Variable-Density Thinning for Parks and Reserves: An Experimental Case Study at Humboldt Redwoods State Park, California

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Abstract—Variable-density thinning is emerging as a valuable tool for the silvicultural promotion of old-growth conditions in second-growth forests of the Pacific Coast. This paper reports on an experimental variable-density thinning prescription applied between 2006 and 2007 at north coastal California's Humboldt Redwoods State Park. The prescription strategy relied on known patterns of second-growth stand development during the stem exclusion phase, and was designed to alter current stand development trajectories in order to promote reference forest conditions. Prescription outcomes are described and tradeoffs are discussed, with management constraints unique to parks and reserves providing the context for this analysis.

Keywords: ecological restoration, forest stand dynamics, disturbance, stand structure.

Introduction

Silvicultural practices and systems in timberlands management are increasingly modeled after patterns of natural disturbance (Puettmann and others 2009), but the converse is also occurring in parks and reserves, where the potential of silviculture as a disturbance force to restore natural conditions in re-growth forests is being developed. In the coastal areas of the western United States, thinning to promote gaps and stand complexity has become a dominant management paradigm for the active restoration of old-forest attributes to second-growth forests (Carey 2003; Carey and Curtis 1996). In this region, vegetation composition and structure in old and young forests differ widely (Bailey and others 1998; Lindh and Muir 2004), and biodiversity is favored by the structural complexity that thinning promotes in second-growth forests (Bailey and Tappeiner 1998; Carey and Wilson 2001; Lindh and Muir 2004; Schowalter and others 2003). New silvicultural techniques are being devised to optimally promote that diversity (O'Hara and Waring 2005).

For these forests of the Pacific Coast, restoration practices are conducted to accelerate and make more certain a developmental pathway that will eventually result in stand structures and compositions comparable to old-growth forests. In younger stands, silvicultural restoration treatments are conducted to manipulate stand structure and composition in order to promote a subset of trees with structural attributes (low height:diameter ratios, high live crown ratios) that enhance their potential for resilience and persistence, and to promote patterns of development that promote the sustained dominance of those individuals (Chittick and Keyes 2007; Plummer 2008). Treatments may also be conducted to remediate

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composition imbalances. In older stands, restoration treatments may be conducted to expedite the development of biodiversity and structural complexity by establishing canopy gaps that promote understory plant recruitment and the initiation of a new tree cohort (Harrington and others 2005; Thysell and Carey 2001). Parks and reserves represent a unique context for the restoration of old-forest features to second-growth forests; in many cases the restoration strategy is constrained to a single-entry opportunity that must maximize ecological benefits while minimizing the potential for negative consequences.

This paper presents a case study in forest restoration at Humboldt Redwoods State Park, where an experimental variable-density thinning prescription was applied during 2006 and 2007. The treatment is discussed from both ecological and operational standpoints.

Methods

Project Area

Humboldt Redwoods State Park was established in 1921 to preserve massive alluvial stands of old-growth redwood along lower Bull Creek and the Eel River. Such forests account for more than 17,000 of the park's nearly 53,000 acres. The remaining 36,000 acres consist primarily of second-growth upland forests. In the aftermath of flooding in 1955, which damaged Rockefeller Forest, a need was recognized to claim and control the upland forests that surround the old-growth stands at higher stream orders. The park was steadily expanded between 1963 and 1984, until the whole of the Bull Creek watershed was annexed (Rohde and Rohde 1992). Most of the upland forests of the Bull Creek watershed (including Panther Creek), however, had been logged between 1950 and 1962, and are now in varying conditions of ecological impairment.

Stands within the Panther Creek watershed are aptly described by three impaired forest condition classes defined in an earlier assessment of second-growth forests in Humboldt Redwoods State Park (Keyes 2005). The project area did not have distinct stand boundaries, but instead was comprised of a mosaic of conditions typical of second-growth forests in this region: namely, compositionally diverse but structurally homogenous even-aged mixed stands (figs. 1 and 2). Due to management history, overstory density was very high, the proportional composition of Douglas-fir (*Pseudotsuga menziessi* (Mirb.) Franco) was very low, and spatial heterogeneity and vertical stand structure were minimal. Remediation of those conditions was the objective of the prescription. The pre-treatment conditions found in these stands were likely beyond the natural range of variability, and given our understanding of second-growth forest stand development patterns (Oliver 1980; Oliver 1981; Oliver and Larson 1996), we believe they are unlikely to achieve the pre-disturbance forest structure that defines the area's reference condition.

Restoration Prescription

A form of variable-density thinning (VDT) was the recommended technique to achieve ecological restoration goals for the forests of Panther Creek. VDT differs from most traditional methods of thinning, which typically emphasize uniformity in tree spacing and form (Nyland 2007; Smith and others 1997), in that it promotes spatial heterogeneity and height differentiation among canopy trees to enhance structural complexity. While several approaches to VDT have been proposed and tested in experimental settings (e.g. Carey 2003), techniques for the efficient implementation of VDT as an operational practice have not yet

Figure 1—Panther Creek watershed, 1959. Panther Creek drains from southwest to northeast through the middle of this aerial photo. Landslides resulting from cutting are evident at bottom center of photo. The photo illustrates the intensity of harvesting activity and high density of skid roads.

been developed or standardized. Existing experimental efforts that have been documented generally introduce spatial heterogeneity in a random manner, without capitalizing on variability that already occurs within the stand. Approaches relying on randomness or stand-level targets (such as inter-tree spacing levels) fail to permit flexibility in tree selection that allows for adaptation to existing heterogeneity, and hence can delay the achievement of treatment goals.

The VDT technique developed for the forests of Panther Creek was designed to capitalize upon differentiation that had already occurred. The prescription consists of a basic size-constrained, species-specific, diameter-based multiplier cutting rule (Dx Rule; see fig. 3 for a schematic):

A) Identify the largest Douglas-fir or redwood tree larger than five inches dbh in the vicinity, multiply the diameter by two, and cut trees for that many feet around the Douglas-fir in a radius up to, but not greater than, twenty feet (the maximum treatment radius is twenty feet).
B) Within the cutting radius, cut no trees smaller than five inches dbh, or conifers greater than ten inches dbh, or hardwoods (broadleaf trees) over fifteen inches dbh.
C) Move on to next closest Douglas-fir or redwood release tree (including Douglas-firs retained in Step B), and repeat Steps A and B.

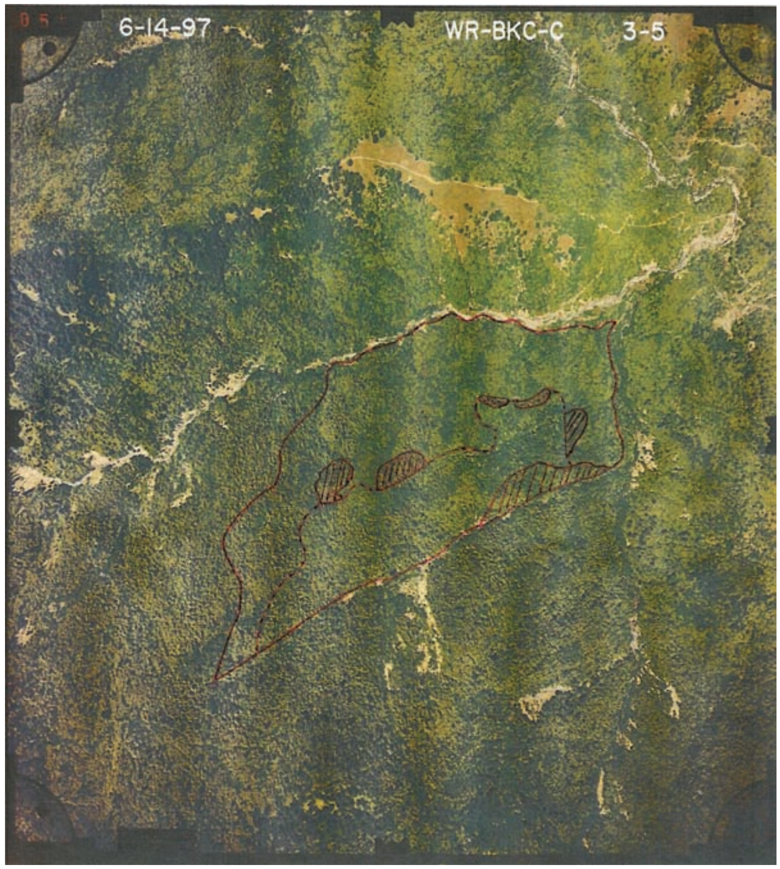


Figure 2—Panther Creek watershed, 1997. Photo reveals the widespread distribution of hardwood re-growth (light green) amidst lesser conifer re-growth (dark green) (red lines reference project area boundaries and landmarks). Although spatially uniform in age structure, the area is compositionally diverse, posing difficulty to identification of stands with distinct boundaries, and difficulty in preparing stand-based prescriptions. Such variability lends itself to tree-scale prescriptions that operate adequately and efficiently across a spatial range of compositions.

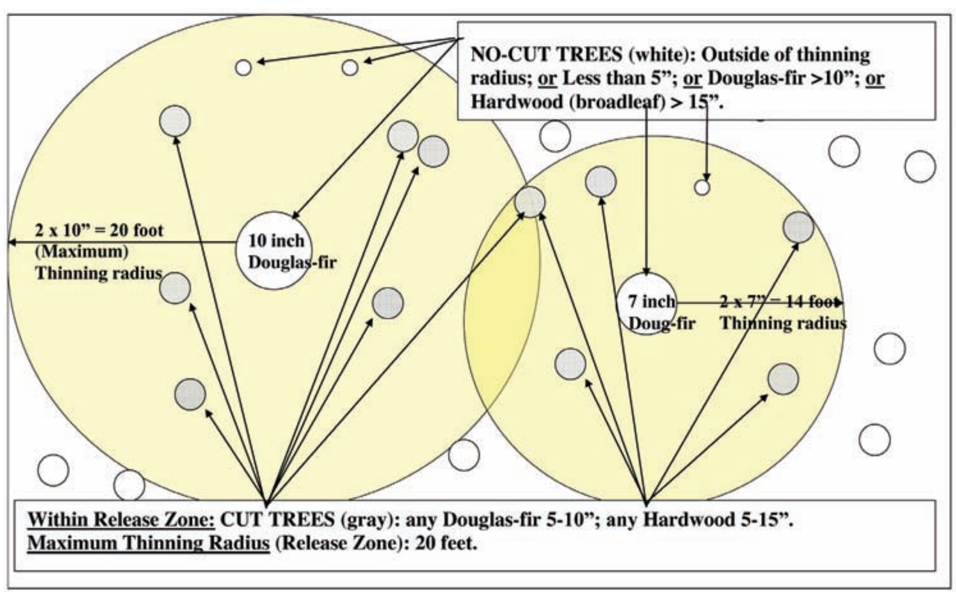


Figure 3—Conceptual diagram of variable-density thinning prescription.

For stands with little structural variation, the Dx Rule does not significantly alter spatial heterogeneity. But in partly-differentiated stands, the Dx Rule exacerbates inequalities in growing space by appropriating proportionally larger gaps around larger trees than around smaller trees. Moreover, two goals in prescription development were simplicity and universality; this necessitated to some extent a compromise that worked across the range of forest conditions. An advantage of the approach is its universal applicability across forest conditions, and an ability to remain effective as contractors move through unanticipated changes in those conditions.

Analysis

We utilized pre-treatment and post-treatment data (1790 tree records) from a semi-permanent plot network of 84 plots. This dataset captured tree species, diameter at breast height, and harvest history (cut versus uncut). Both compositional and structural changes were analyzed to quantify or evaluate general stand characteristics, re-distribution of stand volume, prescription effectiveness, and operator adherence to the prescription.

Prescription implementation effectiveness was indicated by a redistribution of basal area from smaller hardwoods to conifers greater than 10” and hardwoods greater than 15”. Along with a species composition shift to a higher proportion of conifers in the post-treatment stands, an overall reduction in trees per acre, with the greatest reduction in hardwood stems less than 15” is also indicative of effective implementation of the prescription. Maintenance or exacerbation of spatial variability in stand density was another desirable outcome. Adherence of the operator to the prescription was evaluated by focusing on the percentage of plots in which the prescription was correctly versus incorrectly implemented. Consistent operator errors would have indicated either an overly complex prescription or a lower level of operator professionalism.

In addition to the quantitative analysis of plot data, we made numerous qualitative observations during and after the implementation of the prescription. Our goal here was to understand the operational linkages between the prescription and its implementation by forest workers, in order to improve and simplify future prescriptions for similar complex forest objectives.

Results and Discussion

Quantitative Analysis

Figures 4 and 5 reveal that the prescription reduced overall stand density while shifting proportional composition from hardwood to softwood dominance. Hardwoods accounted for 52.6 percent of the original stand basal area and only 5.4 percent of the residual stands basal area. In terms of trees per acre, hardwoods accounted for 71.9 percent of the stems in the pre-cut stand and only 17.8 percent of the residual stand. The greatest reduction in both basal area and trees per acre came from the tanoak component of the stand. Although a desired compositional shift occurred, the removal intensity on this site may be higher than desired given the potential for hardwood sprout regeneration. The intention of the cutting was to release existing conifers, not create new space for stem initiation that would favor those sprouting hardwoods.

Figure 6 displays the pre-cut and post-cut stand structure in terms of both basal area and trees per acre. Cutters by-and-large accurately observed the diameter and species guidelines defined by the prescription, but they did improperly remove some hardwoods above the 10” diameter limit. Such cuttings represented only

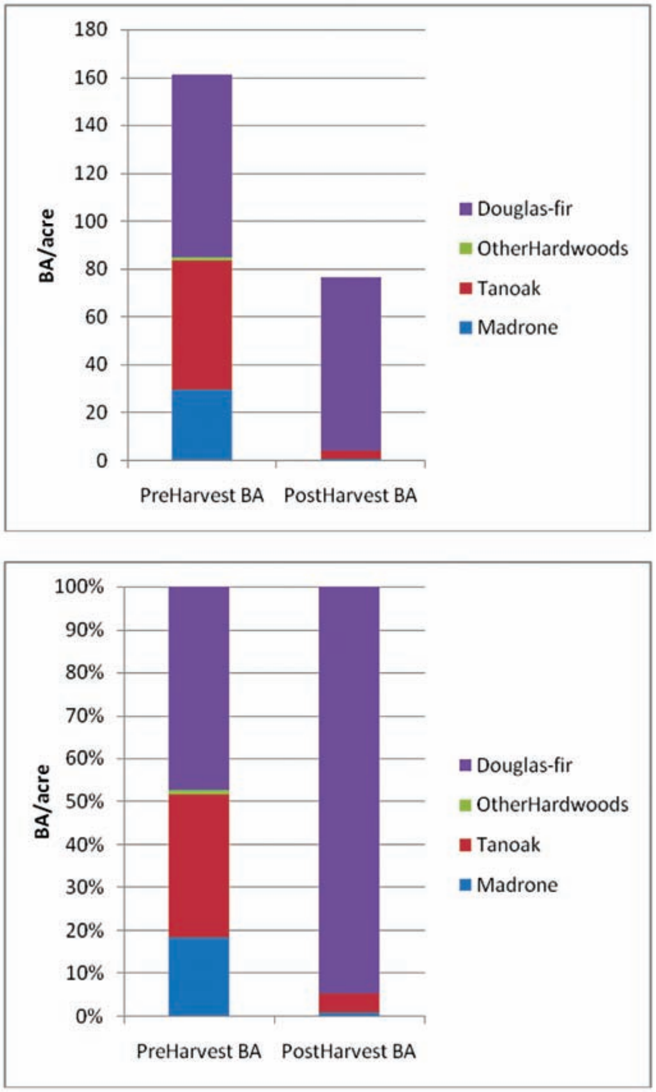


Figure 4—Pre-harvest and post-harvest species compositions expressed in basal area (ft^2 per acre) and Tanoak (*Lithocarpus densiflorus*) Blume, Madrone (*Arbutus* L.) as a percentage of the total basal area.

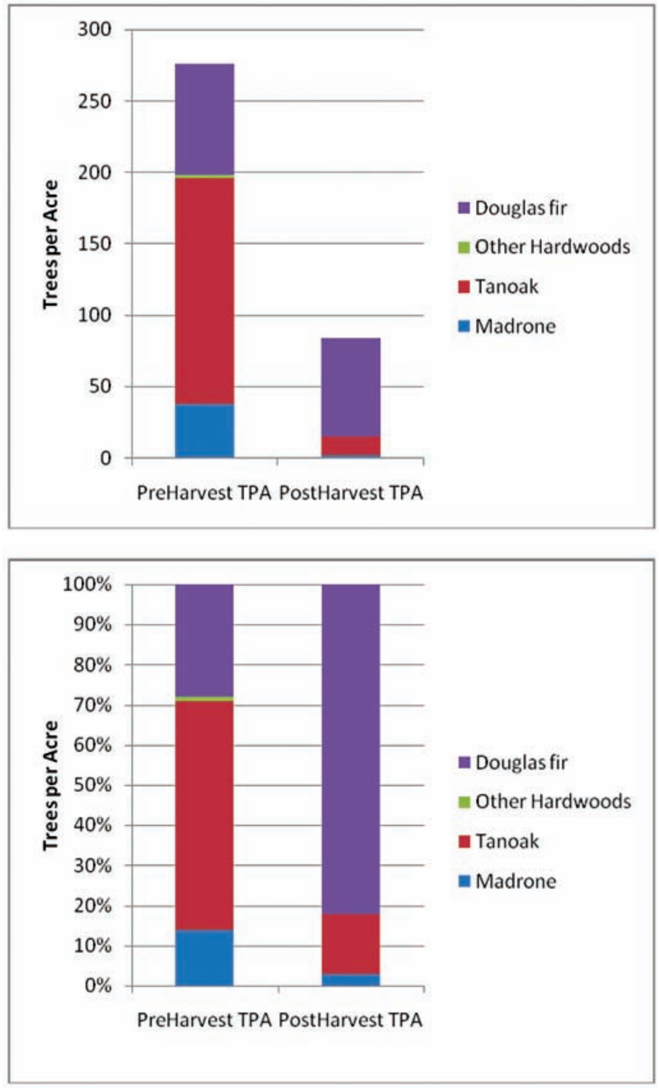
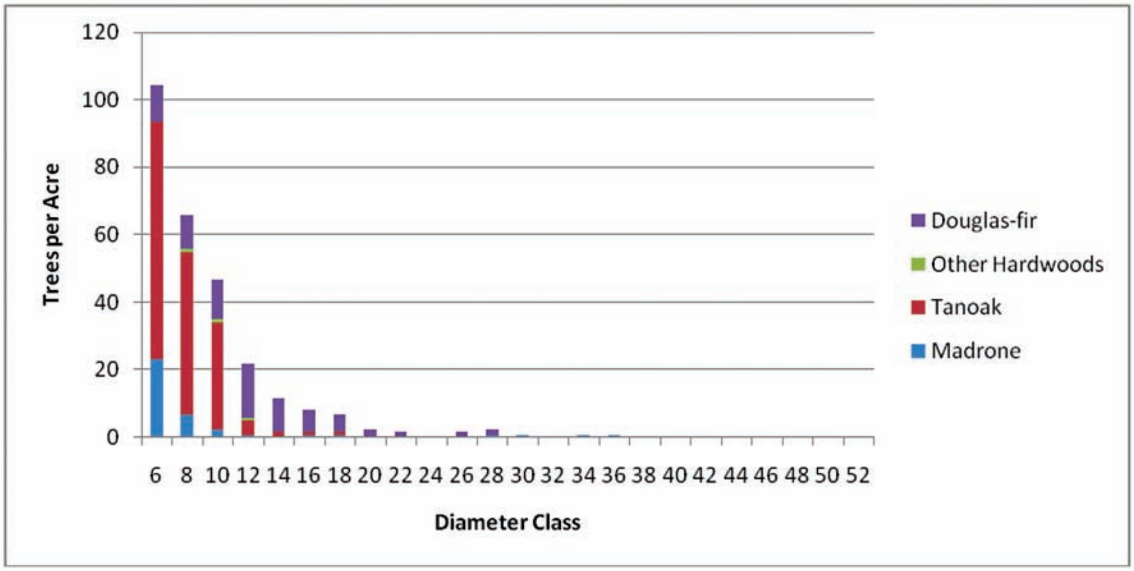


Figure 5—Pre-harvest and post-harvest species compositions expressed in trees per acre and as a percentage of the total trees per acre.

4 trees per acre, but removed a substantial amount of hardwood basal area in these larger diameter classes. This removal was a deviation from the prescribed treatment rather than a failing of the prescription itself; correct implementation would have retained these large diameter hardwoods.

Cutters accurately distinguished between conifers and hardwoods, but did not distinguish between hardwoods. All of the species in the "other hardwoods" group (California laurel [*Umbellularia californica* (Hook & Arn.) Nutt.], coastal live oak [*Quercus agrifolia* Née var. *oxyadenia* (Torr.) J.T. Howell], and California black oak [*Quercus kelloggii*] Newberry) were eliminated by the cutting. Those trees were few in number, representing an average of less than one tree per acre. However, maintaining the site's species richness was an inherent goal of the prescription. Hence, proper species identification proved an important criterion for proper prescription implementation.

To concisely explore the prescription's effect of spatial heterogeneity in stand density, we conducted analysis of grouped decile classes (representing 1/10th of the range of pre-cut density) for trees per acre and basal area (fig. 7), similar to



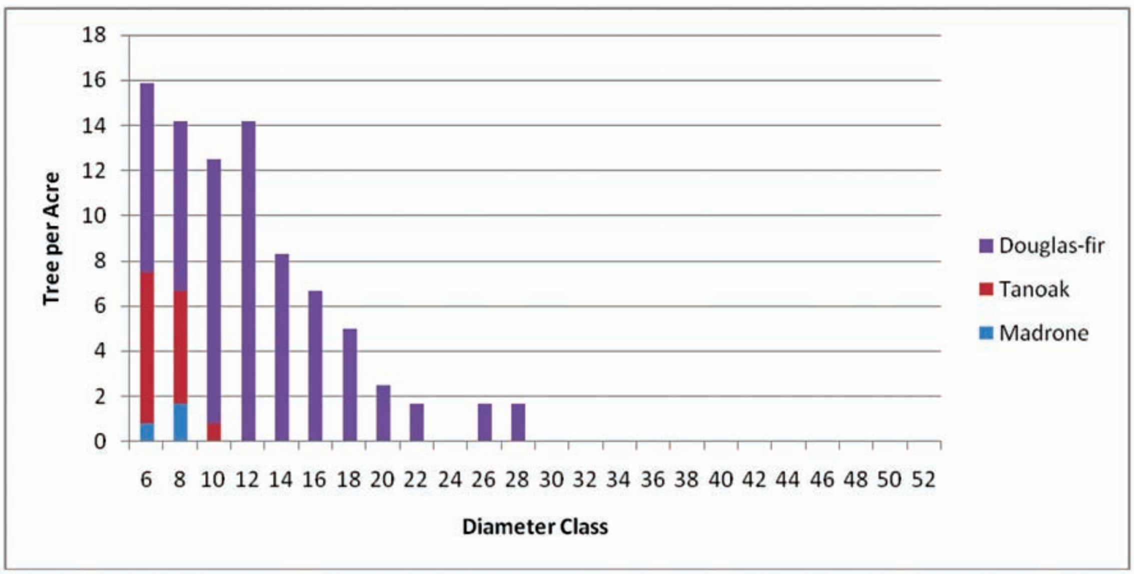


Figure 6—Species-designated diameter distributions displaying pre-cut (top) and post-cut (bottom) trees per acre.

diameter classes. This approach allowed for a contrast of the pre-cut and post-cut structural variation in density. The range of stem densities (in terms of trees per acre) did not change as a result of the prescription; in both the pre-cut and post-cut stand, eight of the ten density classes were occupied. There was a notable redistribution of plots falling into the lowest stem density class. The basal area density classes exhibited the same shift towards the lowest class; however, seven of the eight density classes in the original stand were still occupied. Some structural diversity in basal area was lost, since no post-treatment plots occupied the three highest basal area density classes observed prior to treatment.

According to the rule, no cutting was to be conducted in pure hardwood areas where releasable conifers were not present. Analysis of cut and uncut areas combined revealed that the overall species composition shift was tempered by high hardwood and low softwood stem densities in the uncut areas. Generally, the uncut areas either did not contain releasable softwoods, or if softwoods were present, the hardwood density was low enough to preclude thinning. These untreated plots

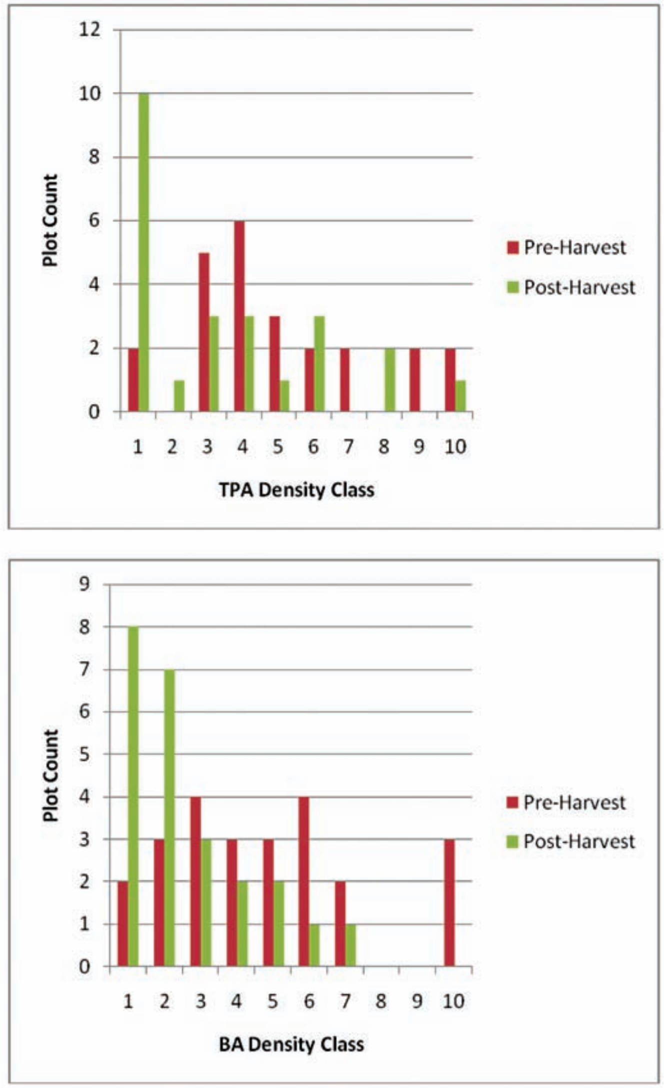


Figure 7—Pre-cut and post-cut plot counts grouped by decile density classes for trees per acre (top) and basal area (bottom). The range of stand densities was reduced since highest density areas no longer exist; however, substantial variation remains in the treated stand, with greater representation in the lowest density classes. Variation in stand density classes indicates spatial heterogeneity in stand structure.

contribute to the large diameter hardwood component and maintained some areas of high stem density, retaining the upper end of the overall range of densities within the stand.

Two different contractors implemented the prescriptions in separate parts of the project area, yielding different trends in removal intensity and the structural retention. Contractor implementation of the prescription proved to be a strong determinant of post-treatment structure, and a critical aspect of a successfully designed and implemented restoration treatment (discussed below).

Development of the stand structures established by this treatment will reveal whether the treatment's objectives will be met over longer timeframes. Occlusion of overstory space by released Douglas-firs and their dominance over hardwood sprouts was the intended result, but whether this will be achieved depends upon rates of crown expansion among residual trees and rates of height growth among hardwood stump sprouts

Qualitative Observations

Thinning crews failed to thin small pockets within the designated project area. It is estimated that the skipped areas comprised less than five percent of the total project area. These mostly occurred in small pockets, apparently between steep stream channels. They were small enough not to be detected during the project implementation, hence even the presence of an on-site compliance worker would unlikely detect them in real-time. At lower slope positions throughout the project area, class I and II streams were impassable chasms. This made contour-based foot-travel impossible, and required substantial upslope and downslope travel during project reconnaissance; it was also probably responsible for many of the pockets that were missed by thinning crews.

Communications between foresters and forest workers posed a potential challenge to the correct implementation of the thinning rule. Communications with the leader of the migrant crew appeared to suffer from both language and cultural differences. The fortunate presence of a compliance forester that was fluent in both English and Spanish, and with a good understanding of forestry principles and the prescription itself, is credited with enhancing treatment implementation at Panther Creek. This element is a vital consideration for similar situations where communication is difficult, the prescription is by description, and the prescription objective and post-treatment structure is unlike that which forest workers are accustomed.

Workers were impatient to start cutting even prior to receiving instructions on the thinning rule. Workers are believed to have been accustomed to the simple instructions associated with pre-commercial thinning's regular spacing method. In retrospect we would have planned and scheduled with the contractor a formal saw-free instruction with all crews present and attentive prior to removal of cutting equipment and prior to entering treatment area. In the absence of tree marking, it is vital that crews recognize that VDT thinning differs in important ways from traditional thinning methods. We provided a demonstration area for the contractor bidding and to familiarize workers with the prescription, but should have contractually required its use in a tutorial provided by us at the outset.

With our makeshift reactions to these apparent deficiencies, immediate post-treatment impressions of the VDT proved positive in regard to achieving project objectives of shifted species composition and reduced density. Residual spacing was variable throughout the area, hence crews did not thin in regular spacing patterns as might have been feared with communications limitations. Workers appeared capable of identifying tree diameters correctly. Diameter-based constraints appeared to be adhered to quite well. Large trees were not cut inadvertently. However, it was difficult to determine whether the diameter multiplier (2x) was being implemented by crews or whether a constant 20-foot radius was applied to all focus trees. Many residual trees by prescription had large diameters, hence had target thinning radii that were capped at 20 feet. In future efforts, we would like to test the radius-multiplier in a stand with smaller pre-treatment dbh's; if the multiplier is not being adhered to by crews, yet the outcomes achieve the treatment objectives, then a standard thinning radius would offer greater simplicity.

Special treatment areas of reserve forest were flagged for exclusion. Such areas included pockets that were not logged during the mid-century, did not require restoration, and could potentially be damaged by cutters. However, this special treatment was not necessary. A pocket that went unnoticed during pre-treatment reconnaissance, and which was not flagged off as an exclusion area, was subjected to the crews and the thinning rule. The thinning rule as written prohibited cutting the large trees that occurred in that area, and it was correctly implemented. We believe that crews with a proven track record in prior contracts can be trusted to adhere to and be able to distinguish accurately diameters and diameter-based constraints for this type of prescription. Hence, the expense and potential for confusion associated with flagging off reserve pockets can be avoided, unless they are not specifically protected by the language of the thinning rule.

Conclusions

The outcomes of restoration treatment applied to Panther Creek were successful in most regards. Concerns regarded the prescription implementation aspect, rather than the prescription formulation itself. Future efforts can benefit by reducing worker confusion, enhancing worker understanding of the prescription, and reducing pre-treatment expense. Structurally and compositionally, the prescription appeared to achieve forest objectives. Since implementation appeared to be a limiting factor to project success, further simplifications to the prescription would prove beneficial if they can be shown to reduce worker confusion and expense while yet resulting in similar post-treatment forest complexity.

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