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# Northern Rocky Mountain Experimental Forests: Settings for Science, Management, and Education Alliances

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Society' s view of forests and what they produce changed considerably during the latter part of the 20th century. Prior to the 1970s, society believed that forests in the western United States provided a seemingly infinite supply of natural resources and economic prosperity. The public trusted experts to make forest management decisions dedicated to resource extraction and controlling nature (Bengston 1994). As a result, forest management objectives emphasized timber production, capital-intensive forest operations, and fire suppression (Bengston 1994, Covington and Moore 1994, Hessburg et al. 2005). During and after 1970, society's view toward forests began to shift toward sustainable development, harmony with nature, an awareness of finite natural resources, and public involvement in decisionmaking (Bengston 1994). As a result, forest management objectives evolved to incorporate these different values. Instead of only producing wood, forest management objectives shifted to favor ecosystem services such as fresh water, food, wood products, carbon sequestration, soil protection, and wildlife habitat. Management objectives also changed their focus to enhance social services that include recreation, ecotourism, and education along with support services such as nutrient cycling and soil development (USDA 2014).

During this same period, in the dry forests, fire suppression and a changing climate favored abundant forest growth and contiguous multistoried forests throughout the western United States (Covington and Moore 1994). In the northern Rocky Mountain moist mixed-conifer forests, western white pine mortality caused by blister rust and salvage cuttings allowed dense multistoried grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) and other late-seral forests to develop (Ketcham et al. 1968, Harvey et al. 2008). Large and damaging wildfires, along with epidemics of forest insects and diseases, scorched the land and killed trees. The large expanses of late-seral, dense, and homogeneous forests; warm temperatures; drought; and extended fire seasons exacerbated these disturbances (Dale et al. 2001, Graham et al. 2004).

Today, forest managers must address not only the social, ecosystem, and support services society desires but also create forest conditions that increase disturbance resilience in western forests (Walker and Salt 2006, Luce et al. 2012). For managers to apply science-based management strategies to address these objectives is challenging and will take time (decades and sometimes centuries) because forests need time to grow and develop to create places where disease and insect infestations are infrequent, damaging wildfires are rare, and societal necessities are provided.

USDA Forest Service experimental forests (EF) are ideal places to develop concepts and silvicultural systems to address contemporary forest management issues and challenges over long time frames (Adams et al. 2008, Wells et al. 2009, Vavra and Mitchell 2010, Yung et al. 2012). Place-based research promotes science partnerships among USDA Forest Service National Forest System (NFS) managers, research and development (R&D) scientists, and other public and private stakeholders. They also serve as living laboratories where research scientists can produce ecological knowledge aimed at informing management decisions and where managers can expand their knowledge and practical experience (Adams et al. 2008, Wells et al. 2009).

Each EF mirrors the ecosystems, disturbance regimes, and management histories inherent to the forests where they occur (Figure 1) (Yung et al. 2012). For example, Priest River EF, in northern Idaho, has five major potential vegetation types common throughout northern Rocky Mountain mixed-conifer forests (Jain and Graham 1996a, 1996b). Deception Creek EF, in the Coeur d'Alene Mountains of Idaho, exemplifies mixed-conifer forests where white pine blister rust (*Cronartium ribicola* Fisch.) killed many western white pines (*Pinus monticola* Douglas ex D. Don), and those that survived were heavily harvested on the perception that they too would die from the disease (Ketcham et al. 1968, Jain and Graham 1996a). Because these EFs typify the vegetative conditions and disturbances of surrounding landscapes, the knowledge acquired on EFs is relevant and applicable to broader forest settings. Moreover, when scientists conduct complementary studies on multiple EFs, regional applicability of scientific findings also increases (Lugo et al. 2006, Vavra and Mitchell 2010, Yung et al. 2012). In this paper, we use four EFs to illustrate silvicultural research, the partnerships developed to accomplish that research, and lessons learned from those interactions. Although focused on EFs, our experiences are relevant to others conducting place-based research.

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This article uses metric units; the applicable conversion factors are: meters (m): 1 m = 3.3 ft; square meters ($m^2$): 1 $m^2$ = 10.8 $ft^2$; hectares (ha): 1 ha = 2.47 ac.

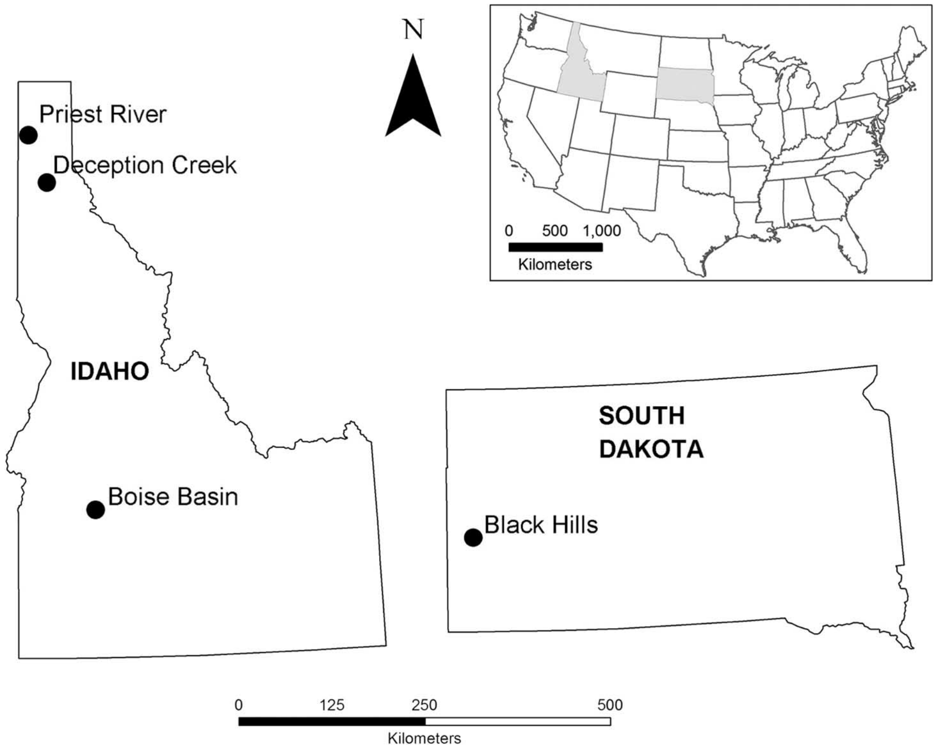


**Figure 1. Experimental forest locations in Idaho and South Dakota, USA.**

**Table 1. Experimental forest characteristics. The integrated restoration studies were placed on Priest River, Deception Creek, Boise Basin, and Black Hills Experimental Forests.**

| Characteristics | Priest River | Deception Creek | Boise Basin | Black Hills |
|---|---|---|---|---|
| Year established | 1911 | 1933 | 1933 | 1965 |
| Size (ha) | 2,600 | 1,425 | 3,700 | 1,391 |
| Average precipitation (cm) | 82 | 139 | 66 | 61 |
| Potential vegetation type | Western redcedar | Western hemlock | Douglas-fir | Ponderosa pine |
| | Western hemlock | | | |
| | Grand fir | | | |
| | Douglas-fir | | | |
| | Subalpine fir | | | |
| Other tree species | Western white pine | Douglas-fir | Douglas-fir | White spruce |
| | Western larch | Western white pine | Quaking aspen | Quaking aspen |
| | Lodgepole pine | Western larch | | |
| | Engelmann spruce | Lodgepole pine | | |
| | White bark pine | Grand fir | | |
| | Quaking aspen | | | |
| | Paper birch | | | |

The scientific names and authorities for species growing on the four experimental forests. Western redcedar (*Thuja plicata* Donn ex D. Don), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), grand fir (*Abies grandis* (Douglas ex. D. Don) Lindl.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), Douglas-fir (*Psuedotsuga menziesii* (Mirb.) Franco), western white pine (*Pinus monticola* Douglas ex D. Don), western larch (*Larix occidentalis* Nutt.), quaking aspen (*Populus trimuloides* Michx), paper birch (*Betula papyrifera* Marshall), lodgepole pine (*Pinus contorta* Douglas ex Loudon), white bark pine (*Pinus albicaulis* Engelm.), Engelmann spruce (*Picea engelmanii* Parry ex Engelm.) ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson), and white spruce (*Picea glauca* (Moench) Voss).

## Integrated Forest Restoration

### Study Areas

We have implemented a series of integrated forest restoration studies on four EFs within the territory of the Rocky Mountain Research Station. The integrated restoration studies are located on two moist mixed-conifer EFs and two dry mixed-conifer EFs in the northern Rocky Mountains (Figure 1; Table 1). Located in northern Idaho, the Priest River (established in 1911) and Deception Creek EFs (established in 1933) represent the moist mixed-conifer forests (Table 1). Priest River EF contains five potential vegetation types and Deception Creek EF is dominated by the western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) potential vegetation type (Jain and Graham 1996a, 1996b). Representing the interior ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) forests, studies are located on Boise Basin (established in 1933) and the Black Hills EFs (established in 1961) (Sloan and Steele 1996, Shepperd and Battaglia 2002, Adams et al. 2008) (Table 1).

### Research Objective

The integrated restoration objective is to develop, implement, and evaluate silvicultural systems and methods designed to sustain disturbance-resilient forests while providing ecosystem services. Heterogeneous forests containing a variety of structural stages, successional stages, tree densities, patch sizes, species compositions, and tree sizes arranged within and among landscapes tend to be resilient to insects, diseases, and wildfire (Weaver 1943, Long and Smith 2000, Graham et al. 2004, Hessburg et al. 2005, Fettig et al. 2007). Even-aged and uneven-aged silvicultural systems were considered for use in these studies, but to create and maintain the desired heterogeneous forest conditions, an irregular selection system was deemed most appropriate because it combines some elements of both even-aged and uneven-aged systems. We came to this conclusion because uneven-aged structure defined by geometrical (q) diameter distributions, target tree sizes, target basal areas, and uniform cutting cycles did not reflect heterogeneous stands and landscapes (Meyer et al. 1961). Although even-aged systems, favor regeneration of shade-intolerant species, they generally do not contain snags, decadence, down wood, and complex forest structures (Anderson 1934, Pearson 1942, Reynolds et al. 1992, Jain et al. 2004, Tews et al. 2004, Graham and Jain 2005, Graham et al. 2007, Jain et al. 2008). We chose to use an irregular selection system where discrete stand and entry metrics did not define the desired compositions and structures but, rather, designed the system to develop key stand structure and composition determinants such as tree vigor, shade-intolerant species, high forest dominance, mature trees, and snag and woody debris recruitment (Anderson 1934, Pearson 1942, Graham and Jain 2005, Graham et al. 2007).

Scientists have used irregular selection system concepts in many forest types with the goal of retaining some overstory trees, gaps, and a variety of opening sizes to create forest conditions that produce wildlife habitat, timber products, and forest legacies (Eichhorn 1922, Haight and Monserud 1990, Mitchell et al. 2002, Puettman et al. 2009, Raymond et al. 2009, Susse et al. 2011, Larson and Churchill 2012). Similar to other studies, our objective was to integrate contemporary and established silvicultural concepts and develop methods that create complex forest structures and compositions that will vary and change over time. This system requires a comprehensive description of the desired forest conditions (target stands) in the short and long term over scales ranging from canopy gaps to landscapes (Graham and Jain 2005, Graham et al. 2007). Such an approach necessitates continuous monitoring and adaptive management to ensure the favored species compositions and structures continue to develop. The system also involves multiple, but irregular, tending and regenerating entries at various time intervals to maintain desired forest conditions.

By using the four EFs, we were able to establish and test treatments representing several phases of an irregular silvicultural system in a variety of forest types and successional stages. At the Priest River EF, regeneration methods were applied; a cleaning was conducted on the Deception Creek EF; the forest floor was treated in an old-growth ponderosa pine forest on the Boise Basin EF; and regeneration, thinning, and cleaning methods were conducted on the Black Hills EF. In all cases, the methods were designed to create and tend irregular forest structures and compositions resilient to insects, diseases, and wildfires. The integrated restoration work will produce (1) implementation strategies, (2) potential treatment combinations, and (3) vegetation regeneration and development metrics over time. Only through this type of research can scientists evaluate irregular selection systems as to how they will produce and maintain desired forest conditions.

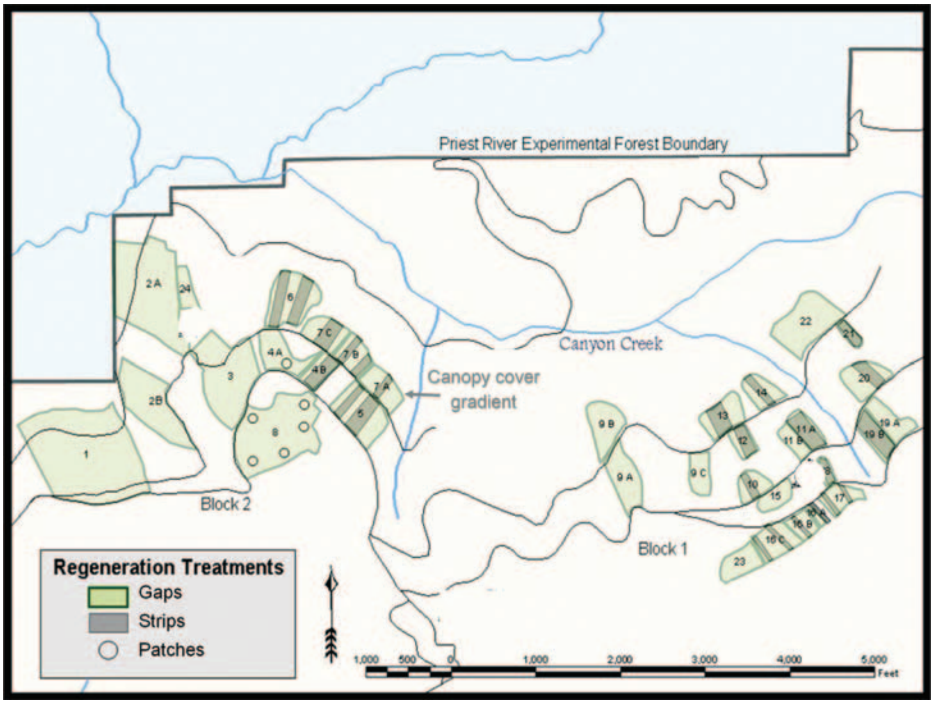


**Figure 2. The integrated restoration study located on Priest River Experimental Forest located in northern Idaho, USA. The harvest units were deliberately placed to enhance landscape diversity and alter fire behavior and progression. Irregular single-tree selection surround strip and patch cuts to create within unit overstory diversity. Strip cuts were 16, 31, 47, and 61 m wide, each replicated three times in each block. Western redcedar canopy cover gradient was created between the strips (gray) and patch edge. Areas without strips contained gaps and continuous canopy cover favoring large tree development.**

## Irregular Selection Regeneration Methods on Priest River EF

On Priest River EF in 2004, a replicated study was implemented using irregular selection regeneration, site preparation, and artificial regeneration methods to increase vegetation diversity (Jain et al. 2008). We used four tree-canopy-opening thresholds to design strip cuts (16, 31, 47, and 62 m wide), patch cuts (0.4 ha), and gap cuts (< 0.2 ha) that provided numerous canopy gap sizes and conditions (Jain et al. 2004) (Figure 2). They included four opening sizes that favor western white pine: when the opening size favors successful establishment (45% canopy opening), when the species has a competitive advantage over grand fir (55% canopy opening), when the species achieves free-to-grow (92% canopy opening), and when western white pine growth is maximized (4 ha). When possible, tree markers retained vigorous western larch (*Larix occidentalis* Nutt.) and western white pine. Along the strip and patch edges, tree markers created a canopy cover gradient using western redcedar (*Thuja plicata* Donn ex D. Don) (Figure 2). Finally, we distributed cutting units across settings with differing slope aspects, adding landscape diversity and altering potential fire behavior (Jain et al. 2008). Within and among the harvested units, we implemented prescribed fire, grapple piling and burning slash, masticating slash, and no postharvest forest floor treatment to diversify the forest floor (charred, organic, mineral soil forest floor surface). Artificial regeneration included altering seedling density and species based on canopy cover and forest floor conditions.

***Lessons Learned.*** During study implementation, Idaho Panhandle National Forests (NF), Priest Lake Ranger District managers and scientists learned several lessons. Tree marking guidelines emphasized creating within-stand heterogeneity using the canopy-opening thresholds and also required retaining vigorous western white pine, western larch, ponderosa pine, western redcedar, and western hemlock. Markers without a forestry background accustomed to marking trees using basal area, tree spacing, or diameter-limit had difficulty applying the irregular marking guidelines compared to markers that had a forestry background. Scientists and managers formed a common understanding and promoted innovative ways to prepare sites and introduce substrate diversity to the forest floor and planting sites by developing a working pamphlet with photographs that identified the research objectives, appropriate slash and forest floor treatments, and planting needs for each potential site condition. For example, district managers used forest canopy cover, residual species, and forest floor surface conditions to develop planting contract specifications. In large openings (≥ 1 ha), western white pine, western larch, and ponderosa pine were planted using a standard 3 × 3 m tree spacing. Contractors planted western redcedar under canopies greater than 50%, rust-resistant western white pine under canopies less than 50%, and western larch in openings greater than 0.75 ha. Planters were paid by the hour when planting sites were limited and paid by the tree when planting sites were abundant. This strategy decreased average costs by 35% compared to the district's average planting costs.

## Tending Young Moist Forests on Deception Creek EF

On Deception Creek EF in 1983, scientists installed strip clearcuts of varying widths to study postharvest fuel treatments and their subsequent influence on seedling establishment and development (Reinhardt et al. 1991). In 2012, these plantations contained thousands of trees per ha of western white pine, western larch, grand fir, and western hemlock. Although there are robust even-aged cleaning prescriptions to produce timber products (Foiles 1955, Deitschman and Pfister 1973, Graham 1988), prescriptions for enhancing sapling spatial diversity are not available for the moist mixed-conifer forests of the northern Rocky Mountains. In 2012 and 2013, a replicated study was established in the strip cuttings to quantify the effects of no treatment, full cleaning (release 450 plus selected trees per ha), and daylight cleaning (release only a few selected trees) on individual tree and stand development (Figure 3). The results from this work (posttreatment data collection commencing in 2014) will identify the economic and ecological benefits from daylight thinning when compared to a no treatment or traditional thinning options.

***Lessons Learned.*** The full cleaning prescriptions used standard Idaho Panhandle NFs protocols; however, innovative protocols were needed for the daylight cleaning to provide a competitive advantage for western white pine and western larch. Scientists and managers identified a target stem density for daylight cleaning to release 90 trees $ha^{-1}$. Prior to the fieldwork, cleaning protocols required releasing individual trees, but this proved impractical in the field. A more applied approach was to release four to five western white pine and western larch (2–4 m spacing) within small patches (approximately 0.10 ha) and create approximately 15 to 18 patches per ha. Patch density per ha also varied depending on western white pine abundance; more patches were created in places with high western white pine density

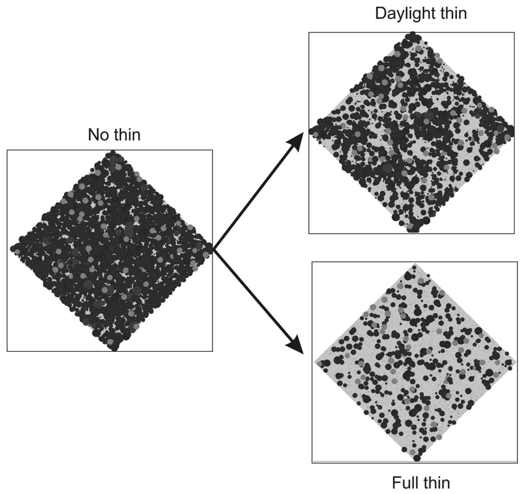


**Figure 3. Illustration of the three treatment types (no thin, daylight thin, and full-thin) tested on Deception Creek Experimental Forest located in northern Idaho, USA. Conceptually daylight thinning was designed to create diversity in density, thus creating a more heterogeneous stand compared to the full thinning that promoted regular spacing and maximized growth of individual trees.**

($\approx$750 trees $ha^{-1}$), and fewer patches in places with low western white pine density ($\approx$ 250 trees $ha^{-1}$). We also learned to promote spatial diversity within economic constraints will require site-specific cleaning strategies rather than standard prescription protocols.

## Forest Floor Restoration on Boise Basin EF

In old-growth dry mixed-conifer forests, fire exclusion has allowed dense understories of ponderosa pine, Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), and true firs to develop. (Covington and Moore 1994). Along with forest structure changes, deep layers of litter and duff have accumulated on the forest floor and augmented with bark slough at the base of large, yellow-barked ponderosa pines (Pyne 1982, Hood 2010). Not only do these layers at tree bases risk cambial injury in the event of a fire, but these organic layers also often contain fine roots. Whether destroyed mechanically (e.g., raking) or by fire, their destruction can stress the largest ponderosa pine, making them vulnerable to bark beetles and root diseases (Hood 2010).

On the Boise Basin EF in 2002 and 2004, we developed and implemented irregular selection silvicultural methods to treat the overstory and forest floor, respectively (Graham et al. 2007). Pretreatment stand characteristics typified other fire-excluded dry mixed-conifer forests that contain dense thickets of ponderosa pine and Douglas-fir seedlings and saplings, along with deep organic layers on the forest floor. Timber and firewood sales were used to remove the unwanted larger trees and cleanings removed the Douglas-fir and ponderosa pine saplings that contributed to ladder fuels. We also tested two treatments designed to treat the forest floor to diminish root abundance and the deep organic layers (Figure 4). Prior to spring root growth, prescribed fire practitioners mixed the surface layers or burned the surface layers when the area under the tree canopies (e.g., snow wells) were free of snow to allow moisture and heat to enhance their decomposition. The treatments were applied when temperatures of the lower organic layers were less than 10° C and their moisture concentrations were greater than 90% (Hood 2010, Jain et al. 2012). Because the organic layers were so deep, the treatments were reapplied 2 years later. As a result, the study contained single mix, double mix, single burn, and double burn treatments replicated eight times and eight replicates of the untreated control with individual trees representing one replicate.

***Lessons Learned.*** This application of irregular selection used multiple entries over a 7-year period. As in other irregular selection treatments, tree marking was a challenge, but removing trees with the goal of protecting the large ponderosa pines and their inherent irregular distribution provided the desired residual stand condition. The entries included a commercial harvest, first and second forest floor mixing and snow-well burning, a firewood harvest, a

**Figure 4. Forest floor restoration methods tested on Boise Basin Experimental Forest, located in southern Idaho, USA. Mixing and burning were used to evaluate their effects at restoring forest floor conditions to reflect historical conditions when fires maintained ponderosa pine forests. We used mixing (A) and burning (B) in early spring.**

cleaning, and finally a low-intensity prescribed fire broadcast through the stand. As fire had been excluded from this stand for nearly 100 years, the old fire scars were no longer resistant to fire and would easily ignite, thus we used snow placed against the fire scar to prevent ignition during treatment. The number of entries along with narrow snow-well and prescribed burning windows required commitment and innovation from managers and scientists. Idaho City Ranger District (Boise NF) managers conducted an expedited environmental assessment, hired prison crews and a miniyarder to harvest fuelwood, and used snowmobiles to access the site for snow-well burning. In the last 8 years, of the thousands of trees that were treated, only 3% have died from insect, disease, or wind. The stands have trees with

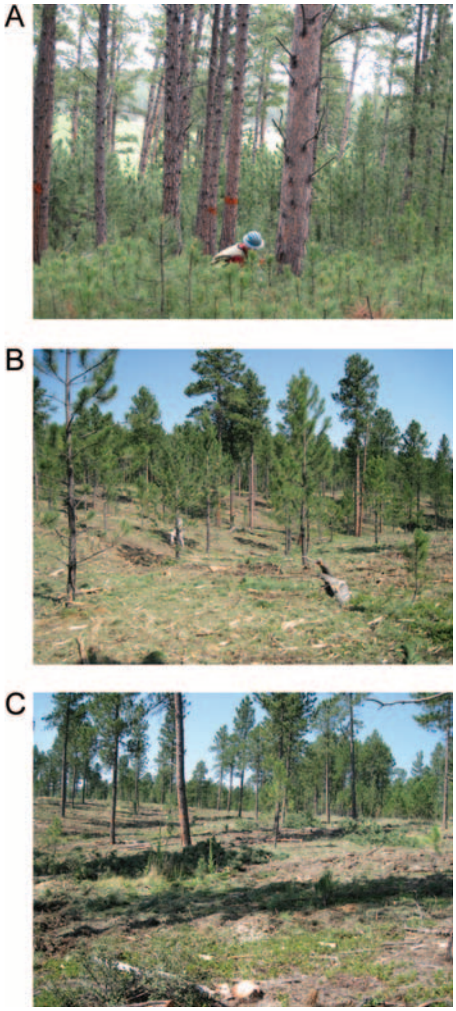

**Figure 5. Ponderosa pine forests on the Black Hills Experimental Forest located in northwest South Dakota, USA. Without fire, regeneration flourished (A). The integrated restoration study is introducing spatial diversity between the large trees and advance regeneration using cleaning methods that space 4 m but ignore overstory trees and treat regeneration as independent stratum (B), the second approach is to space 4 m from large trees in all directions (C).**

high canopy base heights (10 m), low surface fuels, a rich herbaceous understory, and the organic layers surrounding the trees are shallow and do not contain fine roots.

## Regeneration, Thinning, and Cleaning on the Black Hills EF

The ponderosa pine forests in the Black Hills of western South Dakota and northeastern Wyoming support a vibrant timber and tourist industry within a mosaic of private and public lands (Shepperd and Battaglia 2002). From the early 1900s until the mid-1960s, a variety of vigor selection and other uneven-aged systems produced forest products and left a variety of forest structures across the Black Hills (Harmon 1955, Newport 1956). Frequent seed crops and timely spring rains enabled abundant ponderosa pine seedlings to regenerate (Boldt and Van Deusen 1974) (Figure 5A). As in much of the western United States, the Black Hills NF in the late 1960s and early 1970s began more intensive timber management and started using one- and two-step shelterwood systems, buoyed by ease of regeneration, to produce forest products (Boldt and Van Deusen 1974, Alexander 1987). The transition to even-aged systems concentrated harvesting on fewer ha; coupled with fire exclusion, dense and homogenous forests developed and tend to dominate the Black Hills. Unfortunately, these forests are ideal for uncharacteristically severe wildfires and mountain pine beetle (*Dendroctonus ponderosae*) epidemics (Graham et al. 2004, Fettig et al. 2007). Since 2000, more than 100,000 ha have burned. A mountain pine beetle epidemic has affected more than 160,000 ha since 1996 (USDA Forest Service 2012).

Located in the central Black Hills, the ponderosa pine on the Black Hills EF readily reflected the dense and uniform forests that prevailed over much of the area. Heterogeneous, spatially explicit tree diversity, within and among stands, appears to a very desirable forest condition to minimize bark beetle and wildfire hazard (Hornibrook 1939). As with other places we applied the irregular selection to determine if increasing forest heterogeneity reduces wildfire and bark beetle hazard plus produce forest products (Finney 2001, Shepperd and Battaglia 2002, Graham and Jain 2005, Fettig et al. 2007).

On the Black Hills EF, it will take decades and many indeterminate treatments over a variety of time intervals to produce the desired wildfire and bark beetle resilient forests while producing timber and recreation opportunities. The first selection cutting in 2011 created heterogeneity in tree spacing and juxtaposition across all size classes. High priority areas for treatment where those places with tree densities greater than 23 $m^2\ ha^{-1}$ of basal area or had pockets of bark-beetle-infested trees. Dominant and codominant trees were retained only if they had high crown vigor (crown ratio greater than 40%, needle retention greater than 3 years, and diameter to height ratios less than 100) (Hornibrook 1939) (Figure 5A). Using tree vigor as leave-tree criteria, openings for regeneration and overstory spatial diversity were created.

In 2013, we used two approaches to clean advance regeneration. The first approach used standard NFS protocols that cleaned the seedlings and saplings to a 4 × 4 m spacing, ignoring the overstory trees (Figure 5B). This method tends to leave uniformly-spaced seedlings and saplings under overstory trees, producing undesirable ladder fuels. The second approach was to include the overstory trees in the spacing specifications and clean the saplings to 4 × 4 m spacing but also remove all saplings within 4 m of an overstory tree (Figure 5C). This approach provided maximum growing space for each crown class, eliminated ladder fuels, and enhanced spatial heterogeneity of the overstory and understory. Each treatment was replicated at least three times and encompassed 1,200 ha with individual stands as treatment replicates.

***Lessons Learned.*** The partnership among the Black Hills NF, Northern Hills Ranger District, and research personnel was essential and ultimately led to the successful implementation of the study, from preparing the environmental assessment and study plan to marking the treatments and preparing the contracts to administrating the timber sale. Also, in the Black Hills, the cooperation of the timber industry was essential to complete the first entries of the irregular selection system in a timely manner. Managers and scientists were able to create structural diversity by simply using tree vigor. However, developing protocols for cleaning the abundant seedlings and saplings while integrating the presence of overstory trees took some innovative thinking, flexible contract specifications, and diligent contract administration.

## Partnerships and Alliances

### Science Partnerships and Technology Transfer Opportunities

Studies located on EFs provide opportunities for scientists to build partnerships and enhance research results. For example, at Priest River EF, we used an interdisciplinary research team where experts in silviculture, fire behavior, remote sensing, botany, and fuels worked together to evaluate the fuel treatment effectiveness of the treatments. Deception Creek EF cleaning provided opportunities for scientists and managers to develop treatments to introduce spatial diversity and address economic challenges associated with young forest management. At the Boise Basin EF, scientists developed forest floor treatments for other purposes than site preparation for planting. The Black Hills EF was an ideal location to implement and evaluate irregular selection systems targeted at restoring forests, producing timber, and creating recreation opportunities in the face of bark beetles and a changing climate. Interdisciplinary research on EFs forces scientists and managers to work outside their disciplinary comfort zone, and together, the scientists identify integrated science questions leading to unforeseen but often more management-relevant results (Wells et al. 2009).

Place-based research on EFs provides opportunities to integrate studies, overlay other research objectives, provide graduate student education, and apply tested research methods in other locations. The integrated restoration studies have attracted scientists and studies not necessarily related to the original research. For example, on the Black Hills EF, a scientist is investigating the effects of variable overstory density on snow dynamics. On Deception Creek EF, a student who is a trainee for NFS is using the cleaning study as her graduate project. This opportunity not only fulfills a graduate degree requirement but also provides on-the-job training. Results from the old-growth restoration work on the Boise Basin EF led to a companion study on the Kootenai NF in Montana.

Providing relevant and timely science information in field and formal settings is paramount to a scientist's success (Wells et al. 2009). Scientists and students formally present results at symposia, professional meetings, and other workshops. However, often the most successful transfer of knowledge occurs at EFs. For example, state, federal, private industry, small private landowners, members of collaborative groups, students, and the press have visited these four EFs and the study areas. During field visits, scientists illustrate the treatments and discuss their rationale, outcomes, and future direction. District managers discuss their experiences and describe the nuances involved with study implementation. These related studies provide a place for all stakeholders to have open discussions and gain a common understanding of forest dynamics and how this understanding may inform forest management actions (Graham 2004).

Scientists leave a long-term legacy on EFs by implementing silviculture research that is passed from one scientist to another, but these forests also provide a catalyst for documenting research outcomes. Passing a legacy from one scientist to another allows for progression of ideas and promotes innovative science (Wells et al. 2009, Yung et al. 2012). Since 1911, the legacy of five research silviculturists provided the extensive silvicultural knowledge we used to conceptualize the irregular selection system (Graham 2004). Also, scientists working at Priest River, Deception Creek, and Boise Basin EFs have published hundreds of papers in forest ecology, fire, watershed, and silviculture. Similar to past studies, our irregular selection work focused on forest restoration in an integrated fashion will provide concepts, knowledge, and locations along with a variety of forest structures and compositions that will contribute to forestry research for decades (Wells et al. 2009, Vavra and Mitchell 2010).

### Science and Management Partnership

A science and management partnership is embedded in all Forest Service EFs, a major component leading to successful management relevant research (USDA Forest Service 2005, Swanson et al. 2010). The research station director has the authority to determine what occurs on an EF while the regional forester has the authority to sell timber, build roads, and authorize the expenditure of funds for fire suppression, forest thinning, road building, and slash treatments. Similar to NFS lands, site-disturbing activities on EFs require environmental assessments and their approval as described in the National Environmental Policy Act. Personnel from R&D and NFS develop these assessments, promoting a continuous and ongoing partnership among stations, districts, forests, and regions. This process ensures that what is tested on an EF is applicable in other locations.

This partnership between scientists and managers is practical and effective. Scientists can develop research studies that have immediate practical value. For example, logistics limits the breadth of implementation options but also adds practical relevance to the research. For example, on the Black Hills EF, the equipment used in the cleanings prevented tree spacing from being less than 3 m (Figure 5B and C). This diminished potential cleaning treatments to test, but this limitation makes study results realistic and applicable. As such, Black Hills NF managers have concepts, ideas, and results derived locally that can inform their decisions. Similarly, Idaho City District managers were part and parcel in choosing tools and developing burning prescriptions to reduce the organic material at the base of the large ponderosa pines. Science and management partnerships are essential today and in the long term, but mutual learning among managers, scientists, and stakeholders is what makes research relevant.

## Concluding Remarks

Placed-based research studies such as those that occur on EFs provide living laboratories to test original and innovative silvicultural methods and systems. They give future scientists, managers, landowners, and people of all ages and backgrounds a place to learn about forest ecology and management. These research sites offer scientists a place to conduct field trips and to critically discuss tradeoffs and benefits from silvicultural studies. An EF "links people, place, and community with an emerging vision of ecosystem management" (Wells et al. 2009). Networking EFs, such as in the integrated restoration study, strengthens the research and broadens its applicability, but this process also identifies local ecological threads and management strategies and emphases social, economic, and ecological commonalities within and among regions.

## Literature Cited


Adams, M.B., L. Loughry, and L. Plaugher (comps.). 2008. *Experimental forests and ranges of the USDA Forest Service.* USDA For. Serv., Gen. Tech. Rep. NE-321, Northeastern Research Station, Newtown Square, PA. 183 p. [CD-ROM]

Alexander, R.R. 1987. *Silvicultural systems, cutting methods, and cultural practices for Black Hills ponderosa pine.* USDA For. Serv., Gen. Tech. Rep. RM-139, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 32 p.

Anderson, I.V. 1934. *Application of selective logging to a ponderosa pine operation in western Montana.* State University of Montana Studies, No. 2, State University of Montana, Missoula, MT. 56 p.

Bengston, D.N. 1994. Changing forest values and ecosystem management. *Soc. Nat. Res.* 7(6):515–533.

Boldt, C.E., and J.L. Van Deusen. 1974. *Silviculture of ponderosa pine in the Black Hills: The status of our knowledge.* USDA For. Serv., Res. Pap. RM-124, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 45 p.

Covington, W.W., and M.M. Moore. 1994. Post-settlement changes in natural fire regimes and forest structure: Ecological restoration of old-growth ponderosa pine forests. *J. Sustain. For.* 2(2):158–181.

Dale, V.H., L.A. Joyce, S. McNulty, R.P. Neilson, M.P. Ayres, M.D. Flannigan, P.J. Hanson, et al. 2001. Climate change and forest disturbances. *Bioscience* 51(9):723–734.

Deitschman, G.H., and R.D. Pfister. 1973. *Growth of released and unreleased young stands in the western white pine type*. USDA For. Serv., Res. Pap. INT-132, Intermountain Forest and Range Experiment Station, Ogden, UT. 14 p.

Eichhorn, E. 1922. Die freie Wirtschaft und das badische Forsteinrichtungsverfahren [The free economy and the Baden forest management planning process]. *Allg. Forst-Jagdztg.* 98:49–60.

Fettig, C.J., K.D. Klepzig, R.F. Billings, A.S. Munson, T.E. Nebeker, J.F. Negron, and J.T. Nowak. 2007. The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States. *For. Ecol. Manage.* 238(1–3): 24–53.

Finney, M.A. 2001. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. *For. Sci.* 47(2):219–228.

Foiles, M.W. 1955. *Thinning from below in a 60-year-old western white pine stand.* USDA For. Serv., Res. Note 19, Intermountain Forest and Range Experiment Station, Ogden, UT. 6 p.

Graham, K.L. 2004. *History of the Priest River experimental forests.* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-129, Rocky Mountain Research Station, Fort Collins, CO. 71 p.

Graham, R.T. 1988. Influence of stand density on western white pine, redcedar, hemlock, and grand fir in the northern Rocky Mountains. P. 175–184 in *Future forests of the mountain west: A stand culture symposium,* Schmidt, W.C. (comp.). USDA For. Serv., Gen. Tech. Rep. INT-243, Intermountain Research Station, Ogden, UT.

Graham, R.T., and T.B. Jain. 2005. Application of free selection in mixed forests of the inland northwestern United States. *For. Ecol. Manage.* 209:131–145.

Graham, R.T., S. McCaffrey, and T.B. Jain (tech. eds.). 2004. *Science basis for changing forest structure to modify wildfire behavior and severity.* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-120, Rocky Mountain Research Station, Fort Collins, CO. 43 p.

Graham, R.T., T.B. Jain, and J. Sandquist. 2007. Free selection: A silvicultural option. P. 121–156 in *Restoring fire-adapted forested ecosystems: 2005 national silviculture workshop,* Powers, R. (ed.). USDA For. Serv., Gen. Tech. Rep. PSW-GTR-203, Pacific Southwest Research Station, Albany, CA.

Haight, R.G., and R.A. Monserud. 1990. Optimizing any-aged management of mixed-species stands: II. Effects of decision criteria. *For. Sci.* 36(1):125–144.

Harmon, W.H. 1955. Ponderosa pine management in the Black Hills. *Ames Forester* 42:6–8.

Harvey, A.E., J.W. Byler, G.I. McDonald, L.F. Neuenschwander, and J.R. Tonn. 2008. *Death of an ecosystem: Perspectives on western white pine ecosystems of North America at the end of the twentieth century.* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-208, Fort Collins, CO. 10 p.

Hessburg, P.F., R. Salter, J. Brion, and K.M. James. 2005. Evidence of mixed severity fires in pre-management era dry forests of the inland northwest, USA. P. 89–104 in *Mixed severity fire regimes: Ecology and management: Symposium proceedings*, Taylor, L., J. Zelnik, S. Cadwallader, and B. Hughes (eds.). Washington State University Extension and USDA, Pullman, WA.

Hood, S.M. 2010. *Mitigating old tree mortality in long-unburned, fire-dependent forests: A synthesis.* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-238, Rocky Mountain Research Station, Fort Collins, CO. 71 p.

Hornibrook, E.M. 1939. A modified tree classification for use in growth studies and timber marking in Black Hills ponderosa pine. *J. For.* 37(6):483–488.

Jain, T.B., M.A. Battaglia, H. Han-Sup, R.T. Graham, C.R. Keyes, J.S. Fried, and J.E. Sandquist. 2012. *A comprehensive guide to fuel management practices for dry mixed conifer forests in the northwestern United States.* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-292, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 331 p.

Jain, T.B., and R.T. Graham. 1996a. Deception Creek Experimental Forest. P. 45–50 in *Experimental forests, ranges, and, watersheds in the northern Rocky Mountains—A compendium of outdoor laboratories in Utah, Idaho, and Montana,* Schmidt, W.C., and J.L. Friede (comps.). USDA For. Serv., Gen. Tech. Rep. INT-GTR-334, Intermountain Research Station, Ogden, UT.

Jain, T.B., and R.T. Graham. 1996b. Priest River Experimental Forest. P. 51–58 in *Experimental forests, ranges, and, watersheds in the northern Rocky Mountains—A compendium of outdoor laboratories in Utah, Idaho, and Montana,* Schmidt, W.C., and J.L. Friede (comps.). USDA For. Serv., Gen. Tech. Rep. INT-GTR-334, Intermountain Research Station, Ogden, UT.

Jain, T.B., R.T. Graham, and P. Morgan. 2004. Western white pine growth relative to forest openings. *Can. J. For. Res.* 34(11):2187–2198.

Jain, T.B., R.T. Graham, J. Sandquist, M. Butler, K. Brockus, D. Frigard, D. Cobb, et al. 2008. Restoration of northern Rocky Mountain moist forests: Integrating fuel treatments from the site to the landscape. P. 147–172 in *Integrated restoration of forested ecosystems to achieve multi-resource benefits: Proceedings of the 2007 National Silviculture Workshop,* Deal, R.L. (ed.). USDA For. Serv., Gen. Tech. Rep. PNW-GTR-733, Pacific Northwest Research Station, Portland, OR.

Ketcham, D.A., C.A. Wellner, and S.S. Evans Jr. 1968. Western white pine management

programs realigned on northern Rocky Mountain National Forests. *J. For.* 66(4):329–332.
LARSON, A.J., AND D. CHURCHILL. 2012. Tree spatial patterns in fire-frequent forests of western North America, including mechanisms of pattern formation and implications for designing fuel reduction and restoration treatments. *For. Ecol. Manage.* 267(1):74–92.
LONG, J.N., AND F.W. SMITH. 2000. Restructuring the forest: Goshawks and the restoration of southwestern ponderosa pine. *J. For.* 98(8): 25–30.
LUCE, C., P. MORGAN, K. DWIRE, D. ISAAK, Z. HOLDEN, AND B. RIEMAN. 2012. *Climate change, forests, fire, water, and fish: Building resilient landscapes, streams, and managers.* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-290, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 207 p.
LUGO, A.E., F.J. SWANSON, O.R. GONZÁLEZ, M.B. ADAMS, B. PALIK, R.E. THILL, D.G. BROCKWAY, C. KERN, R. WOODSMITH, AND R. MUSSELMAN. 2006. Long-term research at the USDA Forest Service's experimental forests and ranges. *BioScience* 56(1):39–48.
MEYER, H.A., A.B. RECKNAGEL, D.D. STEVENSON, AND R.A. BARTOO. 1961. *Forest management.* Ronald Press Co., New York. 282 p.
MITCHELL, R.J., B.J. PALIK, AND M.L. HUNTER JR. 2002. Natural disturbance as a guide to silviculture. *For. Ecol. Manage.* 155: 315–317.
NEWPORT, C.A. 1956. *Forest Service policies in timber management and silviculture as they affect the lumber industry: A case study of the Black Hills.* South Dakota Department of Game, Fish, and Parks, Pierre, SD. 113 p.
PEARSON, G.A. 1942. Improvement selection cutting in ponderosa pine. *J. For.* 40(10):753–760.
PUETTMANN, K.J., K.D. COATES, AND C. MESSIER. 2009. *A critique of silviculture: Managing for complexity.* Island Press, Washington, DC. 189 p.
PYNE, S.J. 1982. *Fire in America: A cultural history of wildland and rural fire.* Princeton University Press, Princeton, NJ. 655 p.
RAYMOND, P., S. BÉDARD, V. ROY, C. LAROUCHE, AND S. TREMBLAY. 2009. The irregular shelterwood system: Review, classification, and potential application to forests affected by partial disturbance. *J. For.* 107(8):405–413.
REINHARDT, E.D., J.K. BROWN, W.C. FISCHER, AND R.T. GRAHAM. 1991. *Woody fuel and duff consumption by prescribed fire in northern Idaho mixed conifer logging slash.* USDA For. Serv., Res. Pap. INT-443, Intermountain Research Station, Ogden, UT. 22 p.
REYNOLDS, R.T., R.T. GRAHAM, M.H. REISER, R.L. BASSETT, P.L. KENNEDY, D.A. BOYCE JR., G. GOODWIN, R. SMITH, AND E.L. FISHER. 1992. *Management recommendations for the northern Goshawk in the southwestern United States.* USDA For. Serv., Gen. Tech. Rep. RM-217, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 90 p.
SHEPPERD, W.D., AND M.A. BATTAGLIA. 2002. *Ecology, silviculture, and management of Black Hills ponderosa pine.* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-97, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 112 p.
SLOAN, J., AND R. STEELE. 1996. Boise Basin Experimental Forest. P. 39–44 in *Experimental forests, ranges, and, watersheds in the northern Rocky Mountains—A compendium of outdoor laboratories in Utah, Idaho, and Montana,* Schmidt, W.C., and J.L. Friede (comps.). USDA For. Serv., Gen. Tech. Rep. INT-GTR-334, Intermountain Research Station, Ogden, UT.
SÜSSE, R., C. ALLEGRINI, M. BRUCIAMACCHIE, AND R. BURRUS. 2011. *Management of irregular forests—Developing the full potential of the forest.* Association Futaie Irreguliere, Besancon, France. 144 p.
SWANSON, F.J., S. EUBANKS, M.B. ADAMS, J.C. BRISSETTE, AND C. DEMUTH. 2010. *Guide to effective research-management collaboration at long-term environmental research sites.* USDA For. Serv., Gen. Tech. Rep. PNW-GTR-821, Pacific Northwest Research Station, Portland, OR. 12 p.
TEWS, J., U. BROSE, V. GRIMM, K. TIELBÖRGER, M.C. WICHMANN, M. SCHWAGER, AND F. JELTSCH. 2004. Animal species diversity driven by habitat heterogeneity/diversity: The importance of keystone structures. *J. Biogeogr.* 31(1): 79–92.
USDA. 2014. *Valuing ecosystem services.* Available online at www.fs.fed.us/ecosystemservices/About_ES/faq.shtml#ecoservices; last accessed Mar. 26, 2014.
USDA FOREST SERVICE. 2005. *Forest Service manual* 4060: *Research facilities and areas.* Available online at www.fs.fed.us/im/directives/fsm/4000/4060; last accessed Mar. 26, 2014.
USDA FOREST SERVICE. 2012. *Black Hills National Forest. final environmental impact statement for the mountain pine beetle response project.* USDA For. Serv. 372 p. Available online at www.fs.usda.gov/wps/portal/fsinternet/!ut/p/c5/04_SB8K8xLLM9MSSzPy8xBz9CP0os3gDfxMDT8MwRydLA1cj72BTUwMTAwgAykeaxRtBeY4WBv4eHmF-YT4GMHkidBvgAI6EdIeDXIvfdrAJuM3388jPTdUvyA2NMMgyUQQAyrgQmg!!/dl3/d3/L2dJQSEvUUt3QS9ZQnZ3LzZfS000MjZOMDcxT1RVODBJN0o2MTJQRDMwODQ!/?project=36775; last accessed Mar. 26, 2014.
VAVRA, M., AND J. MITCHELL. 2010. Experimental forests and ranges as a network for long-term data. P. 15–23 in *Meeting current and future conservation challenges through the synthesis of long-term silviculture and range management research.* USDA For. Serv., WO-GTR-84, Washington, DC.
WALKER, B.H., AND D. SALT. 2006. *Resilience thinking: Sustaining ecosystems and people in a changing world.* Island Press, Washington, DC. 174 p.
WELLS, G., D. HAYES, K. KRAUSE, A. BARTUSKA, S. LEVAN-GREEN, J. ANDERSON, T. GOUGH, ET AL. 2009. *Experimental forests and ranges: 100 years of research success stories.* USDA For. Serv., Gen. Tech. Rep. FPL-GTR-182, Forest Products Laboratory, Madison, WI. 29 p.
WEAVER, H. 1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific slope. *J. For.* 41(1):7–15.
YUNG, L., M. BRADBURY, AND D.R. WILLIAMS. 2012. *Experimental forests and climate change: Views of long-term employees on ecological change and the role of experimental forests and ranges in understanding and adapting to climate change.* USDA For. Serv., Res. Pap. RMRS-RP-100, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 56 p.

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