark beetle caused tree mortality during and immediately following this period. The control treatment lost basal area, while both thinning treatments (averaged across burning treatments) gained a small amount of basal area (growth > mortality).

confidence in the overall numbers. A potentially important confounding variable in this study was that different marking crews were used for the HighV and LowV treatments. For these reasons we believe that for most stands, approximately equivalent volume would be removed with the HighV or the LowV prescriptions, given the same starting volume and same marking crew. In any case, the volume removed for either treatment (Table 3) was more than enough to make the project revenue positive given hauling costs and log prices at the time.[3]

Both thinning treatments experienced lower drought-related mortality than the adjacent unthinned controls. Between the summer of 2014 and the summer of 2016, live basal area dropped 9.1 percent in the untreated controls and increased an average of 0.6 percent in the thinned treatments (thinning × year interaction: $F = 11.55$, $P < 0.001$) (Fig. 3). While some tree mortality occurred within the thinned treatments as well, it was more than balanced by growth of the surviving trees. There was no difference in the basal area change over time between the HighV and the LowV thinning treatments ($P = 0.989$). Thus treatment-wide, at this initial stage of evaluation, we see no evidence that a variable arrangement of trees, including patches of higher density, leads to higher mortality levels. While rate of mortality in relation to density variation within stands was not determined, any elevated mortality in the denser areas within HighV stands (if present) must have been balanced by lower than average mortality in portions of the stand thinned more heavily.

More basal area was lost in prescribed fire treatments than those left unburned (burning × year interaction: $F = 4.99$, $P = 0.038$). This delayed mortality was likely due to the stress caused by coupling of heavy fuel consumption (124 years since the last record of fire) with severe drought. (The historic fire regime in the study area was reported as a median interval of 6 years between fires, with the last fire in 1889 [Knapp et al. 2013]). Still, the basal area in the unthinned and burned control remained at or above historical values (but with many more and smaller trees). While any additional fire-related mortality was not a desired outcome in the thin and burn units, the comparatively minor loss of an average of 1.5 ft^2 ac^{-1} was within the acceptable range for the burning prescription. Thinning alone without any surface fuel treatment may be not change fire behavior sufficiently to prevent extensive tree mortality in the event of a wildfire (Ritchie et al. 2007).

[3] Personal communication, Dave Horak and Maria Benech, Stanislaus National Forest.

In summary, the combination of HighV thinning with prescribed fire not only re-created a variable forest structure similar to what forests historically contained, but the combination of reduced density and lower surface fuel loads also should make treated stands more resilient to drought and wildfire induced tree mortality.

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Since its inception in 1973, the National Silviculture Workshop (NSW) has brought together forest managers and researchers from across the USDA Forest Service, and more recently our university and other partners, to provide a forum for information sharing and science advancements in silviculture. The 2019 NSW focused specifically on this partnership with the theme "Forest Management-Research Partnerships" in Bemidji, MN. With nearly 300 participants, this proceedings and that of the Journal of Forestry special section (Volume 118, Issue 3), highlight some of the best outcomes of our history of working together, as well as its challenges, and opportunities for the future. The objectives of the workshop included 1) providing a forum to showcase successful partnerships and shared stewardship between forest managers and researchers, 2) enhancing these relationships within the Agency and with our external partners to meet shared goals and objectives, 3) building on the Forest Service strategic objectives for improving the conditions of forests through innovative silviculture and active forest management, and 4) identifying emerging forest management needs to guide future research investment. This report includes of 22 papers (including two from 2017 NSW) and 6 panel-discussion summaries. The report also includes two papers from the 2017 NSW, "Silviculture: The Foundation for Restoration, Resilience, and Climate Adaptation" held in Flagstaff, AZ.

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