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The Effect of Multi-nutrient Fertilization on Understory Plant Diversity

Abstract

This study examined multi-nutrient fertilization effects on understory vegetation diversity at eight forested locations in the inland Northwest. Percent canopy covered by understory plant species of three growth forms (shrubs, forbs, grasses) and total understory were determined over a two year period following treatment. Two diversity indices (Shannon-Wiener index and Simpson's index) were used to quantify multi-nutrient fertilization effects on understory plant diversity. Multi-nutrient fertilization prescribed to increase overstory tree growth did not typically reduce understory vegetation diversity, rather diversity increased following fertilization on some sites. Understory composition at the time of treatment greatly determined fertilization effects on diversity as follows: 1) if most species in the plant community responded relatively the same after treatment, then diversity was unchanged even though total biomass increase may have been large; 2) if a highly responsive species was abundant prior to treatment, then diversity decreased following fertilization; and 3) if a highly responsive species was relatively rare prior to treatment, then diversity increased following fertilization. Multi-nutrient forest fertilization generally did not affect understory plant diversity, but where changes did occur, diversity increases were more common than decreases.

Introduction

Management of forest ecosystems to maintain and enhance biodiversity is becoming increasingly important in forestry (Burton et al. 1992, Lippke and Oliver 1993, DeWald and Mahalovich 1997) and one component of floristic diversity is understory species diversity. The understory plant community provides wildlife habitat (Holechek et al. 1995) and helps maintain a healthy ecosystem (Burton et al. 1992, Baskin 1994, DeWald and Mahalovich 1997). Fertilization is a forest management practice that is increasingly used to promote overstory tree growth and health (Shafii et al. 1989, Moore et al. 1991, Garrison et al. 2000). However, knowledge of fertilization effects on understory vegetation diversity is lacking.

Management practices that maintain a variety of successional stages, stand densities, overstory tree species, understory species, and stand structures in a mosaic of habitats across a landscape best maintain diversity (Hunter 1990). If fertilization directly increases diversity, or results in minimal decreases, then ecosystem diversity will be maintained while also obtaining increased growth rates of the tree overstory. However, understory species diversity decreases at higher overstory densities (Alaback and Herman 1988, Uresk and Severson 1989), and since fertilization increases overstory growth, one possible longer-term indirect effect may be a decrease in understory diversity.

Prescott et al. (1993) found that "nitrogen only" fertilization with rates greater than 100 kilograms per hectare decreased vascular plant species richness, while applications of "sulfur only", as well as sulfur combined with nitrogen, increased diversity. In the same study they also found that mixed fertilization decreased or did not change vascular plant richness in Douglas-fir (*Pseudotsuga menziesii*) stands in Washington. Abrams and Dickmann (1983) saw no significant changes in species richness following fertilization in jack pine (*Pinus lambertii*) stands in Michigan. Diversity may change as a result of certain plants being able to compete better than associates for the increased supply of nutrients following fertilization (opportunistic species), or some species could be eliminated due to nutrient toxicity (Chapin et al. 1986). Fertilization may indirectly alter competitive interactions if another factor, such as light becomes limiting. Our study does not directly address the physiological reasons for diversity change, but rather quantitatively documents if fertilization

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produced a change, thereby providing insight as to possible underlying factors associated with observed treatment differences. These observations should be of ecological interest and useful to land managers.

Methods

Eight different sites from five general locations, three in Idaho, and one each in Oregon and Washington were included in this study. The study sites are representative of mid elevation conifer forests in the inland Northwest with elevations ranging between 670 and 1245 m. A wide range of habitat types, tree densities, and overstory species were sampled (Table 1). Overstory tree species composition included natural, second-growth, mixed conifers as well as plantations composed of Douglas-fir and/or ponderosa pine (*Pinus ponderosa*). None of the study sites had any sort of cutting within the last 10 years.

Study Design

The study areas were designed to be fertilizer trials within much larger operational fertilization areas. Size of experimental areas ranged from 10 to 120 ha, and the physical arrangement of the various study sites differed resulting in variable numbers of transects per site (Table 1). The fertilizer and control treatments were randomly assigned to study stands within a site to the extent possible, given operational constraints. Fertilizers were applied aerially by helicopter and containers were placed throughout each treatment area to collect fertilizer. Collected fertilizer was then weighted to monitor and ensure even distribution throughout the study site. The fertilizer blends and treatment dates for each stand are provided in Table 1. We assume that the small differences in the micro-nutrient component of the fertilizer blends had no significant effect on understory response.

Aerial photographs were used to help determine the exact locations of the fertilized units and boundaries were marked for each treatment location. One hundred meter transects were established in both control and fertilized areas, with 13 m^2 sub-plots located every 10 m along a transect for a total of 11 sub-plots. Six to ten transects were placed in each stand to minimize variability within a transect as well as to capture variation across the treatment unit. A transect is the

TABLE 1. Selected site, stand, and treatment characteristics at the experimental locations.

Site	Dominant Overstory Species	Initial basal area[1] (m^2/ha)	Crown competition factor[1] (%)	Habitat series[2]	Treatment date	Multi-nutrient fertilizer blend (kg/ha)
Bovill, ID	Mixed conifer	30	286	red cedar	Fall 1997	N 220, K 110, S 88, Cu 11, B 5.5
Goldendale, WA	Douglas-fir & ponderosa pine	15	118	Douglas-fir	Spring 1997	N 220, K 220, S 88, Cu 11, Zn 11, B 5.5, Mo 1
New Meadows, ID	ponderosa pine	20	106	Douglas-fir	Fall 1996	N 220, K 220, S 88, B 11, Cu 11, Zn 11, Mo 1
Potlatch, ID	red cedar & grand fir	57	353	red cedar	Fall 1997	N 220, K 110, S 88, Cu 11, B 5.5
	Douglas-fir	5	16	red cedar	Fall 1997	N 220, K 110, S 88, Cu 11, B 5.5
	ponderosa pine	11	14	red cedar	Fall 1997	N 220, K 110, S 88, Cu 11, B 5.5
Wallowa, OR	Mixed conifer	16	103	grand fir	Fall 1995	N 220, K 220, P 110, S 99, B 11, Cu 11, Zn 11, Mo 1
	ponderosa pine	10	60	grand fir	Fall 1995	N 220, K 220, P 110, S 99, B 11, Cu 11, Zn 11, Mo 1

[1] Includes all tree species.

[2] After Steele et al. 1981 and Johnson and Clausnitzer et al. 1992.

sample unit in this study for both understory vegetation and overstory basal area measurements.

Vegetation Measurements

Three life forms were sampled: shrubs, forbs, and grasses, using the 13 m^2 sub-plots following protocols described in Moeur (1985). Sampling occurred in mid and late summer of 1997 and 1998. The exact sampling date differed by site to make plant phenological development stage similar between sites. We wanted to sample during the period of maximum understory production and again at the end of the growing season. Vegetation sampling plots were marked with a PVC pipe in the center. Variable radius overstory tree plots were centered on the vegetation plots to measure overstory tree density and species composition. Each measured tree was marked at diameter breast height (d.b.h.) measurement point to assist in future remeasurements. Average basal area per ha and crown competition factor (CCF) (Krajieck et al 1961) were calculated as the average of the transects for each treatment (Table 1).

Percent Cover and Vertical Layering Estimates

Understory percent canopy cover sampling procedures were taken from O'Brien and Van Hooser (1983). Crown canopy cover by height layers (0 to 0.5m; > 0.5 to 2.0m; and > 2.0m) was defined as the percent area of ground surface covered by the canopy of an understory plant. The canopy coverage for each recorded species was visually estimated and assigned to coverage classes (Daubenmire 1959) as follows: < 5, 5-25, 26-50, 51-75, 76-95, and > 95 percent. For each of the three plant groups (shrubs, forbs, and grasses), individual species information was collected for up to four species, each comprising a minimum crown canopy cover of 5 percent. Using this approach, a maximum of 12 individual species per plot was recorded. Confining the species list to the 12 predominantly occurring plant species on a plot makes field sampling efficient, yet still provides a good representation of the understory vegetation composition since many more than 12 species can occur on a transect and rarely were more than 12 species encountered on an individual plot during the study. Even so, the understory vegetation sampling methods (limited to 12 species per plot) may have truncated possible Shannon-Wiener index diversity values (Pielou 1966). Nomenclature follows Hitchcock and Cronquist (1976) for vascular plants studied. Grazed areas were excluded from the sites except for a light amount of cattle grazing at the New Meadows location.

Species Diversity Measures

We were interested in treatment effects on both abundant and rare plant species. Thus, species diversity was quantified using two diversity indices, the Simpson (Simpson 1949) and Shannon-Wiener (Peet 1974) diversity indices. Simpson's index, which is sensitive to changes in the most abundant species, is the probability of picking two plants randomly that are different species. Values range from 0 to almost 1 (Simpson 1949, Sullivan et al. 1998). Lower values indicate lower diversity. The Shannon-Wiener index is sensitive to rare species changes and quantifies the degree of difficulty in predicting the species of the next individual sampled. It increases with the number of species in the community, and ranges from 0 to approximately 5.0 (Peet 1974, Washington 1984). Higher values mean greater diversity. To better reflect understory biomass composition, species observations were weighted by their coverage percentage in calculating a weighted diversity index similar to the procedures of Sullivan et al. (1998).

Statistical Analysis

Understory plant diversity, as measured by either the Simpson (SI) and Shannon-Wiener (SWI) diversity indices, was the dependent variable in our analysis. Diversity indices were computed and analyzed separately for shrubs, forbs, and grasses, as well as collectively for all 3 growth forms. Transect estimates were averaged within each site and treatment, and these averaged data were then used in subsequent statistical analyses. The experiment was designed for using Analysis of Variance (ANOVA), and statistical comparisons between fertilizer treatments were conducted using PROC GLM of the Statistical Analysis System (SAS Institute Inc. 1985). The significance level chosen for statistical tests was 0.10, which is consistent with Sullivan et al. (1998). Goldendale, Bovill, and Potlatch 1997 data were not analyzed since the fertilization treatments at these locations occurred in late spring of that year.

Results

Diversity, as measured by the indices used, was determined by the weighted abundance of a particular species, as well as by the number of different species sampled in a treatment unit. Fertilization can affect both of these diversity determinants. Diversity changes due to fertilization were variable by plant growth form. Most SWI and SI results were consistent between both years and sampling periods within sites and growth forms, and led to the same conclusions regarding treatment effects on diversity. Thus, in the interest of brevity and clarity, we present results only for SWI. The 1998 analyses probably provide the most reliable results since all sites had one full growing season following treatment, thus our sample size is much larger in 1998 and extraneous variation due to fall versus spring fertilizer application is diminished.

Analysis of variance models and results are provided in Table 2. Fertilization produced different effects on overall plant diversity depending on the characteristics of the different study sites. Shrub, grass and combined growth form plant diversity for both years and forbs in 1998 differed by study site (Table 2). Treatment produced a significant main effect on combined growth form and forb diversity in 1998 but not in 1997. Grass

TABLE 2. Analysis of variance tables for Shannon-Wiener diversity index values by various understory plant growth forms for two study years.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Combined growth forms 1997					
site	3	0.1830	0.0610	40.00	0.025
treatment	1	0.0075	0.0075	4.91	0.157
sample period	1	0.0011	0.0010	0.67	0.500
treat*period	1	0.0055	0.0055	3.62	0.197
site*treat	3	0.1232	0.0411	26.94	0.036
site*period	2	0.0752	0.0376	24.64	0.039
error	2	0.0031			
Shrubs 1997					
site	3	1.2570	0.4190	1233.84	0.001
treatment	1	0.1641	0.1641	483.32	0.002
period	1	0.0180	0.0180	52.98	0.018
treat*period	1	0.0081	0.0081	23.70	0.040
site*treat	3	0.1456	0.0485	142.94	0.007
site*period	2	0.0137	0.0069	20.17	0.047
error	2	0.0007			
Forbs 1997					
site	3	0.0915	0.0305	1.04	0.525
treatment	1	0.0015	0.0015	0.05	0.844
period	1	0.1752	0.1752	5.95	0.135
treat*period	1	0.0097	0.0097	0.33	0.624
site*treat	3	0.0994	0.0332	1.13	0.502
site*period	2	0.2774	0.1387	4.71	0.175
error	2	0.0589			
Grasses 1997					
site	3	1.0964	0.3655	79.75	0.012
treatment	1	0.0930	0.0930	20.29	0.046
period	1	0.0060	0.0060	1.30	0.372
treat*period	1	0.0116	0.0116	2.53	0.253
site*treat	3	0.0745	0.0248	5.42	0.160
site*period	2	0.0135	0.0067	1.47	0.405
error	2	0.0092			
Combined growth forms 1998					
site	7	5.5134	0.7876	90.75	<.001
treatment	1	0.3080	0.3080	35.49	0.001
period	1	0.0059	0.0059	0.68	0.439
treat*period	1	0.0055	0.0055	0.63	0.452
site*treat	7	0.9459	0.1351	15.57	0.001
site*period	7	0.1994	0.0285	3.28	0.070
error	7	0.0608			
Shrubs 1998					
site	7	7.0938	1.0134	48.66	<.001
treatment	1	0.1036	0.1036	4.98	0.061
period	1	0.1239	0.1239	5.95	0.045
treat*period	1	0.0001	0.0001	0.01	0.943
site*treat	7	0.9588	0.1370	6.58	0.012
site*period	7	0.0478	0.0068	0.33	0.918
error	7	0.1458			
Forbs 1998					
site	7	2.6524	0.3789	49.98	<.001
treatment	1	0.2680	0.2680	35.34	0.001
period	1	0.1727	0.1727	22.78	0.002
treat*period	1	<.0001	<.0001	0.00	0.959
site*treat	7	0.8197	0.1171	15.44	0.001
site*period	7	0.3624	0.0518	6.83	0.011
error	7	0.0531			
Grasses 1998					
site	7	6.3636	0.9091	33.00	<.001
treatment	1	1.0273	1.0273	37.39	<.001
period	1	0.0020	0.0020	0.07	0.794
treat*period	1	0.0559	0.0559	2.03	0.197
site*treat	7	3.3941	0.4849	17.65	<.001
site*period	7	0.1798	0.0257	0.93	0.534
error	7	0.1923			

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TABLE 2, cont'd

and shrub diversity was significantly affected by treatment in both years. Shrub diversity varied significantly by sampling period in both years. Forb diversity in 1998 also varied significantly by sampling period. A significant treatment by sampling period interaction was evident only for shrub diversity in 1997. Combined growth forms and shrubs showed a significant treatment by site interaction for both years and for forbs and grasses in 1998. The site by sampling period interaction term was significant for combined growth forms in both years, for shrubs in 1997, and for forbs in 1998.

Site specific least square mean estimates of SWI diversity by year, treatment, and sampling period for each understory plant growth form are provided in Table 3. Most statistical contrasts between treatments showed no significant change in diversity due to treatment. However, increases in SWI combined growth form diversity following fertilization were seen at the New Meadows site during late-summer for both years and mid-summer in 1997, as well as for the Douglas-fir plantation site at Potlatch for mid-summer. Shrub diversity increased after fertilization only at the western red cedar/grand fir site at Potlatch in mid-summer. For other site, year, sampling period combinations, shrub diversities remained the same or decreased. Forb diversity significantly increased for both sampling periods at the Douglas-fir plantation site at Potlatch. Significant increases in diversity occurred for grasses mid-summer 1998 at the New Meadows site, as well as the Potlatch Douglas-fir plantation site in both mid and late summer.

Decreases in overall growth form diversity, measured by SWI, were observed following fertilization in mid-summer 1998 at the Goldendale site (Table 3). Shrub diversity significantly decreased for both sampling periods in 1998 at the

TABLE 3. Shannon-Wiener (SWI) diversity indices mean values by treatment, plant lifeform, year, and sampling period for eight study locations in the inland Northwest.

			Combined		Shrubs		Forbs		Grasses	
Site	Year	Treatment	Mid	Late	Mid	Late	Mid	Late	Mid	Late
Bovill, ID										
	1998	Control	2.40	2.49	1.97	2.14	1.61	1.38	0.00	0.00
	1998	fertilized	2.90	2.69	1.74	1.98	2.14	1.99	0.00	0.00
Goldendale, WA										
	1998	Control	2.69	2.39	1.40	1.29	1.94	1.61	1.35	0.89
	1998	fertilized	2.45↓	2.23	0.80↓	0.85↓	1.83↓	1.24 ↓	1.30	1.38
New Meadows, ID										
	1997	Control	2.28	2.05	0.94	0.97	1.88	1.15	0.70	1.15
	1997	fertilized	2.53↑	2.28↑	0.81	0.76	2.02	1.48	1.17	1.48
	1998	Control	2.29	2.02	0.97	1.04	1.78	1.33	0.78	1.33
	1998	fertilized	2.56	2.35↑	0.70	0.85	1.85	1.25	1.38↑	1.25
Potlatch, ID										
red cedar/grand fir	1998	Control	0.88	0.79	0.18	0.29	0.68	0.66	0.00	0.00
	1998	fertilized	1.48	1.63	0.77↑	0.67	0.93	1.03	0.00	0.00
Potlatch, ID										
Douglas-fir	1998	Control	2.16	2.01	1.32	1.43	1.44	1.24	0.25	0.77
	1998	fertilized	2.68↑	2.81	1.48	1.64	2.10↑	2.12↑	1.35↑	1.64↑
Potlatch, ID										
ponderosa pine	1998	Control	2.39	2.29	0.95	1.16	1.70	1.62	1.03	0.91
	1998	fertilized	2.20	2.19	0.86	0.76↓	1.59	1.62	0.87	0.87
Wallowa, OR										
mixed conifer	1997	Control	2.18	2.34	1.43	1.60	1.47	1.61	0	0.15
	1997	fertilized	2.23	2.33	1.59	1.61	1.32	1.40	0.36	0.27
	1998	Control	2.30	2.41	1.65	1.63	1.43	1.56	0.17	0.33
	1998	fertilized	2.15	2.29	1.26	1.58	1.50	1.46	0.36	0.33
Wallowa, OR										
ponderosa pine	1997	Control	2.04	2.18	0.98	1.17	1.42	1.47	0.32	0.44
	1997	fertilized	1.94	1.91	0.62	0.72	1.68	1.24	0.43	0.58
	1998	Control	1.79	2.07	0.83	0.97	1.26	1.25	0.35	0.63
	1998	fertilized	1.84	2.05	0.42	0.68	1.34	1.42	0.36	0.77

↓↑ Arrows indicate a significant increase or decrease following treatment ($P < 0.10$)

Goldendale site, as well as late summer at the ponderosa pine plantation at Potlatch. Forb diversity significantly decreased at the Goldendale site. Grasses showed no significant diversity decreases due to fertilization at any location.

Discussion

Combined Growth Forms

Total understory diversity is a useful measure to quantify changes in the entire plant community following fertilization. Treatment effects were more pronounced in 1998 as nutritional differences had more time to manifest themselves in the plant communities. Site, treatment and their interaction were statistically significant for all growth forms in 1998. The significant site by treatment interaction derives from the result that only 3 of the 8 sites showed significant treatment effects. The New Meadows and Potlatch Douglas-fir sites increased in understory plant diversity, while at the Goldendale site, diversity decreased. Three factors contributed to the diversity increase at New Meadows: (1) grass diversity significantly increased after fertilization, (2) more species of all growth forms occurred in the fertilized area, and (3) the control showed little diversity, being substantially dominated by pinegrass (*Calamagrostis rubescens*) and elk sedge (*Carex geyeri*). Late-summer diversity also increased at this location in 1997 due to more grass and forb species being sampled in the fertilized area. The forb western yarrow (*Achillea millefolium*) was particularly abundant following fertilization, but remained at low levels in the control areas, which were dominated by pinegrass and elk sedge. Increases in combined growth form SWI diversity occurred for mid-summer in 1998 at the Potlatch Douglas-fir site due to an increase in common snowberry (*Symphoricarpos albus*) cover as well as by more grass species being sampled in the fertilized areas. Furthermore, the forbs speedwell (*Veronica* sp.) and clover (*Trifolium* sp.) were highly dominant in the control area causing relatively low diversity. Prescott et al. (1993) also found that common snowberry responded well to fertilization.

The understory component of the Goldendale site decreased in combined growth form diversity following fertilization because shrubs and forbs showed significant diversity decreases. The change in SWI was due to a large increase in percent cover for the shrub, squaw-carpet (*Ceanothus prostrates*) and the forb, hawkweed (*Hieracium* sp.), following fertilization. Nams et al. (1993) also showed increased growth for western yarrow after fertilization. Pinemat manzanita (*Arctostaphylos nevadensis*), common at this site, showed no response to fertilization, and this result is consistent with the lack of fertilizer response observed by Nams et al. (1993) for kinnikinnik (*Arctostaphylos uva-ursi*).

While changes in overall plant community diversity are important, individual growth form diversity changes are good indications of wildlife habitat differences (Holechek et. al. 1995). Changes in grasses and forbs will have more impact on grazing animals (i.e., cattle and elk) and changes in shrubs should have more effect on animals that are browsers (i.e. white-tailed deer) (Holechek et. al. 1995). Therefore, we analyzed shrub, forb, and grass diversity separately.

Shrubs

Minimal increases in shrub diversity were seen following fertilization. The only significant increase in shrub diversity occurred at the western redcedar (*Thuja plicata*)/grand fir (*Abies grandis*) site at Potlatch in the mid-summer sampling period but not in late summer (Table 3). Shrub diversity probably increased due to the presence of more species in the fertilized area, but this site exhibited low shrub diversity both before and after fertilization. Although statistically significant, actual changes in the understory under the dense tree canopy at this site were small.

Decreases in shrub diversity following fertilization occurred at two sites in our study. Shrub diversity decreased at the Goldendale site for both sampling periods in 1998 primarily due to a large increase in cover of squaw-carpet following fertilization. Late summer in 1998 also showed decreases in shrub diversity at the ponderosa pine plantation site at Potlatch because common snowberry increased in percent cover in the fertilized area.

Forbs

Forb diversity in mid and late summer increased only at the Potlatch Douglas-fir site. The diversity increase was due to speedwell and clover being less dominant in the fertilized area. Perhaps fertilization encouraged additional forb species to become established, but this is speculation.

Forb diversity decreased for the Goldendale site in mid and late summer 1998 following fertilization due to a large increase in hawkweed (*Hieracium* sp.) in the fertilized area. Forbs in the fertilized area were substantially dominated by hawkweed and western yarrow. Nams et al. (1993) also observed significant increases for western yarrow following fertilization.

Grasses

Grasses showed significant increases in diversity for mid-summer in 1998 at the New Meadows site and for the Potlatch Douglas-fir stand (Table 3). Diversity increases at both locations partially resulted from more grass species being sampled in the fertilized area. Possibly, establishment of new grass species was encouraged by fertilization; however, a more likely explanation is that *Poa pratensis* and *Stipa columbiana* exhibited a growth response to fertilization, thereby increasing their percent coverage and consequent inclusion in the sample.

Grasses showed no significant diversity decreases following fertilization at any study location. Therefore, fertilization to increase overstory tree growth should not significantly decrease grass diversity under mid elevation conifer stands in the inland Northwest.

All individual study sites were consistent in their diversity fertilization response across years and sampling periods. A site consistently increased, decreased, or remained unchanged. Most study sites showed no changes in overall diversity following fertilization. The Bovill site and both Wallowa sites showed no changes in overall diversity (Table 3) or for any growth form component of the understory. These sites had some of the same understory species that responded to fertilization at other sites that did show differences in understory vegetation diversity following fertilization. However, one striking difference between the Bovill site, as well as the Potlatch mixed conifer site, compared to all other locations was the complete absence of grasses in the understory. Perhaps combined life form diversity did not change following treatment at the Bovill site and the Potlatch mixed conifer site because of their high overstory conifer density, with CCF values of 286% and 353% respectively (Table 1). However, shrub diversity did increase under the very dense red cedar and grand fir canopy at the Potlatch location, but only for the mid-summer sampling. Although statistically significant for the mid-summer sampling, actual changes in shrubs at this site were small. Shrub diversity was very low prior to treatment and remained low following fertilization (Table 3). Other studies have found less diversity with increasing overstory density (Uresk and Severson 1989, Alaback and Herman 1989). We can only speculate about underlying causal factors that produced our results.

The significant treatment by site interaction means that fertilization effects on understory plant diversity differ by site, making generalizations difficult. However, we can make useful observations regarding pre-treatment differences in the plant communities that produced our results. Fertilization caused increases in understory diversity on two sites, a decrease on one site, and little or no change on the other five sites. Understory composition at the time of treatment greatly determines fertilization effects on diversity as follows: 1) if most species in the plant community respond relatively the same after treatment, then diversity may be unchanged even though total biomass increase may be large; 2) if a highly responsive species is abundant prior to treatment, then diversity may decrease following fertilization; and 3) if a highly responsive species is relatively rare prior to treatment, then diversity may increase following fertilization. Sites with high overstory density, such as the Bovill site, with a CCF of 286%, and the Potlatch mixed conifer location with a CCF of 353%, showed minimal change in combined life form understory diversity following fertilization. This is not surprising since these stands contained late-seral understory species which are adapted to tightly cycled nutrients (Tilman 1985), and they usually show lower response to an increased supply of nutrients (Grime 1977). The first type of response given above was observed at both Wallowa sites, and the second type of response occurred at Goldendale. Sites with moderate and low overstory basal areas showed both increase or decrease in diversity depending on the species present in the understory.

Of the three growth forms studied, grasses showed the least change in diversity following fertilization. Perhaps the grasses most common in our study, pinegrass and elk sedge, respond about the same to fertilization; therefore diversity would not change after treatment. The results of Freyman and Van Ryswyk (1969) for pinegrass, and Riegel et al. (1991) for elk sedge, show that both species respond positively to fertilization. Forbs showed variable responses to fertilization, and western yarrow and hawkweed appear to be opportunistic forbs. Shrubs were also variable with respect to change in diversity following fertilization. Common snowberry seems to be an opportunistic shrub while pinemat manzanita appears not to be opportunistic. A species may respond on one site and not another for the following several reasons encountered in our study: 1) the presence of other, more competitive, understory species, 2) reduced fertilization response due to light or space limitation, or 3) general understory response may be affected by overstory competition. An example of the first two situations may be the grass response at the Goldendale site being limited by low growing shrubs. An example of the third case would be low understory biomass available to show appreciable response at the Potlatch high overstory density western red cedar/grand fir site.

An important issue for resource managers in the inland Northwest is the presence of noxious weeds. Fertilization has the potential to increase not only desirable but also undesirable understory species. In our study hawkweed generally increased in both biomass and relative abundance following fertilization. The species of hawkweed we encountered were *Hieracium albiflorum* and *H. albertinum* rather than the exotic, noxious members of this genus.

Conclusions

Many factors may affect understory response to fertilization and consequent change in understory community diversity. Results from our study suggest that little change in understory diversity will occur in stands with higher overstory density. Therefore, applying multi-nutrient fertilization in mid elevation forests of the inland Northwest to increase overstory growth of these stands normally targeted for operational forest fertilization may not greatly affect understory vegetation diversity. Furthermore, understory composition at the time of treatment greatly determines fertilization effects on diversity as follows: 1) if most species in the plant community respond relatively the same after treatment, then diversity may be unchanged even though total biomass increase may be large; 2) if a highly responsive species is abundant prior to treatment, then diversity may decrease following fertilization; and 3) if a highly responsive species is relatively rare prior to treatment, then diversity may increase following fertilization. In our study the following individual species can be characterized as responsive to multi-nutrient fertilization: the shrubs, *Symphoricarpos albus* and *Ceanothus prostratus;* the forbs, *Achillea millefolium, Fragaria* sp., and *Hieracium* sp.; and the grasses, *Deschampsia* sp., *Festuca occidentalis,* and *Poa pratensis.* We do not intend to imply that the above plant list is exhaustive for those that are responsive to fertilization, merely that these plants showed response in our study. Multi-nutrient fertilization has many positive benefits for a forest community and in our study, in most cases did not drastically reduce understory vegetation diversity. On some sites, understory vegetation diversity increased following fertilization.

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Literature Cited

Abrams, M.D. and D.I. Dickmann. 1983. Response of understory vegetation to fertilization on mature and clearcut Jack pine sites in northern lower Michigan. American Midland Naturalist 110:194-200.

Alaback, P.B. and F.R. Herman. 1988. Long-term response of understory vegetation to stand density in *Picea-Tsuga* forests. Canadian Journal of Forest Research 18:1522-1530.

Baskin, Y. 1994. Ecosystem function of biodiversity. BioScience 44:657-660.

Burton, P.J., A.C. Balisky, L.P Coward, S.G. Cumming, and D.D. Kneeshaw. 1992. The value of managing for biodiversity. Forestry Chronicle 68:225-237.

Chapin, F.S., III., P.M. Vitousek, and K. Van Cleve. 1986. The nature of nutrient limitation in plant communities. American Naturalist 127:48-58.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33(1):43-64.

DeWald, L.E., and M.F. Mahalovich. 1997. The role of forest genetics in managing ecosystems. Journal of Forestry 95:12-16.

Freyman, S., and A.L. van Ryswyk. 1969. Effect of fertilization on pinegrass in southern British Columbia. Journal of Range Management 22:390-395.

Garrison, M.T., J.A. Moore, T.M. Shaw, and P.G. Mika. 2000. Foliar nutrient and growth response of mixed-conifer stands on the Okanogan and Umatilla National Forests to three fertilization treatments. Forest Ecology and Management 132:183-198.

Grime, J.P. 1977. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. The American Naturalist, 111: 1169-1194.

Hitchcock, C.L. and A. Cronquist. 1976. Flora of the Pacific Northwest. University of Washington Press. Seattle, Washington

Holechek, J.L., R.D. Pieper, and C.H. Herbel. 1995. Range Management. Prentice Hall. Upper Saddle River, New Jersey.

Hunter, M.L., Jr. 1990. Wildlife, forests, and forestry. Prentice Hall, Englewood Cliffs, N.J.

Johnson, C.G. and R.R. Clausnitzer. 1992. Plant associations of the Blue and Ochoco mountains. USDA Forest Service Publication R6-ERW-TP-036-92, Portland, Oregon.

Krajieck, J., K. Brinkman, and S. Gingrich. 1961. Crown competition, a measure of density. Forest Science 7(1): 35-42.

Lippke, B. and C.D. Oliver. 1993. Managing for multiple values. Journal of Forestry 91:14-18.

Mocur, M. 1985. Cover: a user's guide to the CANOPY and SHRUBS extension of the Stand Prognosis Model. USDA Forest Service General Technical Report INT-190. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Moore, J.A., P. G. Mika, and J.L. Vander Ploeg. 1991. Nitrogen fertilizer response of Rocky Mountain Douglas-fir by geographic area across the inland Northwest. Western Journal of Applied Forestry 6:94-98.

Nams, V.O., N.F.G. Folkard, and J.N.M. Smith. 1993. Effects of nitrogen fertilization on several woody and non-woody boreal forest species. Canadian Journal of Botany 71:93-97.

O'Brien, R.O., and D.D. Van Hooser. 1983. Understory vegetation inventory: An efficient procedure. USDA Forest Service Research Paper INT-323. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Peet, R.K. 1974. The measurement of species diversity. Annual Review of Ecological Systems 5:285-307.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. Journal of Theoretical Biology 13:131-144.

Prescott, C.E., L.P. Coward, G.F. Weetman, and S.P. Gessel. 1993. Effects of repeated nitrogen fertilization on the ericaceous shrub, salal (*Gaultheria shallon*), in two coastal Douglas-fir forests. Forest Ecology and Management 61:45-60.

Riegel, G.M., R.F. Miller, and W.C. Krueger. 1991. Understory vegetation response to increasing water and nitrogen levels in a *Pinus ponderosa* forest in Northeastern Oregon. Northwest Science 65:10-15.

SAS Institute, Inc. 1985. Statistical Analysis System's user's guide basics. Version 5 edition. SAS Institute Inc., Cary N.C.

Shafii, B., J.A. Moore, and J.R. Olson. 1989. Effects of nitrogen fertilization on growth of grand fir and Douglas-fir stands in northern Idaho. Western Journal of Applied Forestry 4:54-57.

Simpson, E.H. 1949. Measurement of diversity. Nature 163:688.

Steele, R., R.D. Pfister, R.A. Ryker, and J.A. Kittams. 1981. Forest Habitat Types of Central Idaho. USDA Forest Service General Technical Report INT-114. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Sullivan, T.P., R.G. Wagner, D.G. Pitt, R.A. Lautenschlager, and D.G. Chen. 1998. Changes in diversity of plant and small mammal communities after herbicide application in a sub-boreal spruce forest. Canadian Journal of Forest Research 28:168-177.

Tilman, D. 1985. The resource-ratio hypothesis of plant succession. The American Naturalist 125 (6):827-852.

Uresk, D.W. and K.E. Severson. 1989. Understory-overstory relationships in ponderosa pine forests, Black Hills, South Dakota. Journal of Range Management 42(3): 203-208.

Washington, H.G. 1984. Diversity, biotic and similarity indices: a review with special relevance to aquatic ecosystems. Water Resources Research 18:653-694.

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