Site Quality Changes in Response to Slash Retention and Prescribed Fire in Thinned Ponderosa Pine Forests

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Abstract—The ecological effects of post-thinning slash retention on vegetation, wildlife browse, and soil were evaluated in sixty-year-old stands of second-growth pine in central Oregon. Three slash-retention treatments were compared: whole-tree removal, bole-only removal, and thin no removal (boles and slash scattered on site). The study intent was to create a wide gradient of surface organic matter mass among treatments and assess any ensuing changes in site quality. No differences in site or soil productivity indices were found among the slash-retention treatments after 20 years. Tree growth, understory plant production and diversity, wildlife browse cover, litter decay, soil nutrients, and soil biological activity were similar among the treatments, suggesting that the retention of thinning slash is trivial to the health of these forests. In general, thinning alone, regardless of slash treatment, and thinning with subsequent burning were sound options for reducing wildfire hazard and maintaining site quality in these pine ecosystems.

Keywords: site productivity, thinning slash, prescribed fire, organic matter, pumice soil

Introduction

Forest management is a contentious topic. Unresolved issues are numerous and they range in scope from local concerns about public safety and wildfire to the politically charged world of protecting old-growth ecosystems and to the scientific unknown of global climate change. Should forests be managed as carbon stores in order to slow the warming of our planet? Is it unacceptable to harvest moderate-to-large trees on public lands, or should such practices be encouraged on occasion in order to maintain healthy, long-lived forests? Which forests should be actively managed and which should be allowed to develop "naturally" with minimal or no human intrusion? These are complex questions whose practical solutions have evaded some of the brightest minds of today despite, at times, reasonably clear policy and legal direction.

But the beauty of today's forestry issues is that they require discourse, debate, and scientific inquiry. They require the involvement of assorted individuals, groups, and agencies; they require understanding of complex ecosystems; and, perhaps, they require compromise. However, as current issues, many will likely be replaced in time by other contentious issues, just as some of the key concerns of today were not on the radar screen 20 years ago. And this is where the current story begins, with a forestry issue that was on people's minds 20 to 25 years ago, but has since been dropped from many dance cards: long-term site productivity. Within the forest management and research community, this topic was crackling with energy well before biofuel production, biochar, or hybrid cars gained their notoriety.

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The notion of long-term site productivity on public forests owes much to the congressional mandate set by the Multiple Use—Sustained Yield Act of 1960 (National Forests shall provide "sustained yield of the several products and services… without impairment of the productivity of the land") and the National Forest Management Act of 1976 ("Soil will not be irreversibly damaged"). The responsibility of sustaining our nation's forests for future generations was set into law and placed in the hands of forest managers, with open public participation and with full reliance on professionals from a multitude of forestry and ecosystem-related disciplines. Soil scientists, for example, spoke for the land with their concerns about detrimental erosion, compaction, and nutrient losses. By the 1980s, numerous soils-related studies were installed on public forests in an attempt to better understand how forest management practices affected the long-term productivity of the land. Studies such as the Long-Term Soil Productivity study (Powers 2006) and the Long-term Ecosystem Productivity experiment (Bormann and others 2008) steamrolled into view. It was during this time period that the Bend Long-term Site Productivity study (LTSP) was conceived.

The Bend LTSP study began as a collaboration between the Deschutes National Forest, located in the rainshadow of the central Oregon Cascades, and Pat Cochran, a research soil scientist with the Pacific Northwest Research Station. The National Forest was alarmed about bark beetle infestations in young, dense stands of ponderosa pine, and needed to monitor the effects of proposed thinning operations on forest health. Was wide-scale thinning an effective practice to limit bark beetle attack? And how would pine vegetation, fuels, soils, and wildlife respond to an aggressive thinning regime? For Pat Cochran, a golden opportunity was presented to study the fate of thinning residues in pine forests. Should slash material be left on site in order to maintain or enhance site productivity? Soil scientists had long recognized the quintessential quality of soil organic matter as a cornerstone of productive ecosystems. So the definitive question was asked: how important is it to retain site organic matter in the form of thinning slash?

Preliminary evidence from central Oregon suggested that thinning residues were, indeed, important to site productivity. Little and Shainsky (1995) assessed the organic carbon, nitrogen, and phosphorus pools in trees and soils and recommended bole-only harvesting as the best management practice for maintaining site productivity. They suggested that whole-tree harvesting could remove a substantial percentage of the above-ground nitrogen pool. This finding is supported by studies in the boreal forests of Scandinavia, in which growth declines resulted when harvest slash was removed from site (Jacobson and others 2000). And as a general recommendation, Page-Dumroese and others (2010) suggested leaving thinning residues on site, particularly in areas with low fertility soils, to help (1) maintain soil organic matter levels, (2) increase N cycling, (3) promote mycorrhizae development, and (4) minimize detrimental soil compaction.

Evidence to support such recommendations is far from definitive, however. In an effort to resolve this issue, LTSP study plots were installed in 1988, and the effects of retaining thinning residues were evaluated during the succeeding 20 years. The objective of this work was to determine whether surface residues are advantageous to tree growth, understory plant composition and production, wildlife browse, or soil fertility.

Methods

Site Description

The study is located on the Deschutes National Forest, in the pumice plateau region of central Oregon between the Cascade Range to the west and the Great

Basin to the east. Ponderosa pine (*Pinus ponderosa* C. Lawson) forests are common throughout the plateau, with their production limited by cold winters and dry summers. Annual precipitation ranges from about 30 to 50 cm and occurs primarily as snow during the winter months. The growing season for pine typically lasts from mid-May to mid-August.

Three sites were selected in 1988 along a precipitation gradient that extends east from the Cascade crest to the desert fringe. East Fort Rock, the least productive of the three sites (site index of 25 m at 100 y), is located near the desert fringe, 17 km southeast of Bend, OR; Sugar Cast, a medium site (site index of 31 m at 100 y), is located 5 km east of Sunriver, OR; and Swede Ridge, the most productive of the three sites (site index of 35 at 100y), is located 20 km west of Bend, OR. These sites had been clearcut logged in the 1930s and allowed to regenerate naturally. By 1988, stand densities ranged from 480 to 780 trees per hectare (195-315 trees per acre), mean tree diameter at breast height (DBH) was 26 cm (10.2 inches), and basal areas ranged from 24-33 m^2 ha^{-1} (105-144 ft^2 ac^{-1}).

The soil at the three sites is coarse textured (sandy loam), developing from wind blown deposits of pumice and ash from the eruption of Mt. Mazama. Soil fertility is low, with both organic matter and total nitrogen contents particularly sparse at soil depths below 10 cm. Understory vegetation is comprised primarily of woody shrubs, including antelope bitterbrush (*Purshia tridentata* [Pursh] DC.), snowbrush (*Ceanothus velutinus* Douglas ex Hook.), and greenleaf manzanita (*Arctostaphylos patula* Greene). Herbaceous species such as bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey), western needlegrass (*Achnatherum occidentale* [Thurb.] Barkworth), Idaho fescue (*Festuca idahoensis* Elmer), Ross' sedge (*Carex rossii* Boott), Virginia strawberry (*Fragaria virginiana* Duchesne), cryptantha (*Cryptantha affinis* [A. Gray] Greene), and silverleaf phacelia (*Phacelia hastata* Douglas ex Lehm.) are present at low coverage.

Study Design

Four slash-retention treatments, components of the larger Bend LTSP study (see Busse and others 2009 for overall experimental design), were compared: whole-tree removal, bole-only removal, thin no removal, plus a no-thin control. The experiment was a randomized complete block with three replications (one replication per site). Treatment plots were 0.4 ha (1 ac) with 20 m (66 ft) or greater between adjacent plots. Thinning guidelines followed the prescriptions used by the Deschutes National Forest in 1988. Target basal area was 13.7 m^2 ha^{-1} (60 ft^2 ac^{-1}) or less with a tree spacing of approximately 5.5 x 6.1 m (18 x 20 ft), favoring the removal of damaged or smaller trees. Trees marked for thinning were cut by chainsaw between November 1988 and October 1989, and felled trees were removed using either a rubber-tire or track grapple skidder. All harvest material was removed from whole-tree removal plots; boles were removed from bole-only removal plots, with tree crowns lopped and scattered across the plots; and all harvest material was retained on the thin no removal plots, with tree crowns lopped and scattered and boles left intact on the ground (fig. 1). Surface residues at the start of the experiment averaged 12 Mg ha^{-1} (5.3 tons ac^{-1}) for both whole-tree removal and no thin plots, 26 Mg ha^{-1} (11.6 tons ac^{-1}) for bole-only removal plots, and 48 Mg ha^{-1} (21.4 tons ac^{-1}) for thin no removal plots.

Two additional LTSP treatments, repeated prescribed fire (fig. 2) and fertilization, will be introduced briefly in the results of this report. Three replicate plots of each slash-retention treatment were (1) burned in spring 1991 and spring 2002 by low-to moderate-intensity prescribed fire, (2) fertilized in 1991 and 1996 with nitrogen (224 kg ha^{-1}), phosphorus (112 kg ha^{-1}), and sulfur (37 kg ha^{-1}), or (3) left unburned and unfertilized. Details of the burn conditions, fire behavior, and fertilizer application rates are presented by Busse and others (2009).

Figure 1—Thinning and slash-removal treatments, clockwise from upper left: whole-tree removal; bolewood-only removal; thin, no-removal; and no thin.

Figure 2—Typical low- to moderate-intensity prescribed burning in spring 2002. Average flame lengths were 0.4 to 0.8 m, with litter and duff depths reduced by about 50 percent.

Site Productivity Measurements

Trees—Diameter at breast height (DBH) of all trees on all plots was measured in 1988 (pre-treatment), 1991, 1996, 2001, and 2006. Any mortality or damage to trees was recorded at each date. Total tree height was measured in 1991 and 1996 using an optical dendrometer, with a subset of 15 trees per plot (representing a cross-section of tree sizes) measured for volume. Regression equations were then developed that predicted tree volume in 2001 and 2006 as a function of field measurements of DBH. Periodic annual increment diameter and volume growth were calculated for live trees only.

Understory vegetation—Shrub cover was estimated ocularly prior to treatment (1988), and then measured using belt transects in 1993, 1996, 1999, 2003, and 2006 (Busse and Riegel 2009). Three belt transects (5 x 20 m) were located systematically in each plot, and each shrub within a belt transect was measured for canopy length and width. Coverage of an individual shrub was calculated assuming an ellipse-shaped canopy. Total cover on a plot basis was calculated as the sum of the individual shrubs within the three transects.

Herbaceous plants were clipped at ground level for biomass determination during peak season (mid-June to mid-July) in 1992, 1994, 1997, 1998, and 2003. Circular plot frames (1.5 m diam.) were used in 1992 and 1994, and rectangular-shaped frames (0.5 x 0.5 m) were used subsequently. All plants within 8 systematically located plot frames per plot were clipped at each sample date. Plant species were identified for richness and diversity indices, clipped, dried, and weighed separately for dry matter production for 1992 and 1994 samples only. Species diversity was estimated by Simpson's Diversity Index. After 1994, plants were clipped separately by lifeform (forb, graminoid) prior to drying and weighing, and no attempt was made to determine species diversity.

Fuel load—Surface woody fuel mass was measured in 1990 (pre-burn), 1991, 1996, 2001 (preburn), 2002, and 2007 using a modified planar-intercept method (Brown 1974). Downed wood was counted on 12 transect lines per plot. Measurement length on each transect line was 3 m for the 1-h and 10-h timelag fuels; 10 m for 100-h timelag fuels; and 15 m for 1000-h timelag fuels and larger. Litter and duff mass was estimated by collecting 12, 50 x 50 cm samples per plot, located adjacent to each transect line. Dry weights were determined following oven drying at 70 °C for 48 h.

Soil—Soil samples were collected periodically from 1989 to 2006 for measurements of organic matter content, total carbon, nutrient content, pH, fertility index (carbon:nitrogen ratio), microbial biomass and activity, and microbial diversity (phospholipid fatty acids) using standard analytical procedures. Ten samples from the surface 10 cm of mineral soil were composited per plot at each sample date. In addition, a two-year litter decay study examined differences in decomposition rates among the slash-retention treatments. Briefly, litterfall was collected in fall 1992 from areas outside of the treatment plots. A pre-weighed amount of litter (about 5 g) was placed in 3 mm-mesh litterbags, and 8 replicate litterbags were placed on the forest floor surface of each plot. Two litterbags were collected from each plot semi-annually, and the litter was dried and weighed for mass loss.

Data Analyses

The main effects of thinning and slash-retention treatments on vegetation, fuel load, and litter decay were analyzed by repeated measures analysis (PROC MIXED in SAS 9.1). Treatment effects on soil properties for 2003 samples only were tested using ANOVA. Significance for all statistical analyses was set at $\alpha = 0.05$.

Findings and Implications

Twenty years is a brief period in the life of most ponderosa pine forests. Thus, the findings here may represent little more than an extended snapshot in time, far from a complete story. However, 20 years is most likely sufficient to draw a few conclusions about the fate of thinning residues and their contribution to site productivity. Woody residues decay surprisingly fast in this region (Busse 1994), a fact that is evident on the LTSP plots: the organic residues have either been incorporated in the duff layer or they have decayed sufficiently that their presence is visually undetected. Any measurable effect from this pulse addition of foliage and woody material should have registered by now. Of course, whether the pulse effect registers in succeeding years remains to be seen. Nevertheless, the results from the study were unambiguous, no changes in site productivity indices resulted from the gradient of thinning slash left on site. Whole-tree harvesting, bole-only harvesting, and leaving all material on site produced similar vegetation and soil responses in these forests. The following sections document this observation.

Tree Growth and Mortality

No differences in tree diameter or volume growth were detected among the 3 slash-retention treatments during the 15-year span between 1991 and 2006 (fig. 3). This trend held whether the plots were burned or not. In comparison, unthinned plots had a 50 percent lower rate of diameter growth compared to the thinned treatments, as expected following a thinning. The thinning release was expressed in diameter growth only, however. Volume growth was comparable between thinned and unthinned plots, reflecting the greater number of trees of smaller diameter on the unthinned plots.

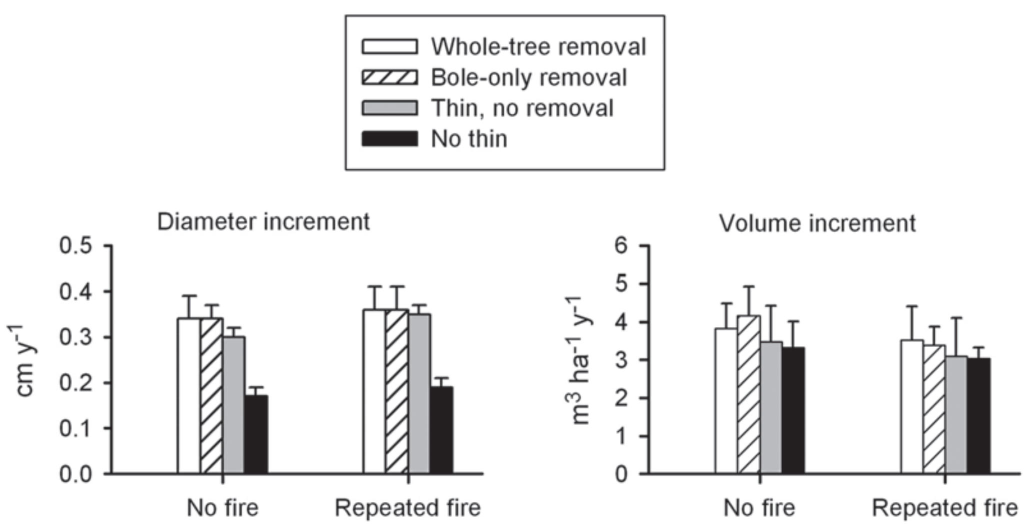

Figure 3—Tree-growth increment between 1991 and 2006. Thinning and slash-removal treatments were completed in 1989, and repeated prescribed burning occurred in spring 1991 and spring 2002. Error bars represent the standard error of the mean (*n* = 3).

Tree mortality was nominal in thinned plots in the absence of fire, with no differences found among the slash treatments (table 1). Repeated fire, in comparison, resulted in a reasonably high rate of mortality in the thin no removal treatment. This finding was triggered by high-velocity, swirling winds that hit a single plot at the time of ignition, killing numerous trees. Still, unthinned plots had the highest rate of mortality during the study due to bark beetles (without fire) and crown scorch (with fire).

Shrub Cover

Bitterbrush, an important wildlife browse species in central Oregon (Gay 1998), was the dominant shrub at two sites, while snowbrush was dominant at Swede Ridge, the highest elevation site. No differences in total cover (fig. 4) or cover of individual shrub species (data not shown) resulted between 1993 and 2006 due to the slash treatments. An initial decline in shrub presence was noted after thinning (pre-thin cover averaged 28 percent), followed by a steady increase in shrub cover which, again, was independent of the slash treatment. Without thinning, the majority of shrubs were gradually eliminated by the end of the study.

Table 1—Stand density (trees per hectare) in 1991 and 2006 and percent mortality during the 15-year growth period for whole-tree removal (WT), bole-only removal (BR), thin no removal (NR), and no thin (NT) treatments. Plots were thinned in 1989 and burned in spring 1991 and 2002. Values are means (n = 3) plus standard errors in parentheses.

	No fire				Repeated fire			
	WT	**BR**	**NR**	**NT**	**WT**	**BR**	**NR**	**NT**
1991	276	278	256	615	298	266	274	603
	(53)	(59)	(56)	(75)	(92)	(37)	(51)	(77)
2006	274	276	256	561	288	262	220	458
	(51)	(57)	(56)	(42)	(92)	(30)	(42)	(23)
Percent mortality	1	1	0	9	3	2	20	24

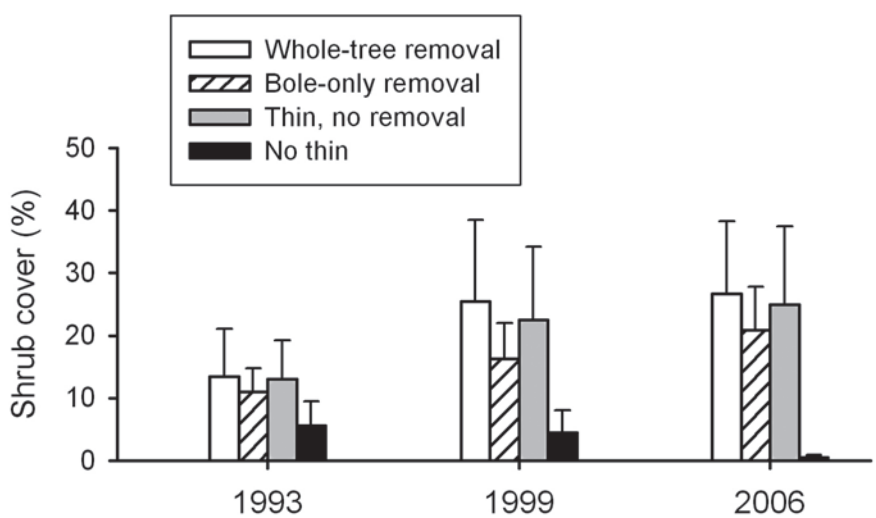

Figure 4—Effect of thinning and slash removal on shrub cover. Average shrub cover in 1988 prior to thinning was 28 percent. Error bars represent the standard error of the mean (n = 3).

Thinning, regardless of slash treatment, was particularly effective at stimulating bitterbrush cover (fig. 5). In comparison, thinning plus repeated fire led to a rollercoaster-like response by bitterbrush. Bitterbrush recovery was fairly rapid after the initial burn, with no statistical difference in cover detected between burned and unburned plots by 6 years after burning (Busse and Riegel 2009). However, the second entry of fire resulted in a near collapse of bitterbrush presence (fig. 5). Busse and Riegel (2009) surmised that this resulted both from extensive seed germination after the first burn, depleting the seed bank, and from the inability of bitterbrush germinants to produce a sizable seed crop in the 11 years between burns. This finding has relevance to the management of bitterbrush as both a desirable wildlife browse and as an unwanted ladder fuel, and it points to a few interesting possibilities for land managers to consider. If the presence of bitterbrush for wildlife habitat is preferred, then thinning alone may offer the best option. Alternatively, repeated burning offers the best option to eliminate bitterbrush from the understory and promote low wildfire hazard. For an ecological balance, a landscape-scale strategy that incorporates a mosaic pattern of thinning alone, thinning plus repeated fire, and occasional unthinned stands based on local knowledge of wildlife needs and wildfire hazard may be preferred.

Herbaceous Plants

Grasses and forbs were largely missing-in-action at the LTSP study sites. Low annual precipitation, the presence of competitive shrubs, and a pumice soil that challenges even the hardiest of seedbanks to survive with its diurnal temperature flux all contribute to low herbaceous production throughout much of the pumice

Figure 5—Stand conditions in 2006, 17 years after thinning, with (a) no thinning, (b) thinning, (c) thinning plus 1 burn, and (d) thinning plus 2 burns.

plateau. As testimony, herbaceous biomass was exceedingly low for every LTSP treatment except one during the study. This response held for the 3 slash-retention treatments, no thin plots, and thin plus burn plots (fig. 6). In concurrence, plant diversity was low and no differences were found among LTSP treatments (Busse and others 2009). Only the fertilizer plots (nitrogen + phosphorus + sulfur) produced sizeable herbaceous biomass for 2 to 3 years following application in 1991 and 1996. This observation suggests a few fact-busting possibilities: (1) fire is not essential to stimulating herbaceous plants in these forests, (2) poor herbaceous production on the pumice plateau is not necessarily related to an impoverished seedbank; instead, a large nutrient pulse is required to stimulate plant germination and growth.

Fuel Loading

Downed woody fuels were measured periodically between 1991 and 2007 to determine if sizeable or long-lasting differences in fuel loads existed between whole-tree removal and bole-only removal thinning practices. Does bole-only harvesting result in undesirable fuel loads from a wildfire hazard perspective? By the second growing season after thinning (1991), the fuel load of small-diameter wood (< 7.5 cm) on bole-only removal plots was about double the amount found on whole-tree removal plots (fig. 7). Five years later, however, the difference between treatments had subsided and, importantly, the absolute quantity of fuel for all treatments was low, and remained low throughout the study. The important results to consider are, (1) whole-tree removal was an effective means to maintain low fuel loads without prescribed burning, and (2) there was not a long-lasting difference in fuel loads between treatments, suggesting that the wildfire hazard due to retention of thinning slash is transient.

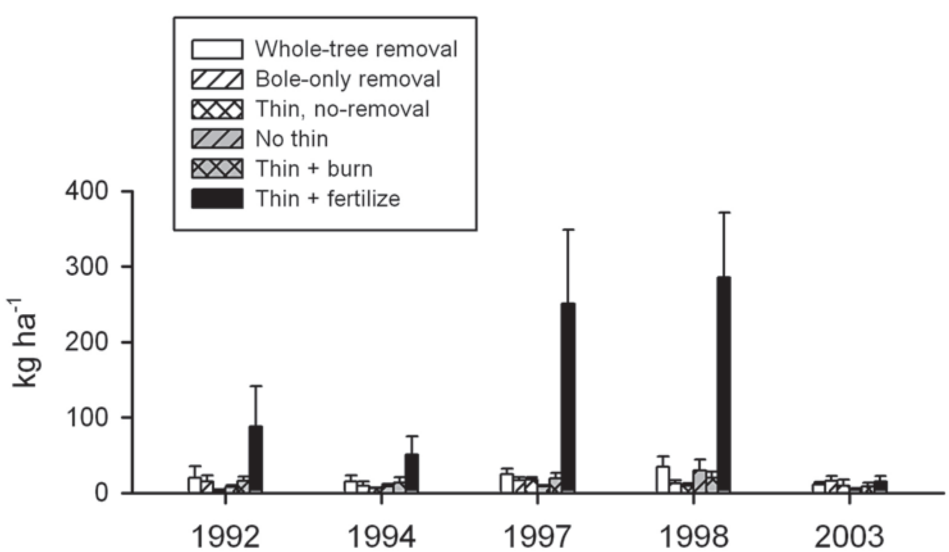

Figure 6—Herbaceous biomass production during peak growing season. Plots were thinned in 1989 and burned in spring 1991 and spring 2002. Error bars represent the standard error of the mean (*n* = 3).

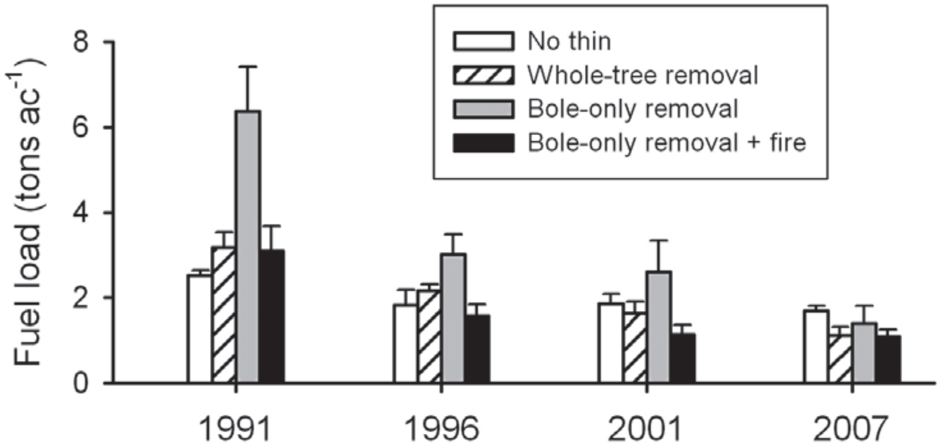

Figure 7—Changes in fine woody fuel mass (0 to 7.5 cm diameter) between 1991 and 2007. The fuel load in 1991 for "Bole-only removal + fire" was measured after the initial prescribed burn. Error bars represent the standard error of the mean (n = 3).

Soil Productivity

The slash-retention treatments had little or no effect on the soil properties by 2003, 14 years after thinning. In addition to the basic measures reported in table 2, no differences among treatments were detected in nutrient concentrations (Ca, Mg, K), microbial respiration and diversity, or duff depth. Similar results showing little effect of slash treatment were noted for soils collected earlier in the study (1993 and 1998). Some soil compaction due to the thinning operation was found on whole-tree removal plots (Parker and others 2007). However, the effects were not extensive, as no detrimental effects to trees or understory vegetation were detected on a plot basis (Busse and others 2009).

Table 2—Effect of thinning and slash removal on selected soil quality characteristics. Samples were collected from the surface 10 cm of mineral soil in 2003, fourteen years after thinning. Means plus standard errors in parentheses within a row followed by different letters are significantly different at α = 0.05 (Tukey's HSD).

Soil property	Whole-tree removal	Bole-only removal	Thin, no removal	No thin
pH	6.5 (0.2)	6.5 (0.1)	6.4 (0.1)	6.5 (0.1)
Carbon (g kg^{-1})	25.3 (3.6)	29.3 (4.0)	26.0 (3.6)	23.4 (3.2)
Nitrogen (g kg^{-1})	0.6 (0.1)	0.7 (0.1)	0.6 (0.1)	0.6 (0.1)
C:N	40 (2) ab	40 (1) ab	43 (2)a	37 (1)b
Phosphorus (mg kg^{-1})	39 (10)	47 (8)	44 (8)	47 (11)
Litter decay (percent mass loss in 2 years)	36 (3)	37 (8)	40 (2)	37 (4)
Microbial biomass (mg kg^{-1})	772 (106)	902 (174)	818 (124)	652 (28)

Conclusions

No differences in vegetation, wildlife browse, or soils due to whole-tree harvesting versus either bole-only harvesting or leaving all material on site were identified in 20 years of study. Thus, to answer Pat Cochran's original question about the importance of retaining site organic matter: thinning slash apparently does not need to be left on site in order to maintain site productivity. This suggests that single-entry thinning operations on the pumice plateau in central Oregon should treat slash residues based on practical concerns (type of logging equipment available, budget constraints), not based on ecological concerns for site productivity. The rapid reduction in fuel load found for the bole-only removal treatment additionally suggests that wildfire hazard due to post-thinning slash is a transient concern.

How universal are the study results? Certainly any inferences made beyond the geographical constraints of the Bend LTSP study in central Oregon should be made with caution. Differences in forest type, soil, climate, thinning prescription, or harvest equipment may all contribute to unique responses to slash treatment among forests and regions. In this regard, Page-Dumroese and others (2010) suggest that the value of retaining thinning slash is greatest for low fertility soils, those that would benefit from added sources of organic matter and nutrients. However, this recommendation was not supported by the LTSP results despite the low fertility of the region's pumice soils. Examination of the nutrient pools in central Oregon pine forests provides clarification for this assertion. Based on the nutrient profile reported by Little and Shainsky (1995) for the three LTSP sites, only about 4 percent of the total site nutrient pool was removed by whole-tree thinning compared to 1 percent by bole-only harvesting. Thus, removal of foliage and limbs during thinning accounted for only a 3 percent loss of the site nutrient pool, helping explain the lack of vegetation and soil responses to the slash treatments.

To summarize the key findings of the Bend LTSP study, (1) the retention of thinning slash was trivial to the health of central Oregon pine forests, (2) increased fuel loads for bole-only compared to whole-tree harvesting were transient, (3) thinning alone had a positive effect on wildlife browse and tree vigor without causing detrimental changes to understory vegetation or soil productivity, and (4) thinning plus repeated fire eliminated wildlife browse (bitterbrush), yet was an effective treatment for reducing wildfire hazard and maintaining site and soil productivity.

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