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Multiresource Effects of a Stand-Replacement Prescribed Fire in the *Pinus contorta-Abies lasiocarpa* Vegetation Zone of Central Washington

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Abstract

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A stand-replacement prescribed fire in an over-mature lodgepole pine (*Pinus contorta* Dougl. ex Loud.)-subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) stand (snag area) and in a mature lodgepole pine thicket (thicket area) resulted in lower plant diversity within the first year after burning, and as fire energy outputs increased, postburn plant cover and diversity decreased. There was no reestablishment of the original plant cover where total heat output exceeded 100 000 kcal/m^2. Apparently, most plants in this habitat were not fire resistant. Postfire recovery appears to depend on immigration of seeds from adjacent unburned areas or on seeds and rhizomes that survive on unburned microsites (refugia) within the burn. After fire, temperatures increased in the forest floor fermentative layer (FL) (10 to 19 °C) and upper 10 cm of the soil layer (SL) (3 to 7 °C) on several dates in summer 1976. Increased pH levels in FL (about 2 units) and SL (about 0.5 unit) after burning provided an improved environment for bacterial development, and counts of total bacteria and proteolytic bacteria both increased. Both nitrogen fixation and nitrification were increased after burning. Despite the apparent increase in microbiological activity, microbial respiration declined after burning—apparently because of reduced forest floor organic carbon energy reservoir. Diversity of birds increased the year after burning. New species of birds included hairy woodpecker (*Picoides villosus*), black-backed woodpecker (*Picoides arcticus*), three-toed woodpecker (*Picoides tridactylus*), common flicker (*Colaptes auratus*), and mountain bluebird (*Sialia currucoides*). Numbers of needle-foraging species, such as Townsend's warbler (*Dendroica townsendi*), hermit thrush (*Catharus guttatus*), golden-crowned kinglet (*Regulus satrapa*), and western tanager (*Piranga ludoviciana*), declined or were absent after fire. Responses of small mammals to fire were not definitive, but there was a marked decline in Townsend's chipmunk (*Tamias townsendii*) after burning. In the first year after burning, forage for elk (*Cervus elaphus*) in the burned area was higher in crude protein than in unburned areas, but low productivity and distance from water diminished the value of the burned area for elk.

Keywords: Forest succession, forest floor, understory vegetation, fuels, soil physical properties, wildlife, snags, downed wood, microbial populations, nitrification, nitrogen fixation, small mammals, birds, elk.

Summary

In September 1975, a prescribed fire was conducted in an over-mature lodgepole pine (*Pinus contorta* Dougl. ex Loud.)-subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) stand (snag area) and in a mature lodgepole pine thicket (thicket area). The purpose of the burn was to determine if a stand-replacing type of prescribed fire would enhance forage productivity and quality, and result in increased elk (*Cervus elaphus*) use. The area to be burned was a traditional summer elk range that was becoming dominated by tree cover. The burn also would provide an opportunity to examine the effects of fire on the indigenous plants, birds, and small mammals. Quantifying combustion of downed roundwood fuels and organic soil material would enable a better understanding of the effects of fire on various physical, chemical, and microbiological characteristics of the forest floor and soil.

The prescription was designed to top-kill the existing overstory plant cover and eliminate surface fuels (less than 2 m tall) while containing fire within designated boundaries. Control areas and preburn measurements were used to assess fire effects. In the snag area, the fire crowned and top-killed virtually all of the overstory plants and reduced the surface fuel loading by 71 percent. In the thicket area, where crowning did not occur, overstory canopy cover was reduced by 18 percent and downed and dead fuels by 52 percent.

Fire resulted in lower plant diversity within the first year after burning. As fire energy outputs increased, postburn plant cover and diversity decreased. Specifically, there was no reestablishment of the original plant cover where total heat output exceeded 100 000 kcal/m^2. Apparently, most plants in this habitat were not fire resistant. Postfire recovery appears to depend on immigration of seeds from adjacent unburned areas or on seeds and rhizomes that survived the fire in unburned microsites (refugia) within the burn. There were exceptions; most notable was the dominance of dragonhead (*Dracocephalum parviflorum* Nutt.) after the fire. In general, plant regeneration on the site likely will be a lengthy process.

Fire resulted in an increase in temperatures of the forest floor fermentative layer (FL) (10 to 19 °C) and upper 10 cm of the soil layer (SL) (3 to 7 °C) on several dates in summer 1976. Increased pH levels in FL (about 2 units) and SL (about 0.5 unit) after burning provided an improved environment for bacterial development. Counts of total bacteria and proteolytic bacteria increased. Both nitrogen fixation and nitrification were increased after burning. Despite the apparent increase in microbiological activity, microbial respiration declined after burning—apparently because of reduced forest floor organic carbon energy reservoir.

Diversity of birds increased the year after burning. New species of birds in postburn surveys included hairy woodpecker (*Picoides villosus*), black-backed woodpecker (*Picoides arcticus*), three-toed woodpecker (*Picoides tridactylus*), common flicker (*Colaptes auratus*), and mountain bluebird (*Sialia currucoides*). Numbers of needle-foraging species, such as Townsend’s warbler (*Dendroica townsendi*), hermit thrush (*Catharus guttatus*), golden-crowned kinglet (*Regulus satrapa*), and western tanager (*Piranga ludoviciana*), declined or were absent after fire. Effects of fire on most small mammals were not definitive, but there was a marked decline in Townsend’s chipmunk (*Tamias townsendii*). In the first year after burning, forage for elk (*Cervus elaphus*) in the burned area was higher in crude protein than in unburned areas, but low productivity and distance from water diminished the value of the burned area for elk.

Introduction

In the 1970s, there was substantial interest among wildland managers in central Washington to devise ways to improve the carrying capacity of summer range for elk (*Cervus elaphus*) in remote forest stands in the *Abies lasiocarpa* zone (Franklin and Dyrness 1988) of the Cascade Range. Tree stands in this area are dominated by subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.). For the most part, the commercial timber value of these stands was considered too low to justify costs of building roads to extract the timber. Densely stocked forest and large quantities of downed woody material severely restrict forage production and animal movement. Prescribed burning was proposed as a method for converting the tree-dominated stands to habitats suitable to support large herbivores. It was determined at the outset that the fire would need to be sufficiently severe to top-kill the existing overstory and remove a large quantity of the large downed logs and other debris. Essentially, this would mean a stand-replacement fire.

Managers were concerned that this type of burn may have adverse effects on other resources that could outweigh benefits associated with improvement of forage and habitat for elk. Many of these effects were largely unknown. The U.S. Department of Agriculture, Forest Service (FS), Pacific Northwest (PNW) Research Station viewed this as an opportunity to gain a better understanding of the effects of a controlled, stand-replacement fire on a variety of resources on the east side of the Cascade Range. In a partnership with the Ellensburg Ranger District of the Wenatchee National Forest, Pacific Northwest Region of the FS, a plan was developed to conduct a prescribed burn in a 10.9-ha area with two different-aged contiguous stands. The younger stand, referred to as the “thicket area,” was dominated by mature lodgepole pine with subalpine fir and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) in the intermediate and suppressed crown classes (Woodard 1977, 1993b). The older stand, referred to as the “snag area,” was over-mature lodgepole pine with large, live subalpine fir and Engelmann spruce as codominants in the overstory canopy. The cooperation of the staff at the University of Washington, Seattle; Washington State University, Pullman; and Central Washington University, Ellensburg, was obtained in an attempt to capitalize on the amount and quality of information to be realized from what eventually would be a moderately expensive study. The PNW Research Station at Wenatchee provided funding to each university through cooperative aid contracts. Results of one study were published by scientists at the PNW Research Station (Fowler and Helvey 1978). In addition, three M.S. theses and one Ph.D. dissertation were completed based on research conducted before and after the prescribed fire. Information from the Ph.D. dissertation of Woodard (1977) was the basis for three additional publications (Woodard 1983, 1993a, 1993b).

The five studies were designed to capture information pertaining to (1) the thermal regime and total heat output at the time of burning; (2) the assessment of physical effects of the fire on standing trees and the downed fuels; (3) the first-year response of plants to a stand-replacing crown fire; (4) the changes in forest floor, to include soil properties and microbial populations and processes; (5) the effects of burning on birds and small mammals; and (6) the changes in forage production, forage quality, and elk use. Although this research plan did not include all factors naturally affected by a fire, it served as a start to understanding the natural role of fire in this subalpine forest zone and to test a fire prescription that may serve managers in the future.

It seems timely to summarize information on the effects of this prescribed fire because of the emphasis on restoring fire to forests of the interior Pacific Northwest (Everett and others 1993, Hardy and Arno 1995, Wickman 1992) and concerns about its effects on all resources (Tiedemann and others 2000). Therefore, the goal of this paper is to synthesize the information in these theses and publications on the effects of prescribed fire in the lodgepole pine-subalpine fir "snag" and "thicket" burn areas. Although a stand-replacement fire is not the goal for most prescribed burns, it must be anticipated that, despite careful planning, this type of fire is likely to occur in some prescribed burns. This compilation is meant to provide much needed information for planning effects of stand-replacement prescribed burning on forest resources. This type of information is important for developing strategies for managing forest resources with prescribed fire (Tiedemann and others 2000). Another purpose of publishing this paper is to make people aware of the wealth of information available from the original Ph.D. dissertation (Woodard 1977) and three M.S. theses (Boltz 1979, Hanson 1978, Husby 1978).

Methods of Study

The Study Area

An area of the eastern slope of the Cascade Range called Table Mountain, located about halfway between Wenatchee and Ellensburg, Washington (USA), was the site chosen for the 10.9-ha prescribed burn. It is about 2 km from Haney Meadow up a steep mountain game trail in S. 24, T. 21N, R. 18E, Willamette P.M. (latitude 14° 18' N., longitude 120° 32' W). The site was representative of many lodgepole pine-subalpine fir stands in the Table Mountain area. The disadvantage of inaccessibility for collection of data was offset by the advantage of lack of disturbance by recreationists using nearby Haney Meadows. Remoteness also provided managers with an indication of the difficulty and costs of conducting prescribed burns in remote sites, but those issues are not addressed in this paper.

Woodard (1977, 1993a, 1993b) provided a comprehensive description of the vegetal and physical characteristics of the study area. Elevation varied narrowly between 1706 and 1761 m on a gentle southwest slope. Soils are described in detail by Woodard (1977) from descriptions provided by McColley (1976). Soils are not named or classified. Surface soils are derived from volcanic ash over residuum of basalt bedrock. Soils vary from 10 to 50 cm in the thicket area and from 40 to 100 cm in the snag area.

According to Woodard (1977), climate is typical of the subalpine zone with mean minimum January temperature about -8 °C and mean maximum July temperature of 28 °C. Most (70 percent) of the annual 80 to 160 cm of precipitation occurs as snow between October and March (Fowler and Helvey 1978).

For the thicket area, the live tree basal area and density were 72.1 m^2/ha and 1,505 trees per hectare, respectively. Live tree basal area and density in the snag area were 55.8 m^2/ha, and 1,368 trees per hectare, respectively. Woodard (1977) described the thicket area as a well-differentiated stand. The canopy of the closed stand was dominated by lodgepole pine, with subalpine fir and Engelmann spruce as codominants in the intermediate crown class. The stand in 1975 was predominately 105 years old, although there were trees of various ages throughout the area. Subalpine fir was the only tree species regenerating in the understory. Elk sedge (*Carex geyeri* Boott), arnica (*Arnica cordifolia* Hook. and *A. latifolia* Bong.), Hood's sedge (*Carex hoodii* Boott), lupine (*Lupinus polyphyllus* Lindl.), and low whortleberry

(*Vaccinium myrtillus* L.) were the predominant understory plant species. In the snag area, standing snags of lodgepole pine were obvious in the overstory canopy suggesting that it was an over-mature lodgepole pine stand (Woodard 1977). The oldest trees established 305 years before 1975. Subalpine fir and Engelmann spruce were codominants in the overstory canopy and appeared in the intermediate strata of the canopy as well. Again, only subalpine fir was commonly found in the understory layer. The principal understory plants in this stand were elk sedge, arnica (*A. latifolia*), and mosses (*Polytrichum commune* Hedw. and *Racomitrium canescens* var. *ericoides* (Brid.) B.S.G.).

The fire history of both stands was determined by Woodard (1977, 1993a). He used fire scars, increment cores, and bole disks from 195 trees to uncover the historical role of fire in the area. He documented the occurrence of three small fires–1835, 1850, and 1890–in this 10.9-ha treatment area (Woodard 1993a). He concluded that "what appeared to be two even-aged lodgepole pine stands with subalpine fir and Engelmann spruce in intermediate height classes, were complex, multiaged, mixed-species stands where all species were common in all age classes and all species were capable of surviving and reestablishing after fire" (Woodard 1993a).

The study area provided habitat for various birds including mountain chickadee (*Parus gambeli*), red-breasted nuthatch (*Sitta canadensis*), golden-crowned kinglet (*Regulus satrapa*), ruby-crowned kinglet (*R. calendula*), yellow-rumped warbler (*Dendroica coronata*), Townsend's warbler (*D. townsendi*), varied thrush (*Ixoreus naevius*), hermit thrush (*Catharus guttatus*), red crossbill (*Loxia curvirostra*), Cassin's finch (*Carpodacus cassinii*), evening grosbeak (*Coccothraustes vespertina*), Stellar's jay (*Cyanocitta stelleri*), chipping sparrow (*Spizella passerina*), and various hawks and owls (Hanson 1978). Elk was the primary large herbivore in the study area. Small mammals included yellow pine chipmunk (*Tamias amoenus*), Townsend's chipmunk, red-backed vole (*Clethrionomys gapperi*), deer mouse (*Peromyscus maniculatus*), northern flying squirrel (*Glaucomys sabrinus*), golden-mantled ground squirrel (*Spermophilus saturatus*), short-tailed weasel (*Mustella erminia*), shrew-mole (*Neurotrichus gibbsii*), vagrant shrew (*Sorex vagrans*), snow-shoe hare (*Lepus americanus*), and Douglas squirrel (*Tamiasciurus douglasii*) (Hanson 1978).

Cattle, sheep, and horses have used the area extensively since the time of settlement (Woodard 1977). Sheep used the area from 1907 until the FS began to restrict use in 1923. Between 1924 and 1972, the treatment area was part of a cattle allotment. After 1972, cattle use was excluded from the allotment. During the recorded period of use, animal use month (AUM) estimates for the entire allotment varied from 8,300 AUMs in 1924 to 925 AUMs in 1958 (Woodard 1977; based on records from the Wenatchee National Forest). In 1975, use in excess of 4,007 AUMs was considered "overuse." This level of use likely had an impact on fuel, plant cover, and soil compaction. According to FS records, elk were introduced in 1915 (Woodard 1977). Currently, these high-elevation areas are used for calving and as summer and fall range for an undetermined number of elk. The length of time the area is used annually is determined by snow depth and hunting pressure.

Table 1—Summary of fire prescriptions (proposed and actual) for the snag and thicket areas of the Table Mountain prescribed burn project in central Washington[a]

	Proposed		
Parameter	**USFS**[b]	**U of W**[c]	**Actual**
Ambient air temperature	Low 16 °C	16-27 °C	16-17 °C
Relative humidity	35-45%	<40%	19-21%
Wind (speed and direction)	<8 km/hr (S)	5-13 km/hr (S)	Calm, gusts to 26 km/hr (S-SW erratic)
Days since rain	–	4+ days, once fuels cured	15 days
Fuel moisture content (fine)	–	10-20%	13.1%
Method of firing	Backfire north side with 3-meter strips, then strip head fire remainder at 15-meter intervals by using 2 crews		As proposed
Proposed date for ignition	Mid-Sept. 1975	Mid-Sept. 1975	Sept. 30, 1975 1400-1600 hrs

[a] From Woodard (1977).
[b] USDA Forest Service.
[c] University of Washington.

Fire Prescription and Conduct of the Burn

The objective of the burn was to achieve a manageable crown fire, which would top-kill the overstory tree cover and eliminate as much of the accumulated surface fuels as possible without exceeding the treatment boundaries. Woodard (1977) detailed the fire prescription and provided a detailed description of the fuel moisture content and weather conditions necessary to accomplish these objectives and the actual conditions at the time of ignition (table 1).

Ignition of the fire occurred on September 30, 1975, beginning at 1406 hours. Woodard (1977) described the procedure for ignition and progress of the fire.

> Two four-man firing crews backfired the northeast quadrant of the treatment area. Fire strips, 3 meters apart for the first 25 meters, were backed into the hand-constructed firebreak, thereby increasing the depth of the control line. The wind was blowing from south to north. A 50/50 diesel oil and gasoline mixture

> dripped from a hand-held torch was used to ignite down and dead fuel. After the safety zone had been widened, the burners proceeded to strip headfire the remaining area. Four men, 6-12 meters apart, dripped parallel lines of fire that traversed the treatment area from northwest to southeast. Within approximately 10 minutes, trees were beginning to crown-out. Flame heights were estimated to be 38 meters by one observer and 15 meters over the tops of 27 meters crowns by two other people.

About 1 hour and 20 minutes were required to ignite the 10.9-ha area. Although burnout time varied among specific locations, most of the area was in the glowing phase of combustion by 2300 hours on October 1, 1975. The fire smoldered throughout most of October 2, 1975, but risk of the fire escaping outside the treatment area was small, and fire crews began to pack up their equipment (Woodard 1977). Within less than 2 weeks of ignition, the winter snows began to fall and the fire was declared out.

This is not a replicated study. Some of the statistical comparisons are pseudoreplication using sample dates as replicates to compare the control with burned areas and for comparisons among years. This is especially true for the soils and forest floor chemical and microbiological results.

Results

Prescribed fire in the snag area resulted in a crown fire that, with exception of one small spot fire, was managed within prescribed limits (Woodard 1977). Crowning was most prevalent in the snag area but rare in the lodgepole pine thicket area. This was likely a result of the differences in surface fuel loadings between the two areas.

Documented Characteristics of the Fire

Fire temperatures measured by Fowler and Helvey (1978) exceeded 900 °C in the snag and thicket areas at the soil surface and up to 2 m height. Only one measurement point was documented for the thicket area, so the information applies mainly to the snag area. Temperatures of 700 °C were achieved at 3 m and in excess of 600 °C at 5 m heights.

Woodard (1977) found the total heat output calculated from fuel reduction measurements provided the best estimate of the thermal environment of the site. Following fuel sampling procedures described by Brown (1974), preburn and postburn fuel loads were determined for 30 permanent, random sample plots. The difference between these two loadings is commonly termed the “available” (Byram 1958) fuel loading (loss). The available fuel weight in metric tons per hectare then was multiplied by 450 to estimate potential heat outputs in kilocalories per square meter. The reader is referred to Woodard (1977) for details of this analysis and the other estimators used in that work. Heat outputs in the snag area ranged from 1 530 to 1 542 420 kcal/m^2. In the thicket area, burned plots were estimated to have released 630 to 908 865 kcal/m^2. Unburned plots were estimated to have a heat release value of 0 kcal/m^2. Woodard (1977) suggested these levels of heat output are inordinately broad, but realistic for natural conditions.

Effects of Fire on Tree Basal Area and Canopy Cover

The basal area of the preburn live tree stems and the overstory canopy cover was reduced because of burning. In the thicket area where crowning did not occur, the average change in basal area of live stems was -1.5 percent, whereas the average percentage change in the overstory canopy cover was -18 percent. In the snag area where crowning had occurred, the basal area was reduced an average of 15 percent, and the average change in the overstory canopy cover was -63 percent.

Effects of Fire on Accumulated Surface Fuels

Total accumulations of the surface fuels, including the organic matter in the forest floor and downed-dead tree boles, averaged 174 t/ha for the thicket area and 268 t/ha for the snag area (Woodard 1977). Fuels were divided into two general categories: duff and downed roundwood. The downed roundwood weight was determined for wood diameters smaller than 0.63 cm, 0.63 to 2.5 cm, 2.5 to 7.6 cm, and larger than 7.6 cm. Fuels between 0 and 7.6 cm in diameter are commonly called fine fuels and contribute significantly to fire spread, whereas fuels larger than 7.6 cm diameter are coarse fuels and are important in burn-out or residence time. Duff is the common name used to describe the fermentation (F) and humus (H) layers of the mineral soil (Hoover and Lunt 1952, Kittredge 1948). It is also known as the O_e and O_a horizons (Page-Dumroese and others 1991). In the thicket area, 54 percent of fuels were in the roundwood categories, while the remaining was duff. Roundwood fuels composed a much higher percentage (75 percent) of total fuels in the snag area. Roundwood larger than 7.6 cm in diameter accounted for most of the difference in the roundwood weight in the snag area. Woodard (1977), however, found that fine fuel loadings were also higher in the snag area (19.8 t/ha) when compared to those in the thicket area (15.7 t/ha). As expected, fuels were highly variable among sample points even within the same area. For example, in the thicket area, total fuel weight varied almost fivefold from 58 to 270 t/ha. Variation in total fuel weight in the snag area was even greater (sixteenfold), from 49 to 781 t/ha.

Burning resulted in total fuel weight reductions in the thicket area that ranged from zero to 84 percent and averaged 52 percent (Woodard 1977). In the snag area, the total fuel weight reduction ranged from 13 to 97 percent and averaged 71 percent. As expected, the largest reductions occurred in fuel smaller than 7.6 cm in diameter—96 percent in the snag area and 70 percent in the thicket area. Reductions in the weight of duff loading were indicative of the extreme severity of the fire in the snag area and the lower severity in the thicket area. The duff weight in the snag area was reduced from 60 to 4 t/ha. In the thicket area, duff weight was reduced from 74 to 49 t/ha. More specific information about fuel reduction by individual fuel size class is in Woodard (1977).

Vegetation Responses

Woodard (1977, 1983, 1993b) studied plant community composition responses to the fire in the snag and thicket areas to determine if the prefire plant community composition could be used to accurately predict the composition of the postfire community during the first year after the burn. He used permanently located belt transects, established before burning, to measure onsite vegetation responses to fire (fig. 1). Understory vegetative cover was sparse before burning—12 percent and 18 percent for snag and thicket areas, respectively (Woodard 1977). Highest understory plant diversity or species richness before burning was found in the snag area where 32 species were identified compared to 27 in the thicket area. However, heat outputs from the fire were so great in the snag area that no plants reestablished the first year on 90 percent of the permanently located plots (fig. 1). Actual percentage of ground covered by vegetation was reduced by burning in both snag and thicket areas, but of the total area available for plant occupation, a greater percentage was covered by postfire plant species. The number of plant species in the snag area was reduced from 32 to 18. This change included 7 new species, which were found for the first time after burning, and the absence of 21 of the original species found before burning. In the thicket area, the total number of plant species declined from 27 to 24 as a consequence of burning. Five new species immigrated to the area, and eight prefire species were absent after burning.

Woodard (1977) assessed the change in cover for subalpine fir, both arnica species, two moss species, lupine, and sedges (*Carex* species summed) as a function of heat output. Although Woodard (1977) was not able to establish statistical relations, the plotted data indicated that as total heat output increased, the percentage of cover of all seven species and species groups declined. More importantly, when heat output exceeded 100 000 kcal/m^2, none of the seven species or groups found on plots before burning had regenerated 1 year after burning. Subalpine fir was the species most sensitive to increasing heat output. It did not regenerate on plots that received more than 60 000 kcal/m^2. Lupine, a rhizomatous species that was anticipated to be capable of regenerating after intense fire, had not appeared on the plots after 1 year when the heat output exceeded 100 000 kcal/m^2. Woodard (1977) did find arnica (*A. latifolia*) and sedges on plots where heat output exceeded 100 000 kcal/m^2, but these were plots where the species were not observed before burning. Woodard (1977) speculated that establishment was the result of seed migration or germination of seed that survived burning.

Plant species that increased most after burning were dragonhead, arnica, and moss (*Polytrichum commune* Hedw.). The response of dragonhead was of particular interest because it contributed most of the postburn cover in the snag area and was not identified in preburn surveys. It appears that this species is a strong invader of burned sites and is an important early seral species in these habitats. The two plant species that seemed most sensitive to burning were fireweed (*Epilobium angustifolium* L.) and columbine (*Aquilegia flavescens* S. Wats.). They were not found in either the snag or thicket burn areas the first year after burning. The response of other individual plant species to the effect of the fire are presented by Woodard (1977, 1993b). In general, field measurements indicated that most of the plants in this habitat were not fire-resistant or did not have adaptive mechanisms that enabled them to survive a high-intensity fire such as the one applied in this study.

Woodard (1977, 1993b) also explored mechanisms of plant regeneration by a greenhouse study of plant emergence from soil cores extracted 1 week before and 2 weeks after burning. For both snag and thicket areas, he identified 16 plant species on preburn soil cores before extraction. After 10 months in the greenhouse, 21 plant species had emerged (Woodard 1993b). Seven species from preburn soil cores were not encountered in field surveys and seven species found in field surveys before core extraction were not found in either preburn or postburn soil cores during the greenhouse test. These results suggest that cores contained seeds of plants that were not found in the area before the fire was ignited. One can assume that the field conditions before burning were not suitable for these species or that these seeds may have been deposited during the previous season from plants outside of the treatment area.

Figure 1—a. Preburn 1975 vegetation transect in the snag area. Note downed-dead and forest floor accumulations and sparse understory cover. b. Postburn 1976 vegetation transect from the same photopoint portrays the aftermath of the fire. c-e. 1977, 1978, and 1980 photos of vegetation transect portrays the slow recovery of vegetation.


c


e

Neither Engelmann spruce nor lodgepole pine were found on field plots after burning (Woodard 1977, 1983). To test the hypothesis that seedbed suitability was the factor that limited recruitment of these tree species after fire, he germinated seeds of Engelmann spruce and lodgepole pine on (1) white filter paper watered with distilled water; (2) white filter paper watered with dilute (500 mL ash and 1000 mL distilled water) and concentrated (500 mL ash and 500 mL distilled water) ash solutions; (3) 35 mL of washed ash solution; and (4) 35 mL untreated ash solution. Both species germinated in all treatments (73 to 92 percent germination). Engelmann spruce germination was not affected by any treatment. Lodgepole pine germination was reduced by both ash solutions and by the untreated ash solution. Even though germination percentages of both species were relatively high for all treatments, Englemann spruce has an advantage over lodgepole pine because it has higher germination levels and was not affected by ash solution or ash bed treatments.

Microbiological Responses of the Fermentative Layer and Mineral Soil

Effects of fire on pH, temperature, moisture content, total bacteria, fungi, proteolytic bacteria, actinomycetes, nitrification rates, nitrogen fixation, and microbial respiration in the fermentative layer (FL) of the forest floor and upper 10 cm of soil were determined by Husby (1978). Husby investigated effects in both thicket and snag areas as separate study units. The FL was defined as that organic material between the litter layer and mineral soil. Mineral soil layer (SL) was sampled to 10 cm depth. The FL, thus, included F and H (Hoover and Lunt 1952, Kittredge 1948) or O_e and O_a layers, respectively (Page-Dumroese and others 1991). Before the fire in 1975, samples were collected from four random locations in 8- by 8-m permanent plots in snag and thicket areas to be burned and from one control plot for each. Control plots were about 300 m from burned plots. Preburn samples were collected biweekly starting when snow was gone from plots and continuing until the site was burned. Postburn sampling in 1976 began as soon as snow was gone and continued biweekly until the first snow of the fall. In 1977, sampling started with snow elimination and continued at biweekly intervals until mid-July. Details of sample handling, preparation, and analytical procedures are in Husby (1978). He measured effects of burning on temperature, pH, and moisture content of the FL and SL because those factors govern the rate of biochemical processes. Results were tested at a probability level of $P < 0.05$ for the F-test and for comparisons of means among years at individual sites. Husby (1978) did not use a statistical analysis that would enable comparison of the control area with the burned area, assess differences among individual sample dates, or determine interaction of burning with sample dates or years. It also should be noted that statistical comparisons between 1977 and the previous 2 years may be compromised because sampling ended in mid-July 1977.

Temperatures of the FL and SL did not differ significantly among years for the control plot (tables 2 and 3). Burning did not significantly influence the FL or SL mean temperatures in the thicket or snag areas. Comparison of temperatures of control and burn areas that Husby (1978) observed on specific dates provided a more comprehensive indication of temperature effects (although not statistical) than did comparison of mean temperatures. For the thicket area, postburn temperatures of the FL were relatively uniform between the control area and burn area for all sample dates (Husby 1978). For the snag burn area, however, temperatures of the FL were 10 to 19 °C greater (no statistical test) than the control in mid-June and July 30 to August 4, 1976. Fowler and Helvey (1978) measured a 26 °C increase in maximum temperature (at 1 cm above the surface) after burning in 1976. In 1977, Husby

(1978) found that increases for individual dates had moderated to 5 to 7 °C. Postburn temperatures in 1976 on individual sample dates in the SL increased by 3 to 7 °C. Husby (1978) attributes these higher temperatures to virtually complete removal of all foliage and most branches from trees, removal of a large proportion of the litter, and the blackened remnant of the forest floor (Woodard 1977). The fire in the thicket area, in contrast, was not nearly as severe as in the snag area and did not crown out; much of the tree foliage, therefore, was left intact. Also, there was not nearly as complete consumption of litter and duff, and the forest floor was not as thoroughly blackened as in the snag area.

Moisture contents of the FL and SL did not differ significantly among years for the control plots (tables 2 and 3). In the thicket area, burning resulted in increased moisture in the FL in 1977 and in the SL in both 1976 and 1977. Moisture content more than doubled between 1975 and 1977 in both layers. In the snag burn area, there were no significant moisture-content differences among years for the FL or SL.

Mean pH in the snag area control did not change significantly among years in the FL or SL (table 2). However, in the thicket area control, there was a significant increase of 0.5 pH unit in both the FL and SL between 1975 and 1977 (table 3). Husby (1978) attributed this to natural year-to-year variation. In the thicket area, burning resulted in a significant increase of nearly 2 pH units in the FL and about 0.5 pH unit in the SL. The increase was significant in both layers in 1976. In the snag area, burning resulted in increased mean pH in the FL for both postburn years (table 2). Increases in 1976 and 1977 were 2.2 and 1.8 pH units, respectively. After burning, the SL pH in the snag area increased significantly only in 1976, but only by 0.4 pH unit.

Bacteria are involved in mineralization processes, whereby nutrients such as nitrogen (N) and sulfur (S) are converted from an intrabiotic organic state to a mineral state, which is required for plant uptake. Fire has the potential to influence many factors that govern bacterial populations, specifically pH, moisture, temperature, and energy substrates. Total bacteria counts (number per gram) were not significantly different among years in the FL or SL of control plots (tables 2 and 3) (Husby 1978). Counts increased significantly from 1.9×10^6 before burning in 1975 to 1×10^8 in 1977 after burning in the FL of the thicket area, but there was no change in counts of the SL (table 3). After burning, bacteria counts increased significantly in both the FL and SL of the snag area (table 2). In the FL, counts increased from a preburn level of 7.6×10^6 to 1.1×10^8 between 1975 and 1977. A significant increase in counts in the SL also occurred between 1975 and 1977 (1.7×10^6 to 1.8×10^7) in the snag area.

Fungi were measured as part of this study because they compose the largest proportion of total microbial protoplasm in well-aerated soils (Alexander 1961, Husby 1978). They also are known to be important in the decomposition of substances, such as lignin, which are resistant to bacterial degradation (Alexander 1961, Husby 1978). Generally, fungi are more common in acidic soils, whereas bacteria are more abundant in soils that are nearly neutral for pH. Husby (1978) found that fungi displayed a large natural variation among years as indicated by significant differences among years on the control plots (tables 2 and 3). It appeared that fire influenced only fungi in the SL of the thicket burn area (table 3). However,

Table 2—Comparisons among years of several physical and microbiological characteristics in the fermentative layer (FL) and upper 10 centimeters of soil (SL) for snag burn (SB) and control areas (C) of the Table Mountain prescribed burn project in central Washington[1]

		FL			SL		
Characteristic		**1975**	**1976**	**1977**	**1975**	**1976**	**1977**
pH	C	5.2a[2]	5.1a	5.2a	5.5a	5.4a	5.5a
	SB	4.9a	7.1a	6.7b	5.4a	5.8b	5.9b
Temperature (°C)	C	8.4a	6.9a	5.7a	7.1a	5.7a	4.7a
	SB	9.2a	13.9a	10.9a	7.2a	9.7a	8.9a
Moisture content (percent)	C	35.5a	61.5a	55.6a	18.8a	20.8a	19.6a
	SB	31.0a	14.0a	25.0a	19.7a	23.6a	23.0a
Total bacteria (number/gram)	C	6.8×10^{6}a	1.6×10^{7}a	1.6×10^{7}a	4.3×10^{6}a	3.8×10^{6}a	3.8×10^{6}a
	SB	7.6×10^{6}a	5.9×10^{7}b	1.1×10^{8}c	1.7×10^{6}a	9.7×10^{6}ab	1.8×10^{7}bc
Fungi (number/gram)	C	4.8×10^{5}a	1.6×10^{6}b	6.5×10^{5}a	1.9×10^{5}a	5.1×10^{5}a	2.5×10^{5}a
	SB	3.5×10^{5}a	3.3×10^{5}a	4.9×10^{5}a	1.8×10^{5}a	4.8×10^{5}a	7.1×10^{5}a
Proteolytic bacteria (number/gram)	C	1.2×10^{6}a	3.1×10^{6}a	4.8×10^{7}a	5.4×10^{5}a	7.8×10^{5}a	4.5×10^{7}a
	SB	5.7×10^{5}a	1.8×10^{6}a	1.5×10^{7}b	3.2×10^{5}a	7.0×10^{6}a	2.3×10^{6}b
Actinomycetes (number/gram)	C	2.4×10^{5}a	1.0×10^{6}a	5.8×10^{5}a	1.2×10^{5}a	1.3×10^{6}a	1.4×10^{5}a
	SB	1.2×10^{5}a	4.2×10^{5}a	1.0×10^{4}a	5.2×10^{4}a	1.9×10^{5}b	1.3×10^{6}c
N_2 fixation (nanomoles ethylene/day)	C	1.6a	.8a	1.4a	<.1a	0a	<.1a
	SB	.5a	14.5a	32.2b	<.1a	.1a	.9
Microbial respiration (mg CO_2/day)	C	3.0a	3.5a	3.2a	.9a	.9a	.7a
	SB	2.7b	1.2a	1.4a	.9a	.8a	.7a

[1] From Husby (1978).
[2] Values in a row within an individual FL or SL category with the same lowercase letter are not significantly different among years at $P < 0.05$.

because of the natural variation that was of similar magnitude among years at the control area, the effect of fire cannot be statistically determined.

Proteolytic bacteria are important in decomposition of proteins to amino acids (Alexander 1961). Husby (1978) observed a significant year-to-year variation in the control plot FL of the snag area (table 2). Proteolytic bacteria in 1977 were more than 10 times greater than in 1975 or 1976. There were significant increases in proteolytic bacteria as a result of burning in the SL of the thicket area (more than tenfold increase) and in the FL of the snag area (slightly less than tenfold increase) (tables 2 and 3). Husby (1978) found that actinomycetes did not vary significantly among years on

Table 3—Comparisons among years of several physical and microbiological characteristics in the fermentative layer (FL) and upper 10 centimeters of soil (SL) for thicket burn (TB) and control areas (C) of the Table Mountain prescribed burn project in central Washington[1]

		FL			SL		
Characteristic		**1975**	**1976**	**1977**	**1975**	**1976**	**1977**
pH	C	4.4a[2]	4.4a	4.9b	5.1a	5.3a	5.8b
	TB	4.5a	6.4b	6.3b	5.2a	5.9b	5.9b
Temperature (°C)	C	8.9a	6.8a	6.4a	7.8a	5.9a	4.9a
	TB	9.2a	6.8a	5.8a	7.6a	5.9a	3.9a
Moisture content (percent)	C	59.3a	100.1a	62.8a	25.7a	30.6a	29.4a
	TB	55.0a	68.0a	116.2b	23.7a	37.4b	63.0c
Total bacteria (number/gram)	C	$1.6x10^7$a	$1.7x10^7$a	$6.2x10^6$a	$4.4x10^6$a	$4.8x10^6$a	$9.7x10^6$a
	TB	$9.9x10^6$a	$8.7x10^7$ab	$1.0x10^8$b	$3.0x10^6$a	$1.8x10^7$a	$8.2x10^6$a
Fungi (number/gram)	C	$1.4x10^6$a	$3.7x10^6$a	$3.7x10^6$a	$2.4x10^5$a	$2.5x10^5$a	$7.0x10^5$b
	TB	$1.8x10^6$a	$8.6x10^5$a	$1.3x10^6$a	$2.6x10^5$a	$1.6x10^5$a	$5.3x10^5$b
Proteolytic bacteria (number/gram)	C	$2.8x10^6$a	$6.5x10^6$a	$2.5x10^7$a	$6.9x10^5$a	$8.6x10^5$a	$3.3x10^6$a
	TB	$3.1x10^6$a	$1.4x10^7$a	$3.4x10^7$a	$3.2x10^5$a	$2.4x10^6$a	$5.4x10^6$b
Actinomycetes (number/gram)	C	$1.3x10^5$a	$1.1x10^6$a	$5.8x10^5$a	$1.3x10^5$a	$2.5x10^5$a	$2.5x10^5$a
	TB	$7.2x10^4$b	$4.3x10^5$a	$3.7x10^5$a	$5.9x10^4$a	$1.8x10^5$a	$3.3x10^5$a
N_2 fixation (nanomoles ethylene/day)	C	1.4a	.6a	43.3a	<.1a	.2a	12.6b
	TB	1.2a	15.1a	58.8b	.1a	2.0a	39.1
Microbial respiration (mg CO_2/day)	C	3.3a	4.3a	3.0a	1.0a	1.0a	.7a
	TB	3.4b	1.8a	1.8a	.8a	.9a	.7a

[1] From Husby (1978).
[2] Values in a row within an individual FL or SL category with the same lowercase letter are not significantly different among years at $P < 0.05$.

the control plots (tables 2 and 3). There were significant increases in actinomycetes in both the FL and SL of the thicket area in response to burning (table 3). In the snag area, actinomycetes increased significantly after burning only in the SL (table 2).

Effects of fire on N fixation were measured to determine whether N replenishment of the soil/forest floor system was enhanced after fire. These high-elevation sites typically are deficient in N (Tiedemann and Klock 1977), and losses from fire can be substantial (Raison and others 1984). Inputs from precipitation are small, commonly less than 2 kg/ha per year (Tiedemann and others 1978). Thus, fixation is probably the primary means of N replenishment (Binkley 1986). Nitrogen fixation as measured by acetylene reduction was less than 2 and less than 0.1 nanomoles of ethylene per day in the FL and SL, respectively, of the snag area control plot (for all years). Levels were similar before burning on thicket area and snag area burn plots (tables 2 and 3). However, N fixation in the control plot of the thicket area increased substantially in both the FL and SL during the 1977 sampling season (table 3). Nitrogen fixation increased significantly (14 to 28 times) after burning in the thicket area and snag area in the FL and SL. The increase was significant only for comparisons of 1975 and 1977.

Nitrification is part of the N mineralization process whereby plant proteins are converted from ammonium-N to nitrate-N. These are the two forms of N taken up by plants and used in formation of proteins and metabolites. Husby (1978) measured nitrate production (micrograms per gram of FL or SL after 15-day perfusion) before and after burning (only in the snag area) as an indication of the effect of fire on rate of nitrification. Nitrate accumulation before burning in the FL and SL was less than 0.01 µg/g. For the mid-June and early July samples in 1976, there was no apparent effect of fire on nitrification. Nitrification, however, rose sharply in both layers after July 1, 1976. Nitrate levels observed July 15 through October 20, 1976, in the FL ranged from 10.5 to 61 µg/g. In the SL, levels for the same period ranged from 1.7 to 16.7 µg/g. Nitrification was still elevated (7.5 to 23 µg/g) in the FL during the 1977 sample period. In the SL, nitrate production in 1977 was sharply lower than 1976 (0.1 to 0.2 µg of nitrate per gram of soil).

Measurements of microbial respiration (mg of carbon dioxide per day) are indicative of microbial processes and adequacy of relatively available energy sources for microbial populations (Hu and others 1972). In Husby's (1978) study, respiration was used to provide an indication of the net effects of burning on microbial populations and processes. Microbial respiration in the FL was about three times greater than in the SL (tables 2 and 3). In the thicket area control, there was significant yearly variation (table 3). Mean microbial respiration declined from 4.3 to 3.0 mg of carbon dioxide per day between 1976 and 1977. Burning caused a significant reduction in mean microbial respiration in the FL at the snag and thicket areas (tables 2 and 3). In the thicket area, mean FL respiration declined from 3.4 to 1.8 mg of carbon dioxide per day between 1975 and 1977 (table 3). In the FL of the snag area, the decline was from 2.7 to 1.4 mg of carbon dioxide per day (table 2).

Effects of Fire on Bird and Small Mammal Populations

Hanson (1978) conducted preburn and postburn censuses of bird and small mammal populations. The snag burn area and thicket burn area were combined into a single unit (snag-thicket). Hanson's (1978) unburned control was near Haney Meadow about 1.6 km north-northwest of the snag-thicket burn area. Forest composition and structure of the control were similar to those of the snag-thicket burn area.

Birds—Hanson (1978) made same-day measurements in the snag-thicket burn area and in the control area. Both areas were gridded by Cartesian coordinates to provide permanent reference points. Bird density by species was determined on each area between 0530 and 1100 hours on seven dates June through July 1975, and May through July 1976, except that in 1976, there were only six census dates in the control area (Hanson 1978). A total of 244 and 252 points were sampled in the snag-thicket burn area in 1975 and 1976, respectively. In the control area, 151 and 111 points were sampled in 1975 and 1976, respectively.

Territories of male birds were determined by plotting the locations of singing male birds over space and time onto composite maps (Hanson 1978). Diversity indices were calculated from counts of all birds recorded using the area. Relative abundance summed over time was used to give an index of community bird diversity. Refer to Hanson (1978) for detailed descriptions of methods used. Species for which densities were not determined as territories, but for which relative abundances were used in determination of diversity indices included varied thrush, red crossbill, Cassin's finch, evening grosbeak, Stellar's jay, gray jay (*Perisoreus canadensis*), chipping sparrow, and hawks and owls.

During 1975, Hanson (1978) found seven species of breeding birds in the control area and eight species in the area to be burned (tables 4 and 5). Townsend's warblers, golden-crowned kinglets, and hermit thrushes showed a preference for preburn conditions. Present as residents or peripheral visitors were juncos (*Junco* spp.), western tanagers (*Piranga ludoviciana*), and American robins (*Turdus migratorius*). Hansen (1978) states that Townsend's warbler had an "almost invariable association with subalpine fir trees, which achieve their greatest density and foliage height diversity in this vegetation type." He further states, "the community architecture contains a very large surface area of needles in which these birds forage."

In the control area, species composition in 1976 was similar to that in 1975 with only one additional species—a peripheral visiting red-breasted nuthatch (table 4).

After fire, the bird community was radically different from that before burning. After fire, breeding bird species increased from 8 to 13. Five of these postburn species had not been recorded previously in the snag-thicket area (table 5). Four of the new species were single pairs of woodpeckers, including the hairy (*Picoides villosus*), common flicker (*Colaptes auratus*), black-backed (*Picoides arcticus*), and three-toed (*Picoides tridactylus*) (Hanson 1978). They nested in the charred, limbless spires of the snag-thicket burn area. According to Hanson (1978), this corresponds with Blackford's (1955) observations that woodpeckers concentrate on burned forest.

Hanson (1978) also observed that common flickers, black-backed woodpeckers, and Williamson's sapsuckers (*Sphyrapicus thyroides*) were present at the still-smoldering site 3 days after the burn in 1975. Woodpeckers drilled holes in snags, which provided nesting sites for three pairs of mountain bluebirds (*Sialia currucoides*) and mountain chickadees during 1976 (table 5). Also in 1976, Hansen (1978) found increased numbers of aerial- and needle-feeding yellow-rumped warblers, and ground-foraging American robins and juncos in the burned area. In an unburned portion of the burned area, he observed a pair of bark-gleaning brown creepers (*Certhia familiaris*). Numbers of needle-foraging species, including Townsend's warblers and hermit thrushes, declined precipitously after fire. Golden-crowned kinglets and western tanagers were absent from the snag-thicket burn area in 1976.

Hanson (1978) suggests that the most significant finding of the bird population portion of the study was the change in diversity that occurred as a consequence of fire. In the snag-thicket burn area, species diversity increased significantly ($P < 0.05$) after fire. There was no change in the diversity index in the unburned control area between 1975 and 1976. Other bird population variables that increased after fire in the snag-thicket burn area were species richness and average number of species

Table 4—Total numbers and densities of breeding birds on the 12.5-hectare snag-thicket control area at the Table Mountain prescribed burn project in central Washington by year and foraging guild[a]

1975			1976		
Species	Guild[b]	Pairs	Species	Guild	Pairs
Brown creeper	BG	2.0	Red-breasted nuthatch	BG	.5
Hermit thrush	GF	2.0	Brown creeper	BG	.5
Dark-eyed junco	GF	2.0	Hermit thrush	GF	1.5
Mountain chickadee	NF	1.0	Dark-eyed junco	GF	1.0
Golden-crowned kinglet	NF	1.0	Mountain chickadee	NF	1.5
Yellow-rumped warbler	NF,A	1.5	Golden-crowned kinglet	NF	2.0
Townsend's warbler	NF	5.5	Yellow-rumped warbler	NF,A	1.0
			Townsend's warbler	NF	4.5
Total		15.0	Total		12.5
Pairs/10 hectares		12.0	Pairs/10 hectares		10.0

[a] After Hanson (1978).
[b] BG = bark gleaning; GF = ground foraging; NF = needle foraging; A = aerial flycatching.

per census. Concurrently, these values declined in the control area between 1975 and 1976. Refer to Hanson (1978) for detailed descriptions and maps of bird territories.

Small mammals—In 1975, Hanson (1978) sampled small mammals by live-trapping on a 36-point grid with 15 m between points and two traps per point. Each grid was trapped for 7 days during the last week in July, August, and September 1975. In 1976, the grid was expanded to 144 points. The same number of traps was used, but traps were rotated so that after 8 days, all 144 points had received four trap-nights of coverage. Each individual mammal was sexed, tagged, and its position noted in the grid. If the animal was recaptured, its identifying number and trap site were noted before release. Hanson (1978) made population estimates from multiple recapture frequencies using the modified Schnable technique (Overton 1965). Hanson (1978) was unable to determine home ranges for the mammals he trapped because of limitations of the study design. Small mammal population estimates were highly variable, partly because of the change in sampling techniques between 1975 and 1976 (Hanson 1978). Also yellow pine chipmunk numbers appear to have declined between 1975 and 1976 for burned and control areas. Hanson concluded that the response of yellow pine chipmunk to burning was neutral or slightly positive. Hanson's (1978) results also suggest that the number of Townsend's chipmunks was severely affected by burning. The species was present in the snag-thicket and control areas in equal numbers before burning but absent from the snag-thicket burn area in 1976. Results were not definitive regarding the effects of burning, on any other species. Refer to Hanson (1978) for further details about the numbers of individual animal species found during trapping sessions and years for the snag-thicket and control areas.

Table 5—Total numbers and densities of breeding birds on the 12.2-hectare snag-thicket burn area at the Table Mountain prescribed burn project in central Washington by year and foraging guild[a]

1975			1976		
Species	**Guild[b]**	**Pairs**	**Species**	**Guild**	**Pairs**
Red-beasted nuthatch	BG	2.0	Red-breasted nuthatch	BG	1.5
American robin	GF	.5	Brown creeper	BG	1.0
Hermit thrush	GF	4.0	Hairy woodpecker	BD	1.0
Dark-eyed junco	GF	1.5	Black-backed woodpecker	BD	1.0
Golden-crowned kinglet	NF	3.0	Three-toed woodpecker	BD	1.0
Yellow-rumped warbler	NF,A	2.5	Common flicker	GF	1.0
Townsend's warbler	NF	14.0	American robin	GF	2.0
Western tanager	NF	1.0	Hermit thrush	GF	2.5
			Mountain bluebird	GF,A	3.0
Total		28.5	Dark-eyed junco	GF	3.0
Pairs/10 hectares		23.0	Mountain chickadee	NF	1.0
			Yellow-rumped warbler	NF,A	3.5
			Townsend's warbler	NF	2.0
			Total		23.5
			Pairs/10 hectares		19.0

[a] After Hansen (1978).
[b] BG = bark gleaning; GF = ground foraging; BD = bark drilling; NF = needle foraging; A = aerial flycatching.

Forage Production, Forage Quality, Elk Forage Use, and Elk Diets

Boltz (1979) studied the effect of the burn on forage production and quality, elk forage use, and elk diet preferences. Because elk are wide-ranging herbivores, Boltz (1979) assessed the importance of the forage produced and used on the prescribed burn site in the context of that of surrounding habitats used by elk. His studies included wet meadow, dry meadow, spruce swamp, open pinegrass-sedge, closed pinegrass-sedge, lupine-whortleberry, whortleberry, whortleberry-forb, sagebrush, clearcut areas, and the snag-thicket burn area (table 6). For each plant community type shown in table 6, Boltz (1979) determined the understory standing crop of forage by species, forage utilization by species, crude protein content by species, elk use and forage utilization, and elk food habits for each of these habitats. In this paper, only results of the various species groups, such as shrubs, grasses and grasslike species, and forbs, are presented. Refer to Boltz (1979) for detailed species information. Lupine-whortleberry with an overstory dominated by lodgepole pine and subalpine fir as a codominant comprised the largest proportion of total area (38 percent) (Boltz 1979) studied (table 6). The smallest proportion (0.9 percent) was occupied by the snag-thicket burn area. The sample period on which his results are based was June through September 1977. Whortleberry/forb lupine/whortleberry, and whortleberry habitats studied by Boltz (1979) are probably comparable to the snag-thicket burn area. At the burn area, he did not distinguish the snag area from the thicket area.

Table 6—Elk habitats sampled in the area of the Table Mountain prescribed burn project in central Washington, including the snag-thicket burn area[a]

Community	Overstory	Percentage of total area
Wet meadow	None	2
Dry meadow	None	1
Fir-spruce swamp	Subalpine fir	6
Open pinegrass-sedge	Lodgepole pine-subalpine fir	4
Closed pinegrass-sedge	Lodgepole pine-subalpine fir	11
Lupine-whortleberry	Lodgepole pine-subalpine fir	38
Whortleberry	Lodgepole pine-subalpine fir	12
Whortleberry-forb	Subalpine fir-lodgepole pine	18
Sagebrush	None	1
Clearcut	None	6
Snag-thicket burn area	Lodgepole pine-subalpine fir	1

[a] From Boltz (1979).

Productivity of forage suitable for use by elk in summer 1977 was highest for the wet meadow (1379 kg/ha) and lowest for the burn area (34 kg/ha) (table 7). Productivity in areas comparable to the preburn setting (whortleberry-forb, whortleberry, and lupine-whortleberry) for the snag-thicket burn area ranged from 37 to 375 kg/ha (table 7).

Boltz (1979) compared crude protein concentration (as a percentage of foliage dry weight) for 11 species found in the snag-thicket burn area with the same species on unburned sites monthly from June through September 1977. Burning enhanced crude protein concentration for every month of measurement. In June 1977, crude protein concentration for the 11 species averaged 23 percent for the burned area compared to 19 percent for the unburned area. Among species in the burned area, concentration ranged from 7 percent for whortleberry to 33 percent for lupine. Between June and September, average crude protein declined as foliage matured, but the difference between burned and unburned areas in September was about the same as in June (15 percent for burned compared to 10 percent for unburned). In September 1977 on the burned site, lupine was still highest and whortleberry still lowest in crude protein of the 11 species.

Crude protein production (average of June through September 1977 values of Boltz [1979]) on a per-hectare basis was lowest (5 kg/ha) in the snag-thicket burn area (table 7). Commensurate with highest productivity, crude protein production was highest in the wet meadow. In the whortleberry-forb habitat, crude protein production was comparable to that of the snag-thicket burn area. It ranged up to 73 kg/ha in the lupine-whortleberry habitat exceeded only by wet meadow at 200 kg/ha.

Table 7—Forage production, crude protein production, and elk use for habitats used by the Naneum Creek elk herd, including the snag-thicket burn area in summer 1977 at the Table Mountain prescribed burn project in central Washington[a]

Habitat	Forage production[b]	Crude protein production[b]	Elk use[b]
	Kilograms per hectare		*Percent*
Wet meadow	1,379	200	41.2
Dry meadow	323	37	7.7
Fir-spruce swamp	86	13	5.8
Open pinegrass-sedge	388	41	13.4
Closed pinegrass-sedge	435	65	6.8
Lupine-whortleberry	375	73	9.5
Whortleberry	234	29	5.7
Whortleberry-forb	37	6	2.0
Sagebrush	431	46	6.4
Clearcut	427	39	Not included
Snag-thicket burn	34	5	1.6

[a] From Boltz (1979).
[b] Values averaged for June, July, August, and September sample dates.

Among all habitat types (excluding clearcuts), forage use by elk was greatest for the wet meadow and least for the snag-thicket burn area (table 7). Elk use of forage was higher in forested habitats comparable to the preburn conditions of the snag-thicket area than in the snag-thicket burn area (table 7).

Within each habitat type, elk diets were further characterized by percentage coming from each plant group: shrubs, grasses and grasslike species, and forbs (Boltz 1979) (table 8). For the June through July 1977 measurement, Boltz (1979) found that forbs constituted 90 percent of the diet for elk in the snag-thicket burn area. The primary forbs used were arnica, aster, and dragonhead. Elk sedge was the most heavily used of grass and grasslike species. Forbs were also a dominant part of the elk diet in lupine-whortleberry and whortleberry-forb habitats (81 and 86 percent, respectively). For the same period in the whortleberry habitat, shrubs (mainly whortleberry) were the primary forage used by elk. By September 1977 in the snag-thicket burn area, percentage of shrubs and grasses increased in elk diets to 15 and 27 percent, respectively. The proportion of forbs in the diet declined to 57 percent. Forbs remained the largest part of elk diets in September 1977 in lupine-whortleberry, whortleberry-forb, and whortleberry habitats (69 to 95 percent).

Table 8—Percentage of elk diet from each class of plant in each habitat, including the snag-thicket burn area for the Naneum Creek elk herd in summer 1977 at the Table Mountain prescribed burn project in central Washington[a]

Habitat		Sample period		
		June-July	August	September
		Percent		
Wet meadow	S[b]	0	0	0
	G	54.8	89.5	80.1
	F	45.2	10.8	20.0
Dry meadow	S	0	0	0
	G	26.3	76.6	100.1
	F	73.8	23.3	0
Fir-spruce swamp	S	0	10.4	0
	G	0	0	0
	F	100	89.6	100.1
Open pinegrass-sedge	S	7.1	4.7	0.1
	G	71.4	62.5	99.8
	F	21.5	32.9	0
Closed pinegrass-sedge	S	10.8	10.9	0.1
	G	56.6	59.2	66.2
	F	32.6	29.9	33.8
Lupine-whortleberry	S	5.7	5.6	2.3
	G	13.7	18.7	13.1
	F	80.7	75.9	84.7
Whortleberry	S	61.5	21.5	13.2
	G	18.7	16.5	17.6
	F	19.7	61.9	69.2
Whortleberry-forb	S	13.8	3.7	5.1
	G	0	0	0
	F	85.7	96.5	94.9
Sagebrush	S	0	4.4	24.4
	G	44.8	51.7	51.0
	F	55.2	44.0	24.7
Snag-thicket burn				
	S	1.2	1.3	15.3
	G	8.7	2.0	27.3
	F	90.0	96.7	57.4

[a] From Boltz (1979).
[b] S = shrubs G = grasses/grasslike F = forb.

Conclusions

Objectives of the fire prescription generally were achieved in this high-elevation subalpine fir/lodgepole pine habitat. In the snag burn area, the crown fire killed all the trees and removed most of the foliage. Overstory canopy cover was reduced by 63 percent, and fuel loading was reduced an average of 71 percent (Woodard 1977). The duff layer (F and H or O_e and O_a) and fuels from 0 to 7.6 cm in diameter were reduced by more than 93 percent in the snag burn area. Fuels larger than 7.6 cm in diameter were reduced by 45 percent. In the thicket burn area, burning was spotty and the fire did not crown out. Overstory canopy cover was reduced by 18 percent. The lower fire intensity resulted because fuel accumulations were not as great as in the snag burn area. Fuel reductions reflected the lower fire severity in the thicket burn area. Average fuel reduction was 52 percent. Duff, fuels 0 to 7.6 cm in diameter, and fuels larger than 7.6 cm in diameter were reduced by 70, 34, and 34 percent, respectively.

Woodard (1977) showed that as fire energy outputs increased, postburn plant cover decreased. If heat output exceeded 100 000 kcal/m^2, there was no reestablishment of the original plant cover. Woodard (1977, 1993b) also determined that plant diversity was reduced in both snag and thicket areas 1 year after burning, and that when heat output increased, species diversity declined. The thicket burn area exhibited lower species diversity than the snag area but had higher stability or resiliency than the snag burn area. Woodard (1977, 1993b) concluded that the preburn plant community composition was not a good predictor of the immediate postburn plant community.

Woodard's (1977) observations of low plant survival after fire suggest that most of the plants were not fire-resistant or did not have adaptive mechanisms that enabled them to survive a high-severity fire such as the one applied in this study. His work suggests development of the postfire plant community occurred by three principal mechanisms: (1) emergence of seedlings from species of heat-resistant seeds or those that remain viable for many years in the forest floor (dragonhead, arnica, and moss); (2) import of light-seeded species, such as subalpine fir, arnica, and sedges; and (3) seeds or rhizomes on microsite refugia that were sheltered from intense fire. Refugia were beneath large logs, at the downhill base of large-diameter trees, or near large rocks where fuel accumulations were low. Seedlings of heat-resistant plants contributed substantially to the first year cover after fire. Woodard (1977, 1993a) concluded that the most important mechanism of regeneration is import from the perimeter of the burn and microsites in the burn interior that provide refugia for viable seeds of indigenous plants. He further suggested that the gene pool of interior microsites is of special significance for regeneration of large burn areas.

Woodard's (1977, 1993b) historical review of the fire history of the area and tree regeneration patterns suggests that the stand will replace itself, but that such a process will take a long time.

Fire markedly altered several of the physical and microbiological properties and characteristics in the FL (F and H or O_e and O_a layers) and the upper 10 cm of mineral soil in the snag and thicket burn areas (Husby 1978). In the FL, pH was elevated by 1.9 to 2.2 units during the first 2 years after burning. Soil pH increased by 0.4 to 0.7 units. Moisture contents of the FL and SL increased after burning in the thicket area only. Surprisingly, the fire had no detectable effect on mean temperatures of the FL or SL. There were, however, four sample dates in 1976 when the temperature of the FL of the snag burn area was 10 to 19 °C greater than that in the snag area control. Increased pH in the FL and SL provided an improved environment for bacterial growth that was reflected in the large increase in total bacteria in both burned areas in 1976 and 1977 (Husby 1978). Improved moisture in the thicket area likely facilitated the development of bacteria, but lower moisture levels in the snag burn area probably exerted a moderating effect on bacterial development. Bacterial numbers likely would have been higher in the snag burn area if moisture levels had been greater. Along with increased counts of total bacteria, proteolytic bacterial activity also increased (Husby 1978). Development of these organisms was facilitated by a higher amount of protein from the increased microbial pool and the postburn rise in N-fixing organisms. Increased numbers of bacteria were, however, not accompanied by an increase in microbial respiration from the FL. Microbial respiration declined significantly in the FL after burning. Husby (1978) indicated that Viro (1974) attributed this decline in respiration to the loss of the most easily used energy source for micro-organisms, the organic carbon of the forest floor. Nitrification and N fixation both increased after fire. Because N was likely limiting after the large losses from burning, increased N fixation would partially offset that limitation. Increased levels of nitrate after fire coincided with results of many other studies (Klemmedson and Tiedemann 1995).

Fire resulted in an increase in the numbers of birds that established territories and nested in the area (Hanson 1978). New birds included four varieties of woodpeckers and western bluebirds. Diversity indices did not differ between 1975 and 1976 for the control area but increased significantly in the burned area between preburn and postburn years (Hanson 1978). Needle-foraging species declined after burning. There was a sharp decline in numbers of Townsend’s warbler and hermit thrush, and disappearance of golden-crowned kinglet and western tanager.

Hanson’s (1978) study showed that numbers of Townsend’s chipmunk declined sharply following burning. Yellow pine chipmunk was the only species of the five sampled that showed a neutral or positive response to burning.

Heat output of the fire, particularly in the snag area, was sufficient to severely limit development of vegetation the first 2 years after burning (Woodard 1977, Boltz, 1979). This area had the lowest usable forage for elk of any of the habitats that Boltz (1979) sampled in summer 1977. Forage quality, as indicated by increased crude protein, was improved by burning, but low productivity and distance from water reduced the value of the area for elk forage.

Results of these studies suggest that, in the short term (2 years), the fire exerted a detrimental effect on the forest floor and understory vegetation. The potential benefits of releasing the understory vegetation to provide forage for the resident elk herd were not realized because of the poor development of vegetation. Nearly complete elimination of the duff and litter on the forest floor in the snag area and in some parts of the thicket area was likely associated with substantial losses of essential plant nutrients, such as N (Raison and others 1984), S (Tiedemann 1987), and phosphorus (P) (DeBano 1991, Raison and others 1984), especially at the temperatures achieved during this fire.

The short-term period of postfire studies limits the application of the information. However, the manner in which the study was designed and set up in a remote area and the extensive baseline data provide an unprecedented opportunity to explore longer term (24 years) effects of fire on this forested ecosystem. It would seem appropriate to now conduct studies that examine the same parameters.

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English Equivalents

When you know:	Multiply by:	To find:
Centimeters (cm)	0.39	Inches
Meters (m)	3.28	Feet
Square meters (m^2)	1.20	Square yards
Kilometers (km)	0.62	Miles
Hectares (ha)	2.47	Acres
Square meters per hectare (m^2/ha)	4.36	Square feet per acre
Metric tons per hectare (t/ha)	.445	Tons per acre
Kilocalories per square meter (kcal/m^2)	.369	BTU per square foot
Milligram (mg)	.000035	Ounces
Micrograms per gram (µg/g)	.000001	Ounces per ounce
Kilograms (kg)	2.205	Pounds
Kilograms per hectare (kg/ha)	.89	Pounds per acre
Milliliters (mL)	.034	Fluid ounces
Celsius (°C)	1.8 and add 32	Fahrenheit

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