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silviculture

Variable-Retention Harvesting as a Silvicultural Option for Lodgepole Pine

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Bark beetle-induced mortality in forested landscapes of structurally uniform, even-aged lodgepole pine stands has inspired a growing interest in the potential of silvicultural treatments to enhance resilience by increasing spatial and vertical complexity. Silvicultural treatments can simulate mixed-severity disturbances that create multiaged lodgepole pine stands, which, along with heterogeneous forest landscapes, can play a role in mitigating susceptibility to primary disturbance agents (bark beetles and wildfire). With this article, we review multiaged lodgepole pine stand dynamics and discuss variable-retention harvesting as a silvicultural option for lodgepole pine. We describe the establishment and initial outcomes of an experimental variable-retention harvesting project established at the Tenderfoot Creek Experimental Forest (Montana) in 1999–2003 and the objectives of a collaborative multiagency effort that is presently revisiting and analyzing that experiment.

Keywords: uneven-aged management, forest stand dynamics, silviculture, forest restoration, mountain pine beetle

Lodgepole pine (*Pinus contorta* Douglas ex Loudon var. *latifolia* Engelm. ex S. Watson) forests throughout the interior West have lately been the setting for a storm of disturbance ecology. Severe and spatially extensive levels of mortality by mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (MPB) have prompted managers to reassess the relationship of stand structure to MPB outbreaks and to consider less-common silvicultural management techniques for lodgepole pine. Along with heterogeneous forest landscapes, silvicultural treatments that create more heterogeneous stand structures can be part of a mitigation strategy that enhances resilience to future disturbances (Whitehead et al. 2004, Fettig et al. 2007, Turner et al. 2013). To support this effort, researchers from the University of Montana and the US Department of Agriculture (USDA) Forest Service's Rocky Mountain Research Station and Northern Region Forest Health Protection programs formed an interdisciplinary, interagency research team that is revisiting two variants of variable-retention harvesting conducted in 2000 at Montana's Tenderfoot Creek Experimental Forest (TCEF) (Adams et al. 2008).

As the fourth largest forest type in the western United States, lodgepole pine forests (SAF cover type no. 218; Eyre 1980) provide the basis for varied and diverse ecological and economic benefits throughout western North America. Lodgepole pine forests occupy 4.8 million acres in Montana, 14.8 million acres throughout the Rocky Mountain and Pacific Coast regions, and 49 million acres in western Canada (Lotan and Critchfield 1990). In the northern Rockies (USDA Forest Service Region 1), the USDA Forest Service's Forest Health Protection program, which tracks MPB activity via an annual aerial insect and disease detection survey, has reported a dramatic expansion of MPB-affected areas and increased mortality levels since 1999. By 2012, the affected area had reached nearly 8.5 million acres, and although the MPB outbreaks continue in some locations, rates of mortality are declining across the region (Egan et al. 2013).

Drought and warmer winter temperatures are considered just part of the reason

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Figure 1. Multiaged lodgepole pine stands that are ubiquitous at TCEF, as formed by historical low- to mid-severity fires. Older cohort trees exhibit large, dense branch remnants in the lower crown that are indicative of fire survivors.

for the outbreak's facilitation; the present structure of the lodgepole forest landscape is probably much more susceptible to MPB than was historically so (Gillette et al. 2014). An abundance of dense, pure or nearly pure, even-aged stands of lodgepole pine supplies a contiguous source of uniformly available MPB host material, offering little resistance to the intensification and spread of MPB outbreaks on landscape scales. In British Columbia, where MPB-caused mortality since 1999 totals more than 44.7 million acres (BC Ministry of Forests, Lands, and Natural Resource Operations 2012), researchers analyzed fire, harvest, and current inventory records to reconstruct temporal changes in the distribution of lodgepole pine stand ages across the province (Taylor and Carroll 2004). Those authors estimated that in 1910, just 17% of the landscape comprised mature lodgepole pine stands susceptible to MPB (age classes 80–160 years). Owing largely to the exclusion of natural wildfires from stands that emerged after early 20th century logging and wildfires, the area of lodgepole pine forest in those MPB-susceptible age classes more than tripled to 53% by 1990. That trend was presaged many years ago by noted American entomologist F.C. Craighead, who expressed his concern that, "The intensive fire protection of overmature lodgepole pine stands is not improbably producing a condition favorable to widespread epidemics of the mountain pine beetle" (Craighead 1925).

As the MPB outbreaks are starting to wane in the northern Rocky Mountains, attention has focused on the next generation of forests and on silvicultural strategies to promote heterogeneous stands and landscapes with greater resilience to multiple disturbances. This trend coincides with an ongoing discourse on the role of silviculture as a mechanism for sustaining and enhancing forest complexity (e.g., Seymour and Hunter 1999, Puettmann et al. 2010). It is also consistent with the current nationwide emphasis on promoting the resilience of public lands. Enhancement of ecosystem resilience is a formal Climate Change Adaptation goal of the USDA (USDA Forest Service 2008), with novel treatments that enhance stand structure diversity being considered especially important in the face of likely increases in disturbance events under a dynamic and changing future climate (Westerling et al. 2006, Raffa et al. 2008, Bentz et al. 2010, Gillette et al. 2014).

Lodgepole Pine Forest Paradigms

Mainly associated with stand-replacing (wildfire-based) disturbance regimes, lodgepole pine has long served as the paragon of even-aged silviculture in the West, with the clearcut system believed to best simulate

Management and Policy Implications

Even-aged management has long been an effective silvicultural strategy for lodgepole pine, but complementary alternatives that can increase forest resilience exist. In the northern Rocky Mountains, structural uniformity at stand and landscape scales has exacerbated the susceptibility of lodgepole pine forests to bark beetles and stand-replacing wildfire. Evidence of natural mixed-severity fire regimes that create multiaged lodgepole pine stands, combined with favorable comparative growth analysis of multiaged and even-aged stands, suggests that multiaged management of lodgepole pine is a realistic silvicultural option to complement even-aged approaches. Variable-retention harvesting, with retention trees distributed uniformly or in aggregates, represents a form of transformation silviculture for developing greater horizontal and vertical complexity in structurally simple, even-aged stands. Widening the range of silvicultural treatments applied to lodgepole pine can help mitigate the threats to this important and widespread forest type.

the historic stand-replacing wildfire regime under which lodgepole pine apparently evolved. A coincidence of silvical and operational factors (shade intolerance, prolific and frequent seed production combined with good wind dispersal distances, modest product value, and comparatively high logging [trucking] costs among them) contributed to the widespread application of the block clearcut system for lodgepole pine stands. As a result, lodgepole pine stands both before and after harvest are typically pure, even-aged, single-storied, and dense.

Tree diameter and stand age have long been associated with the likelihood of MPB attack, and conventional mitigation strategies for even-aged lodgepole pine stands focused primarily on shifting species composition, reducing stand densities, and limiting rotation lengths (Roe and Amman 1970, Safranyik et al. 1974, Cole and Cahill 1976, Amman et al. 1977). Those principles have since been incorporated into density management diagrams that help silviculturists steer the stand development pathways of young even-aged stands toward reduced susceptibilities (Anhold and Jenkins 1987, Anhold et al. 1996, Whitehead et al. 2001).

However, alternative stand structures in lodgepole pine stands and alternative silvicultural approaches to their management have long been recognized. More than three decades ago, the influential Forest Service reference, *Silvicultural Systems for the Major Forest Types of the United States* (Alexander et al. 1983), noted that,

> . . . lodgepole pine may occur in virtually any age or stand configuration as a result of meadow invasion, past silvicultural treatments, scattered trees that produced seed for subsequent stand development, or the gradual deterioration of even-aged, old-growth.

Drawing on Colorado's experience with partial cutting in lodgepole pine stands at the Fraser Experimental Forest (Alexander 1975, also see Alexander 1986), those authors also acknowledged that "although an even-aged silvicultural system is preferred for lodgepole pine, both even-aged and uneven-aged systems can be used to regenerate lodgepole pine."

Similarly, fire ecologists have noted exceptions to the stand-replacing wildfire regime in lodgepole pine forests; mixed-severity fire regimes in the Rocky Mountains have been described for decades (Arno 1976, Arno 1980, Barrett et al. 1991, Agee 1993).

Figure 2. Dispersed retention treatments retained trees in a roughly regular spatial pattern, ranging in appearance between a uniform shelterwood cut and a heavy thinning.

Mounting evidence shows the relation of low- and mid-severity fires to the natural occurrence of multiaged lodgepole pine stands. For example, a recent study in lodgepole pine stands of the Canadian Rockies (Alberta) reconstructed fire history and stand dynamics by cross-dating fire scars with tree age distributions (Amoroso et al. 2011), yielding evidence that ties the occurrence of low- to moderate-severity fires to the emergence of even-age cohorts and to the formation of structurally complex, mixed-species, multiaged stands. The authors of that study concluded that "a broader range of silvicultural systems than is currently practiced would be consistent with historic forest dynamics" and argued that a variety of unconventional silvicultural systems, notably, variable-retention harvesting and multiaged management, would be compatible with the fire patterns they observed.

Evidence of that dynamic is prominently featured at Montana's TCEF. A fire history study performed throughout the watershed analyzed burn scars resulting from 12 fires between 1580 and 1992 (Barrett 1993). Low- and mixed-severity fires, sometimes occurring adjacent to stand-replacing fires, were common. Most occurred at sites that had burned within 50 years previously and were probably facilitated by regeneration and snags derived from the previous fire (Barrett 1993). Mapping fire boundaries by linking scar data to stand observations, aerial photographs, and timber type maps revealed that less than half of the lodgepole pine forest area at TCEF is even-aged; a surprisingly large area (53.9%; 4,480 acres) consists of lodgepole pine stands with at least two cohorts (Figure 1).

That high frequency of multiaged lodgepole pine stands led researchers to include the TCEF in a rare study of multiaged lodgepole pine forest stand dynamics (Kollenberg and O'Hara 1999). Extending similar work performed previously in multiaged ponderosa pine (O'Hara 1996), the study compared the leaf area indexes (LAIs), stand growth rates, and growing space efficiencies (annual stand volume growth per unit foliar area) of even-aged and multiaged stands in western Montana. Even-aged lodgepole pine stands were 16.2% more efficient than multiaged stands; however, multiaged stands supported substantially higher levels of leaf area (LAI of 2.6) than even-aged stands (LAI of 1.9). That 36.8% greater leaf area apparently more than offset the lower growing space efficiency levels, as the annual volume increment (ft^3/acre) of multiaged stands was 13.9% greater than that of even-aged stands. Overall, the study's findings indicated that from a stand growth perspective, the silviculture of multiaged stands represents a viable alternative to even-aged management, if operationally feasible systems to establish and sustain that structure are identified.

Experimental Variable-Retention Harvesting in Lodgepole Pine

Variable-retention harvesting (Franklin et al. 1997, Mitchell and Beese 2002, Aubry et al. 2009) represents one technique of "transformation silviculture" that can be applied to structurally simple, even-aged stands to initiate a transition to multiaged structures and systems (O'Hara 2001, Nyland 2003). In lodgepole pine forests, implementation of variable-retention cutting is hampered by a lack of documentation about the benefits of this silvicultural strategy and its advantages over the no-treatment alternative. Hence, we commenced the remeasurement and analysis of an innovative variable-retention cutting study conducted in lodgepole pine stands at TCEF (hereafter, "Tenderfoot Research Project" [TRP]). Established in 1961 on the Lewis and Clark National Forest, the 9,125-acre TCEF encompasses the headwaters of Tenderfoot Creek in Montana's Little Belt Mountains (Adams et al. 2008). The TCEF is representative of the lodgepole pine forests that are ubiquitous east of the Continental Divide in Montana, Wyoming, and southern Alberta.

Figure 3. Aggregated retention treatments produced harvest gaps and retention clumps of roughly equivalent area. Gaps and clumps vary widely in both size and shape.

The TRP treatments, which involved combinations of cutting (1999–2000) and postharvest broadcast burning (2002–2003), were designed to establish an eventual two-aged, two-tiered structure (Hardy et al. 2000). Two distinct cutting treatments were formulated to "emulate two stand conditions that occur from fires that create two-aged stands" (USDA Forest Service 1997). Both cutting prescriptions specified the removal of 40–60% of stand basal area, with live and commercially salvageable dead trees marked for removal, plus retention of 9–15 snags per acre for wildlife usage.

The two prescribed harvest methods were distinguished by pronouncedly different spatial patterns of tree retention. The Dispersed Retention cutting prescription resembled a uniform shelterwood cut or heavy thinning, in which half the trees were designated for removal and the remaining half reserved in a regular spatial pattern (Figure 2). The Aggregated Retention cutting prescription consisted of fully cleared gaps interspersed with fully intact leave-tree clumps, each condition (gaps and clumps) assigned half the total area and both varying widely in shape and size (Figure 3). In practice, the resulting retention tree levels were substantially less than prescribed, owing to immediate posttreatment windthrow and possibly a degree of overcutting (Hood et al. 2012).

After cutting, each harvest unit was divided in half, and one of each subunit pair was subjected to a postharvest prescribed broadcast burn. Two replicates of each cut-burn treatment combination (four) were conducted in each of two blocks (subwatersheds) on the flanks of the East-West flowing Tenderfoot Creek, producing a total of 16 treatment units. The total treatment area was 649 acres: 254 acres of dispersed retention and 395 acres of aggregated retention.

Present Outlook

With several exceptions, analyses of the TRP treatment outcomes have been spare in scope and few in number, and the need for comprehensive data synthesis remains. McCaughey et al. (2006) examined the project costs, stumpage receipts, and financial returns of the harvests, and declared them economically viable, reporting a net return to the Lewis and Clark National Forest of $443,155. Evaluation of the short-term effects of the prescribed fire revealed that fire-induced mortality in the dispersed retention units was very high (42–78% of retention trees lost), despite the fact that the burn plan was conservative and the burn was carefully executed (Hardy et al. 2006). Mortality levels were lower in the aggregated retention units, primarily because fires burned poorly and incompletely within the retention clumps (Hood et al. 2012), yet even in those units the burn mortality levels were high (19–41% of retention trees lost). Overall, evidence to date from the TRP suggests the potential of variable-retention harvesting as an option for increasing age-class diversity and resilience within lodgepole pine stands, but heavy near-term losses indicate that consideration of the specific form of the harvest prescription is essential.

Much remains to be learned about the benefits and challenges of the TRP's two forms of variable-retention harvesting. By comprehensively analyzing posttreatment outcomes in the TRP experimental cutting units, the present study is developing decision support knowledge that we hope will assist managers in planning silvicultural strategies that promote resilient lodgepole pine forests. The objective is to quantify and characterize differences between the two variable-retention harvest methods in regard to key posttreatment responses: bark beetle activity, retention tree mortality (levels and causes), stand density and volume growth, regeneration density and composition, loads and arrangement of forest fuels, and potential fire behavior. Study results should help managers design variable-retention harvesting prescriptions in lodgepole pine to transition structurally simple stands to more complex, multiaged structures and systems. It should also provide managers with the basis to evaluate the potential tradeoffs among variable-retention harvest forms, compare them with traditional even-aged harvests or the no-action alternative, and communicate them to the public. A silvicultural strategy that enhances stand heterogeneity, when combined with a strategy for enhancing landscape heterogeneity, should go far toward producing disturbance-resilient forest landscapes.

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