

The Intertwining Paths of the Density Management and Riparian Buffer Study and the Northwest Forest Plan

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Abstract

Initiated simultaneously, the Density Management and Riparian Buffer Study of western Oregon and the Northwest Forest Plan have had intertwining paths related to federal forest management and policy changes in the Pacific Northwest over the last 15 to 20 years. We briefly discuss the development of the Northwest Forest Plan and how it changed the way forest policy was developed in the region. The concurrent conceptualization and implementation of the Density Management and Riparian Buffer Study within this new management framework resulted in a proof-of-concept for adaptive management approaches outlined in the Plan, especially relative to riparian and upland restoration practices. The Density Management Study serves as a model for integrated knowledge discovery and adaptive management within the context of the federal forest plan. The future of the study appears to be similarly interconnected with the interagency plan for federal lands management.

Keywords: Forest thinning, western Oregon, Bureau of Land Management, Forest Service.

Introduction

The Density Management and Riparian Buffer Study (DMS) originated in 1993 as a long-term, operational-scale experiment to investigate silvicultural techniques intended to accelerate development of late-successional and old-growth forest characteristics in western Oregon (Cissel et al. 2006). To accomplish this, the study tested alternative thinning prescriptions that were not yet tested or established in the scientific literature at the time of study establishment. The upland thinning design of DMS was conceived before finalization of the Northwest Forest Plan (hereafter, the Plan) (USDA and USDI 1994a), but was implemented within the new policy

framework created by the Plan. Although not an initial goal of the study, the implementation of the DMS identified ways that federal agency land managers in western Oregon, in particular the U.S. Bureau of Land Management (BLM), could adapt to work within the new policy framework and more quickly achieve Plan goals, especially in reserved land allocations.

By examining the DMS study, we explore the intertwining threads of policy changes, knowledge discovery, and new management questions asked during development and implementation of the Plan. We briefly discuss the history of the Northwest Forest Plan and how

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it changed the way forest policy was developed. We show how the DMS arose within the new management framework, and finally discuss how the DMS has affected federal forest management at district and forest levels relative to regional management policy. It appears certain that western Oregon forest managers will continue to employ adaptive management to adjust to new challenges. The future of the DMS appears to be similarly interconnected with the Plan.

The Northwest Forest Plan: Abbreviated Synopsis

The listing of the Northern Spotted Owl (*Strix occidentalis caurina*) as a threatened species under the U.S. Endangered Species Act in 1990 (55 FR 26114 26194) was neither the beginning nor the end of the struggle between old-growth forest preservation and timber management. Regional scientists had been concerned about loss of owl habitat since the early 1970s (Forsman 1975; Yaffee 1994). Although the spotted owl was the poster child for the forest-management conflicts coming to a head in the early 1990s, numerous scientists had been researching forest fragmentation effects on many different species, characterizing species-habitat relationships, and conducting species risk assessments (e.g., Ruggiero et al. 1991; Thomas et al. 1993). In addition to threatened species concerns, an emerging paradigm shift toward ecosystem management with multiple resource and restoration objectives came into conflict with conventional management practices on federal forests in the Pacific Northwest (Yaffee 1994). Historical timber harvest practices were geared toward wood commodity production and implemented to “get the cut out” (Thomas 2008; Williams 2009). Clashes between old-growth forest preservationists and federal land management agencies climaxed with a series of lawsuits that prevented timber sale and harvesting activities throughout the range of the Northern Spotted Owl (Thomas et al. 2006). These lawsuits in part defined a new era for

natural resource management in the U.S. where the management of public land was decided by legal determinations made by judicial courts (Thomas 2008).

In the polarized forest management climate of the early 1990s, President Clinton assembled the Forest Conference in 1993 to discuss the different social, economic, and environmental issues concerning old-growth forests. He ordered federal land management agencies to draft a balanced, long-term policy that would direct the management of federal forests in the Pacific Northwest in the range of the spotted owl (USDA and USDI 1994b).

President Clinton mandated that the “policy must:

- Never forget the human and the economic dimensions
- Protect long-term health of our forests, our wildlife, and our waterways
- Be scientifically sound, ecologically credible, and legally responsible
- Produce predictable and sustainable levels of timber sales and nontimber resources
- Make the federal government work together and work for you” (FEMAT 1993).

The Forest Ecosystem Management and Assessment Team (FEMAT), which included representatives from the BLM, U.S. Forest Service, Fish and Wildlife Service, National Park Service, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, and Environmental Protection Agency, was created to craft this difficult policy. The final report was released in July of 1993 (FEMAT 1993) and was adapted into the Northwest Forest Plan in 1994 (USDA and USDI 1994a; 1994b). Numerous detailed discussions of the Plan are available (e.g., see USDA and USDI 1994a; Yaffee 1994; Marcot and Thomas 1997; Thomas 2008).

The Northwest Forest Plan started a process toward implementing ecosystem-scale, science-based forest management (Thomas 2008). One hallmark of the Plan was that for the first time, scientists led development of land management

alternatives and played a key role in crafting federal policy (Bormann et al. 2007). FEMAT consisted of a team of scientists with expertise in various aspects of forest management and its economic, ecological and social impacts. The team was led by the “Gang of Four plus Two”—wildlife and fisheries researchers from the Pacific Northwest aided by a cadre of hundreds of consultants (FEMAT 1993). This unique set of expertise manifested itself in a new management approach. The Plan was the first effort to manage a forest ecosystem at the regional scale across an expansive area of ~10 million hectares (24.5 million acres) using a science-based, multi-resource approach. The original FEMAT design conceptually ensured that management actions taken on a local scale would not impair ecosystem function at a regional scale (FEMAT 1993). Fine-scaled management elements were later integrated into the regional Plan, providing for a multi-scaled management framework. “Survey and manage” requirements were added by President Clinton’s Council on Environmental Quality to manage sensitive species with restricted distributions that were not otherwise protected by the Plan. Fine-scale survey and manage requirements combined with coarser-scale land-use allocations (LUAs) were intended to facilitate Plan implementation without triggering additional environmental regulations for species protections. With these requirements in place, the intent of the Plan was to assess projects by their outcomes as part of the interconnected regional ecosystem rather than assessing management impacts only on individual stand-level land parcels (Diaz 2004).

The integrated management of a regional ecosystem required that federal agencies, which had previously operated as fragmented administrative units, become partners. However, integrated management led to several operational challenges. Previous forest management actions had been planned through the local district personnel, including foresters and silviculturists, and were approved based on District or Area plans for inventory and timber harvests. When

the first comprehensive meetings between federal and state land managers and researchers were convened to discuss the spotted owl and old-growth management, participants lacked standardized approaches among agencies to assess multi-ownership forest blocks. For example, region-wide maps of forest resources were not available, and local or agency-specific mapping conventions made existing smaller-scale maps incompatible (Yaffee 1994). Plan implementation was delayed as procedural issues were worked out.

The Density Management and Riparian Buffer Study as an adaptive learning platform

Much of what the FEMAT discussed was founded in research conducted in the 1980s to 1990s to address characterization of old-growth forest (e.g., Franklin and Spies 1991), and to understand its development (Spies and Franklin 1988). Other researchers sought to understand how to manage young Douglas-fir (*Pseudotsuga menziesii*) plantations for eventual old-growth characteristics. Dr. John Tappeiner, a Senior Research Forester of the Bureau of Land Management Cooperative Research Unit and Oregon State University Professor, wanted to investigate new restoration management practices on BLM lands. Contemporary studies such as forest thinning in the Black Rock Forest Research Area (Del Rio and Berg 1979) or the Young Stand Thinning and Diversity Study (Hunter 1993) were designed to contribute to this topic. Those studies provided excellent information on the growth of forest stands, especially the relationships between tree and stand characteristics and stand density. However, they did not represent the variability that would occur in the overstory and understory at the stand level (J. Tappeiner, emeritus professor, Oregon State University College of Forestry, personal communication). The need for studies with broadened scope, such as the DMS, was apparent

as other large-scale silvicultural experiments were also implemented during this time (Poage and Anderson 2007). The DMS treatments were designed to be implemented at the large-stand scale (50- to 300-ha treatments), with study sites encompassing the range of managed stand conditions more representative of western Oregon managed forests.

The Riparian Buffer Study component was added to the initial density management study objectives in 1994 (Cissel et al. 2006; Olson 2013). This component addressed the “interim” provision in the NWFP regarding riparian reserves. The riparian reserve land-use allocation in the Northwest Forest Plan was defined to provide specific conservation and mitigation for aquatic and riparian resources. The interim riparian reserve widths (ranging from two site-potential tree heights for fish-bearing stream reaches to one site-potential tree height for intermittent streams) were intended to be adjusted after watershed and project-specific analyses of aquatic-riparian resources. The riparian buffer aspect of DMS was designed specifically to test various widths of riparian buffers in conjunction with upland thinning according to Plan Standards and Guidelines (USDA and USDI 1994b), as well as possible management options within riparian reserve boundaries (Hohler et al. 2001; Cunningham 2002; Diaz and Haynes 2002).

Thus, by 1994, the DMS had become the first stand-scale test of joint riparian and upland management prescriptions in the Pacific Northwest, and sought to address knowledge gaps identified during Plan development. In summary, the DMS was implemented to answer two general questions: 1) How well do alternative thinning pathways accelerate the development of late-successional forests? and 2) What are the effects on aquatic-riparian resources of riparian buffers of varying widths in conjunction upland thinning?

The DMS presented logistical and organizational challenges that echoed other hurdles in implementing the Plan. Processes

developed during early DMS implementation were later used to address questions and concerns about Plan implementation. For example, DMS site selection and study implementation processes helped to frame later discourse about procedures for forest management planning under the Plan. During study-site selection for the DMS, several criteria were weighed. These included geographic representation, forest type and condition, and land-use allocation as described in the Plan on lands owned by the BLM. In the early 1990s, much of the federal landscape (52 percent of BLM holdings) in western Oregon consisted of Douglas-fir plantations younger than 80 years old (Cissel et al. 2006), with 35 percent of BLM holdings younger than 40 years (Muir et al. 2002). Thinning projects in young Douglas-fir stands had already been proposed on some national forests and BLM resource areas, and hence areas suitable for the study were easily found. Some administrators expressed doubt about the efficacy of the heavy thinning prescription proposed in the variable-density treatment (Cissel et al. 2006), and local natural-resource managers raised concerns about the use of treatments within the range of the spotted owl or the Marbled Murrelet (*Brachyramphus marmoratus*). On the heels of the forest management paradigm shift signaled by the entire Plan, which included a new set of land-use allocations for the federal lands of the Pacific Northwest, field-level personnel also raised concerns about potentially locking up lands that were intended to be managed for later regeneration harvests (“matrix” land-use allocation) into a long-term study (C. Thompson, BLM, personal communication). Others held the opinion that the study aims might be irrelevant because the BLM had been thinning stands for a number of years and knew its effects on stand development, and also because with a new [federal] administration, public land-use policy would revert to what it had been (J. Tappeiner, emeritus professor, OSU College of Forestry, personal communication). Eventually, the scope of the study was narrowed, when the Medford

BLM district was dropped from the study because the forest types and stand conditions in this sub-region were deemed to be too different from the other BLM ownerships to warrant inclusion in the study. DMS sites were selected from four western Oregon BLM districts, including seven stands in lands allocated as matrix and three stands in late-successional reserves (LSR). Three additional sites on LSR-designated lands managed by the Siuslaw National Forest were selected specifically for implementation of the Riparian Buffer Study component, with elements of the moderate upslope thinning (Cissel et al. 2006). DMS study sites were among the first forest management projects implemented by field units after finalization of the Northwest Forest Plan, and in many cases, set the stage for later Plan management-unit implementation.

The study was conducted at an operational scale, addressing many logistical issues that arose later in other thinning operations. The DMS treatments were designed to diversify stands with gaps and, leave islands, as well as variable-density thinning. Consequently, sale-preparation crews had to be trained in new methods to select trees for harvest to achieve a heavier and more spatially variable thinning, compared to more conventional thinning operations. Marking crews were quick to adapt to the challenge, with most stands being adequately marked to meet prescriptions with a single effort (C. Thompson, BLM, personal communication). Additionally, methods for marking riparian buffers also needed to be developed. Researchers from the PNW along with BLM personnel developed approaches at DMS sites that were subsequently used along headwater streams in other areas of western forests. These have been general guidelines, however, and many districts still implement a buffer width of one or two site-potential tree heights for riparian buffers as proposed in the Plan (USDA and USDI 1994a). Study site coordinators from the BLM were also able to resolve concerns about sensitive species and microhabitats by adjusting how leave islands were placed. Although random selection

of upland treatment units and reaches for buffer treatments was preferred, site-specific delineation adjustments to address implementation barriers allowed the DMS to act as a model for resolving project conflicts at multiple scales (Olson et al. 2002). Loggers and other equipment operators adjusted to felling and maneuvering trees in and around riparian reserves and leave islands.

Furthermore, socioeconomic considerations of implementing the DMS were projected relative to both operational and implementation costs. To make DMS sales profitable, patch openings and off-site parcels were included in some DMS sales, as they increased harvest amounts and market values (Olson et al. 2002). Wood harvest as a result of DMS implementation at individual BLM study sites was estimated to range from ~1 to 8.5 mmbf (million board feet; 2359 to 20 058 m³) from site-specific project areas ranging from 73 to 162 ha (Olson et al. 2002). DMS harvest volumes exceeded those of conventional thinnings, largely due to inclusion of patch cuts. As with any profitable harvest on BLM-administered land at the time, the DMS harvests provided timber benefits to the economy of local counties (Olson et al. 2002). The DMS demonstrated that despite various hurdles, complicated management prescriptions can be implemented in a way that provides silvicultural and operational learning opportunities. Subsequent timber-project planning efforts benefited from the lessons learned from DMS implementation.

In contrast, reviews of the success of adaptive management in the Northwest Forest Plan have mostly identified short-comings in adaptive management areas. Problems with the application of adaptive management generally lie in the lack of a learning framework for management and a failure to close the learning loop even after monitoring is completed. Adaptive management areas included flexible provisions to address the need for development of innovative management approaches and integration of site-specific contexts into local projects. Surveys of federal land

managers who have operated designated adaptive management areas identified factors limiting successful implementation, such as regulations, especially the Endangered Species Act, a lack of support from higher-level administrators, and a lack of cooperation between researchers and managers (Stankey et al. 2003). Other criticisms such as risk aversion, poor record keeping and budget misallocation also were identified as hurdles to implementation (Bormann et al. 2007). The primary failures of adaptive management were the lack of integrating learning opportunities from project inception through to final monitoring and the testing of alternative strategies. These aspects would heighten the efficacy of adaptive management approaches, and go beyond the collection of just monitoring data (Bormann et al. 2007).

However, there were some bright spots in implementing adaptive management, such as the creation of a formal monitoring program (Haynes et al. 2006), increased stakeholder involvement (Stankey et al. 2006), and increased respect and cooperation between researchers and decision makers (Bormann et al. 2007). Suggestions to improve the way adaptive management areas function included defined leadership and support roles, continuity, standardized documentation, and a commitment to learning (Stankey et al. 2003, 2006). After receiving the interpretive report (Haynes et al. 2006), federal regional managers developed and approved a formal adaptive management framework, and refocused questions for future efforts. This completed the cycle of adaptive management for the first 10 years of the Plan. The DMS sets forth a model of how a more formal question-focused learning effort can be carried out and fit within a learning environment across multiple land allocations.

Application of the DMS

The DMS study is an example of effective active management and research in support of the Plan. In line with the objectives of the

study, the DMS has: shown that variable-density thinning, including gaps and heavy thinning, moved canopy heterogeneity closer to old-growth conditions (Wilson and Puettmann 2007); demonstrated that 15-m buffers largely maintained the stream microclimate within the upland thinning context (Anderson et al. 2007); and identified headwater-dependent aquatic species that may warrant consideration during forest management, for their habitat maintenance and landscape connectivity considerations (Olson et al. 2007; Olson and Burnett 2009, 2013; Olson 2012). Although set up primarily to answer basic questions about forest and riparian management, the study has included additional studies on bryophytes, lichens, songbirds, macroinvertebrates, and other natural-resource elements (Cissel et al. 2006). Over 100 research papers and technology-transfer products have resulted from the study (<http://ocid.nacse.org/nbii/density/pubs.php>). Additionally, through field trips, presentations, and outreach programs such as “Teachers in the Woods”, over 5000 people were exposed to the DMS or visited the study sites from 2003–2006 (USDI, unpublished data). The study has provided an opportunity for prolific knowledge discovery, and has become a platform for diverse discussions regarding forest management.

From the outset, the DMS was designed to be relevant to forestry operations. Many of the original study designers from the BLM and PNW are still involved in the study. The result of this continuity has been a steady stream of management-relevant products and face-to-face workshops to disseminate the results of the study. In this way, the DMS has been, by design, not only relevant to the researchers, but has intimately involved managers and resource specialists as well. As a result of effective technology transfer, the DMS study has had a direct effect on the way forest thinning projects are planned by field management units. Research produced by the DMS has been cited in several recent Environmental Assessments to provide evidence

that the planned management is scientifically sound. BLM districts with DMS experience as well as Forest Service projects in western Oregon have used the DMS in project planning. Projects in the Salem BLM district like the Gordon Creek Restoration Project (USDI BLM 2009) cited the district's experience with the DMS as evidence for the effectiveness of variable-density thinning treatments. The Highland Fling Project used the DMS to predict effects on riparian species (USDI BLM 2010). The Forest Service also uses results from the DMS. The Siuslaw National Forest used results from the DMS to predict the response of the understory to project actions in the environmental assessment for the Salmon/Neskowin Project (USDA FS 2011).

In addition to the technology transfer provided by the DMS, direct alliances among DMS researchers, field managers, and natural-resource specialists have aided in bridging science and application to on-the-ground forest thinning and riparian management. The combined effort from the DMS and other large-scale silvicultural experiments provides a wealth of useful information for project planners and implementers (Poage and Anderson 2007; Anderson and Ronnenberg 2013). The sustained flow of technology transfer, including science publications as well as summary articles and workshops geared for managers, is an essential part of applied research programs. Furthermore, DMS has been used as a demonstration project for broader learning opportunities. University classes, natural-resource specialist training workshops, and national to international forestry and natural-resource specialists have visited the sites in order to understand the relevance of the variety of treatments established there. Flyers, brochures, and Web-site materials have allowed further outreach to the broad forestry community. DMS concepts have been presented to forestry organizations such as the Society of American Foresters and the International Union for Forest Research Organizations, raising the profile of DMS research applications. Finally,

the DMS is an example of the evolving concept of adaptive management. Findings from the first 10 years of the study have led to "phase 2" treatments, with heavier thinning treatments and further-modified riparian buffers. Phase 2 of the DMS now tests the application of an additional thinning harvest at the sites, conducted within the existing treatments, and includes a case study of thinning without a riparian buffer. Additional response variables could be investigated within this new context to expand the learning paradigm offered by the overarching study template. If DMS sites can be retained as designated research areas beyond the scheduled end point of current studies, they could continue to be used to refine the ideas of adaptive management in the future.

Although the DMS has shown its relevance to individual projects conducted by local administrative units, it has had less impact on recent regional planning efforts like BLM's Western Oregon Plan Revision (WOPR; USDI BLM 2008) or national-level planning such as the recently proposed Planning Rule Revision from the Forest Service. The WOPR included provisions to increase timber harvest on BLM lands in western Oregon. Increased harvest would be accomplished by increasing the amount of land where harvest was allowed, reducing the width of riparian buffers and streamlining the process to approve higher thinning intensities. Although directly relevant to many WOPR issues, DMS findings were seldom referenced (USDI BLM 2008), with exception of microclimate results. The DMS findings can contribute more to science-based forest management decisions in western Oregon; closing this apparent gap is a challenge to the DMS researchers and their partners who directly navigate this science-management interface. This is an area for further development as DMS outreach to managers and decision-makers continues into the future.

Whereas the vacated WOPR was unsuccessful in changing provisions in the Northwest Forest Plan on the regional level, the Forest Service is working to alter how forest management

decisions are being made at the local level. In the last decade, the Forest Service has tried to implement policies to make it easier to conduct thinning projects or other forest management activities. A sample of these policies includes President G.W. Bush's Healthy Forests Initiative in 2003, and the 2008 Planning Rule Revision (USDA FS 2008), which was suspended in 2009. A new final planning rule was recently released (<http://www.fs.usda.gov/planningrule>), and includes national-level process guidance for programmatic planning at the unit (national forests and grasslands) and regional scales, to set the context for local project and landscape-scale decision-making. It also emphasizes learning while planning and direct stakeholder involvement in collaborative assessments. Local project National Environmental Policy Act (NEPA) compliance will need to be constrained within regional and individual national forest plans, but will most likely be less prescriptive than the Northwest Forest Plan (B. Bormann, USFS, PNW Research Station, personal communication). The proposed Planning Rule Revision also emphasizes consideration of climate change and carbon storage in management decisions, and increasing public participation in project planning (USDA FS 2011). Approval of the revision will increase opportunities for DMS findings to significantly inform project planning, especially in west-side national forests. Continued development of informational products geared toward field managers will be important for DMS technology transfer to stay current. Bridging science and management across organizational scales of local areas to regions presents new challenges for studies such as the DMS and their proponents.

Finally, the DMS and density management research must stay relevant in the face of trends of declining research support from the federal government. With the DMS, the BLM has shown that it can incorporate research and sound management practices using agency personnel and agency land. By involving researchers and management personnel from multiple agencies,

field offices, and districts, management projects have been funded and implemented to benefit all parties. New research paradigms may be needed to expand research capacity, because funding may be lacking in an economically austere environment. However, by partnering researchers with specialists at field units who manage lands, new projects can be conceived and implemented by a suite of collaborators, not by scientists alone: DMS has been a model in this regard. The DMS has shown how multiple agencies can work together and solve problems at study, design, implementation, and information delivery stages (Olson et al. 2002).

Several ongoing and emerging research questions included or brought about by the DMS still need attention. Further study is needed on the management of young stands for late-successional and old-growth characteristics, including the age-range within which management toward the development of these characteristics can be effective; on how to manage fuel loads; and on how to work within the "80-year rule" (Tappeiner 2009). There is also a need to use matrix lands, especially those controlled by the BLM, for biodiversity management research, especially on early-seral habitat (Spies et al. 2007). Many questions remain about the efficacy of riparian reserve widths with upland regeneration harvests. Most managers do not vary from widths prescribed in the Plan, although studies from western Washington including those by Bisson et al. (2013) and Raphael and Wilk (2013) are contributing to this arena. In recent years, the initial success of the DMS has carried the momentum to other inquiries, such as the interplay between upslope treatment and water availability in riparian areas (Burton et al. 2013; K. Ruzicka, unpublished data) and modeling how climate change will affect the trajectory of the stands (K. Ruzicka, unpublished data). These projects rely on the long-standing relationships among Oregon State University, the Forest Service Pacific Northwest Research Station, and the BLM. Cooperation between researchers and

land management agencies is more important than ever.

Many collaborative land-management research projects, including the DMS, can improve their communication and partnering efforts with regional to national interest groups. Local managers of BLM and Forest Service lands understand the importance of research findings for the development of science-based management proposals. They can apply research results directly to management plans, including citing appropriate publications in NEPA documents. The absence of integration of DMS findings in recent national and regional management planning efforts suggests that research communication and advocacy to higher-level managers and policy-makers needs more attention. Project scientists and their science managers need to consider development of more effective mechanisms to actively engage regional administrators in dialogues about the outcomes and impacts of their work for regional-to national-scale management and policy development. Ensuring the integration of science findings at higher administrative scales would result in improved science-based policy decisions. Science communication across geographic scales of natural resource management and administration, and across agencies, makes this a complex task. Without integrated communication, including both the processes and the personnel such liaisons would entail, the outcome and impact of valuable studies such as DMS are not fully realized. In an era of constantly emerging issues, such as global climate change, invasive species, disease, and fire and pest management, science communication across administrative boundaries has never been more important.

Conclusion

The Northwest Forest Plan was the first regional ecosystem management plan, and tested the logistical, operational, and cooperative capacities

of land managers in the region. The Density Management Study originated in an atmosphere of new forest and riparian management questions, with important policy implications proposed to be answered through adaptive management. Over a decade of research in adaptive management has identified that the opportunity for learning must be realized at all stages of the project for management to be successful. The DMS also has provided a set of lessons-learned for how to successfully plan, implement, and communicate stand-scale research to a wide audience. With climate change and other emerging natural resource issues on our horizon, increased uncertainty in research funding, and anticipated changes in forest policy, the importance of the DMS will only increase. The DMS can serve as a model for integrative studies conducted jointly by collaborative partners from diverse research communities and land-management agencies. Furthermore, DMS study sites can continue to be relevant as documented locations that provide opportunities to efficiently address new, emerging forest-management questions. The DMS remains a golden opportunity for cutting-edge forest research in the future.

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