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Abstract

This study quantified the effects of operational multi-nutrient fertilization on understory shrub, forb, and grass production in forests of eastern Oregon, Washington, and Idaho. The greatest understory response to fertilization occurred in low density overstory stands. One additional cattle Animal Unit Month (AUM) can be produced per acre, one year following treatment, in stands with overstory basal area less than 50 $ft.^2$/ ac.. One additional white-tailed deer equivalent AUM can be produced in stands with less than 75 $ft.^2$/ ac. overstory basal area. Multi-nutrient fertilization is an effective treatment for increasing understory production and generally improving wildlife habitat and rangeland yield in addition to tree overstory growth and yield.

Introduction

Forest fertilization may provide an effective treatment to increase or maintain multiple resource outputs on a declining land base. Most forests in the inland Northwest are nutrient deficient and overstory conifers respond favorably following fertilization (Shaffii et al. 1989, Moore et al. 1991, Garrison et al. 1998). However, information regarding fertilization effects on understory vegetation is minimal. Overstory tree density effects on subordinate understory vegetation response to fertilization have also not been quantified.

Many factors influence productivity of forest plants; i.e. genetics, climate, nutrition, soil water (Gessel et al. 1960, Riegel et al. 1995, Klinka et al. 1996). Nutrition is one factor that can be feasibly and economically manipulated. Site specific fertilization prescriptions can overcome soil nutrient deficiencies resulting in increased growth of the tree overstory as well as understory vegetation (Gessel et al. 1960).

With fertilization, understory growth may potentially increase because existing plants are nutrient limited, may remain unchanged because optimum nutrient amounts already exist, or may decrease because of increased competition from the tree overstory, toxicity, or nutrient imbalance. The outcome substantially depends on the nutrient requirements of the existing plant community (Chapin et al. 1986).

Several studies have shown that the understory plant communities respond to nitrogen fertilization in mature forests (Abrams and Dickmann 1983, Freyman and van Ryswyk 1969, Nams et al. 1993, Papanastasis, et al. 1995, Prescott et al. 1993, Riegel, et al. 1991). These studies from other geographic areas suggest that fertilization may increase understory vegetation production in mixed conifer stands but that the level of response will likely depend on specific site/treatment interactions. One of these factors is overstory tree density (Alaback and Herman 1988, Jameson 1967, Klinka et al. 1996, Persson 1981, Nabuurs 1996, Riegel et al. 1995).

Growth response of understory vegetation to fertilization may be affected by increased overstory tree growth, as well as by initial stand density. Studies have shown that tree foliar biomass increases following fertilization (Turner and Olson 1976, Turner 1977). This derives from both increases in needle production and retention of older needle age classes (Turner 1979). Understanding the interaction between overstory and understory response is important since wildlife species use understory vegetation for cover, nesting, and food (Alaback and Herman 1988, Stubbendieck et al. 1997). Many forest stands are also grazed by livestock (Tisdale 1961, Geist 1976). Thinnings, coupled with fertilization could increase biodiversity, wildlife habitat, and range productivity. The above literature suggests that fertilization increases the quantity of the understory for browse and forage. Other research has shown that animals prefer fertilized vegetation over unfertilized (Anderson, et al. 1974, Geist et al. 1974, Nams et al.1993). If annual understory vegetation production increases in fertilized areas, then wildlife habitat and grazing conditions will be generally improved since there will be more vegetative growth available for food and cover. Timing of fertilization treatments in relation to stand age and stocking level (Young et al. 1967, Clary et al. 1975) and the nature of the vegetative community will produce different effects on animal carrying capacity (Rochelle 1979). Accurate quantification of response to different nutrient applications is important to allow resource managers to better manipulate understory vegetation to best meet management objectives. Thus, the primary objective of this study was to develop a model to quantify understory annual production as a function of overstory tree basal area and fertilization treatments.

Methods

Site Selection

Five general locations, comprised of eight different stands, were included in this study; three in Idaho, and one each in Oregon and Washington. All study stands were located within operational fertilization units. A wide range of sites, habitat types (Steele et al. 1981, Johnson and Clausnitzer et al. 1992) 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 (Table 1).

Study Design

The study areas were designed to be operational fertilizer trials within much larger operational areas. Test stand size ranged between 15 and 300 ac., and the physical arrangement of the various study locations differed (Table 1) resulting in variable numbers of transects per location. The fertilizer and control treatments were randomly assigned to study stands within a unit to the extent possible, given operational constraints. Fertilizers were applied aerially by helicopter. To monitor and ensure even distribution, "fertilizer buckets" were placed throughout each fertilizer treatment area. 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.

One hundred meter transects were established in both control and fertilized areas in each study stand, with 1/300th of an acre quadrats located every 10 meters for a total of 11 quadrats. Transects were placed to minimize variability within a transect as well as to capture variation across the treatment unit. The transect is the sample unit in this study for both understory vegetation and overstory basal area measurements.

Vegetation measurements

Three life forms were sampled: graminoids, forbs, and shrubs using 1/300th acre quadrats (Moeur 1985). Sampling occurred in mid and late summer of 1997 and 1998, although we analyzed only 1998 or one year after treatment data depending on a site's year of treatment. The exact sampling date differed by site to make plant phenological development stage similar between sites. Aerial photographs were used to help determine the exact locations of the fertilized units. Boundaries were marked for each treatment location and 100 m transects located within each unit to span the variation within a treatment unit. Transects were oriented to minimize site (slope, aspect, etc.) and vegetation variation within a transect. Vegetation sampling plot centers were established every 10 meters along the transects and plot centers were marked with a PVC pipe to facilitate measurement. 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 the d.b.h. measurement point to assist in future remeasurements. Average basal area per acre is the average of the transects for each treatment.

At each permanent understory sample plot, two separate components were involved in estimating annual production: destructive (clipping and weighing) and non-destructive (ocular estimates) plots. The need to quickly and accurately estimate the amount of herbage in a pasture or forest is recognized by most researchers (Haydock and Shaw 1975). Measuring plant yield directly by clipping is accurate; however only a limited number of samples are feasible and the method is destructive (Haydock and Shaw 1975, Tucker 1980, Erixson 1993). Many samples of lower precision are better than few samples of high precision to account for vegetation variability across a site (Haydock and Shaw 1975). Tucker (1980) analyzed five different methods to obtain yield and found that the comparative yield method is the most reliable. This method allows for greater numbers of sample plots compared to using the clipping only method, although there is a loss of individual quadrat precision. However, due to larger sample size, the precision of the overall site estimate of annual production may increase (Haydock and Shaw 1975).

A reference unit method proposed by Erixson (1993) was used to estimate shrub production. This method consists of using a clipped twig from a plot perimeter representing between 30 and 100 percent of the average above ground annual production for shrubs. The selected twig becomes the reference unit to which all other twigs are compared. Live annual production for each shrub was ocularly estimated to the nearest one percent of its weight relative to the reference unit (i.e. the selected twig), estimates for each shrub are then summed to obtain plot totals. The reference unit method was used in our study to efficiently obtain green and dry weights for shrubs in the clipped square meter plots. Several researchers have found that this method is nearly as accurate as clipping and weighing (Andrew et al. 1979, Kirmse and Norton 1985, Erixson 1993), although errors associated with mental fatigue are a concern (Kirmse and Norton 1985).

Understory biomass was estimated using the comparative yield method of Haydock and Shaw (1975) to reduce the amount of vegetation destruction and sampling time. General methodology was as follows: first, five reference quadrats were selected which constituted the yield scale against which the yields of sample quadrats were rated for each site. Two quadrats (standards 1 and 5) were established on low and high yielding areas to define a range that included most dry matter yield samples within each site. Then a location within the site was selected that approximated dry matter yield mid-way between those for 1 and 5. Subsequently, quadrats (standards 2 and 4) were selected that approximated yields mid-way between 1 and 3, and 3 and 5 respectively. Next, the quadrats along the transect lines were ocularly estimated using the previously established yield rating and each quadrat was rated according to one of the five scale categories. After all plots were rated, the five intensive sampling quadrats were harvested at each study site. Forbs and grasses were clipped at ground level. All harvested material was stored in plastic bags, placed in a cooler, transported back to the laboratory, and then oven dried at 70 degrees Centrigrade for 48 hours (Erixson 1993). A site specific regression equation was developed relating dry weight yield from the clipped plots to the ocular scale rating from the same clipped plots. Yield for any quadrat was then obtained by substituting its ocular rating into the regression equation. Grazing was excluded from the study sites, except for a light amount at the New Meadows location.

Statistical Analysis

We wanted the model to be statistically sound as well as be easy to apply. The independent variables selected were overstory density (basal area) and fertilizer treatment. As seen from the literature, basal area is related to understory production and can be measured relatively quickly, or is already contained in most forest inventories. Ordinary least squares regression analysis was conducted using PROC GLM of SAS Institute Inc. (1985) to estimate the parameters in the following model:

$$Y_{ijk} = e^{(\mu + Fi + \log BAj + F*BAij + eijk)} \qquad [1]$$

where: Y_{ijk} is the annual understory production for a treatment and overstory basal area combination, (either 1998 sampling year or one year after treatment), μ is the overall mean effect, F_i is the fertilizer treatment (control or multi-nutrient), BA_j is the basal area for each transect, $F*BA_{ij}$ is the interaction between fertilizer treatment and basal area for each transect, and e_{ijk} is a random error effect.

Bias corrections when converting from logarithmic units to arithmetic units for the model means and predicted values from equation (1) were accomplished using the methodology of Baskerville (1972). Goldendale mixed-conifer site data were not included in the analysis for mid-summer yields since treatment was applied in the spring of that same growing season. Models were developed separately for mid and late summer sampling periods. Visual inspection of the data showed that the relationship between annual biomass production and overstory basal area was curvilinear for both sampling periods. Equation (1) was fit to the data in a linear fashion by logarthimic transformation of both sides of the equation. Alternative model formulations were tested; however, their statistical properties were not as good as equation (1).

Results

Basal area and fertilizer treatment (equation 1) accounted for a substantial amount of variation in annual understory production. The R-square values were 0.62 and 0.60 for the mid-summer and late-summer sampling periods respectively, thus the models accounted for a significant amount of variation in understory production ($p = .0001$). Parameter estimates for equation (1) are provided in Table 2.

For better clarity, predictions derived from equation (1) are summarized in Table 3. To generate the yield values in Table 3, the treatment variable was alternately set at control and then fertilized, while basal area was varied at 25 $ft.^2$/ac. intervals across the density range sampled in this study. To help establish management guidelines for a "significant" increase in understory vegetation in relation to overstory density, the concept of the Animal Unit Month (AUM) was used. An AUM is the amount of forage required by a mature cow weighing 1000 lbs. with an unweaned calf for one month assuming an average daily consumption of 26 lbs of forage dry matter. It is assumed that one cattle AUM can provide forage for 5 white-tailed deer (Kingery 1999). Percent cover of understory vegetation by lifeform was determined for each site based on cover data and averaged across all sites for each treatment and sampling period. These cover values were then multiplied by the estimated annual production (in pounds / ac.) by treatment for a range of basal area values to obtain an estimate of annual production by lifeform. To determine AUMs, forb and grass estimates were summed together at each basal area level in Table 3 and divided by 780 pounds per acre. The AUM equivalent for white-tailed deer was similarly determined by dividing the estimated shrub annual production by 156 pounds per acre. Estimates of AUM increases following multi-nutrient fertilization are provided in Table 3.

Results from our study show that overstory basal area significantly explains variation in understory vegetation production in a similar fashion as described by Jameson (1967), Wolters and Schmidtling (1975), and Uresk and Severson (1989). Estimates of annual understory production in control areas using equation (1) ranged from a low of 54 lbs. per acre to a high of 4171 lbs. per acre for the mid-summer sampling period (Table 3); these values are within the range observed by Cooper (1987) and Erixson (1993). Higher overstory basal area resulted in less annual understory production regardless of treatment, likely resulting from more overstory competition for light, water, and nutrients (Jameson 1967, Persson 1981, Riegel et al. 1995, Nabuurs 1996).

A log-log model fit the data best, indicating that understory vegetation growth decreases non-linearly as basal area increases. At extremely high basal areas, understory production remains very low as basal area continues to increase.

The fertilization treatment variable explained differences in production between fertilized and control areas. The relationship between overstory density (basal area) and understory vegetation production response to fertilization is clear in our study. Low-density overstory stands, particularly those with densities less than crown closure, those stands below 75 ft.^{2}/ac. basal area, show much greater understory vegetation response to multi-nutrient fertilization than do dense stands. Understory biomass differences were visually striking in the field one year after fertilization. Our results suggest that understory response at the mid-summer sampling period is more than 2 tons per acre under low-density tree overstories (Table 3). Understory yield response to multi-nutrient fertilization, as affected by overstory density, was significant at the fall sampling period, however, the absolute levels were about half those observed during mid-summer.

Discussion

Fertilization guidelines in the inland Northwest suggest that a basal area range of about 125 to 175 ft^2/ac. is best for overstory volume response (Moore et al. 1998). Our study shows that understory response would be low in stands with high priority for overstory fertilization. However, in low-density stands, multi-nutrient fertilization can produce large increases in understory biomass production within one year of treatment. Regardless of whether a fertilization treatment is applied, tree density reduction in moderate basal area stands would produce more understory response than that for high density stands reduced a similar absolute amount following thinning or other density control treatments. To obtain greater understory vegetation production response to multi-nutrient fertilization in inland Northwest forests, overstory density must also be controlled.

Wild animals use forested areas in the inland Northwest for food, cover, and nesting (Alaback and Herman 1988, Stubbendieck et al. 1997). Cattle also graze many forests in the inland Northwest. For our study, cattle and white-tailed deer (Odocoileus virginianus (Halls)) were selected for comparisons since these animals are frequently managed on forestlands in the inland Northwest. Effects of fertilization on carrying capacity of other animals can be estimated from Animal Unit Equivalency tables. Understory vegetation response from multi-nutrient fertilization provides one additional cattle AUM up to 50 square feet per acre of overstory tree basal area (Table 3). White-tailed deer carrying capacity can be increased by one animal per acre following multi-nutrient fertilization up to an overstory basal area of 75 square feet per acre (Table 3). Wildlife habitat and rangeland quality would be generally improved by fertilization, since increases in AUMs and AUM equivalents were evident. In stands with overstory densities greater than 75 sq. ft./ac., understory responses would still occur. In higher density stands, even though browse and forage increases would be less than an estimated one AUM per acre, increases could be substantial over large acreages following multi-nutrient fertilization. The estimated increases in AUMs that we used are general and do not account for palatability of the existing understory vegetation composition, potential destruction of forage at full animal stocking rates, slope values, distances from watering holes, and all the other complex interactions that affect actual animal use. However, we suggest that fertilization provides a powerful tool to manage the spatial distribution of animals. For example, the increased forage and browse produced on fertilized upland sites would provide a strong attraction to move animals out of riparian zones.

Resource managers can use our results to evaluate trade offs between wildlife habitat/rangeland quality (annual production) and overstory wood production. Future studies may refine nutrient application rates and blends relative to understory vegetation response. The predictive equation developed in our study can be applied to inland Northwest forests since overstory basal area, the predictor variable, is easy to obtain. Small differences in the fertilizer rates and blends tested in our study made little difference in understory response. However, substantially different fertilizer treatments could produce significantly different understory response.

Conclusions

This study demonstrated that multi-nutrient fertilization can increase annual understory production and carrying capacity for wildlife and cattle in conifer stands throughout the inland Northwest. The results were developed from a wide range of sites, vegetation series, overstory and understory species. Overstory density, as measured by basal area per acre, greatly affects understory vegetation growth and response to multi-nutrient fertilization. Stands with tree basal areas less than 50 square ft.^{2} / ac. are estimated to produce an understory response equivalent to one cattle AUM / ac.. Furthermore, fertilization is estimated to produce an additional white-tailed deer AUM equivalent for overstory densities up to basal area of 75 ft.^{2} / ac. of basal area. Multi-nutrient fertilization can be used to increase understory vegetation production and generally improve wildlife habitat and rangeland forage quantity.

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

Site	Dominant Overstory Species	Initial basal area (ft.^{2}/ac.)	Habitat type series	Treatment date	Multi-nutrient fertilizer blend (lbs./ac.)
Bovill, ID	Mixed	121	red cedar	Fall 1997	N 200, K 100, S 80, Cu 10, B 5
Goldendale, WA	Douglas-fir & ponderosa pine	60	Douglas-fir	Spring 1997	N 200, K 200, S 80, Cu 10, Zn 10, B 5, Mo 1
New Meadows, ID	ponderosa pine	80	Douglas-fir	Fall 1996	N 200, K 200, S 80, B 10, Cu 10, Zn 10, Mo 1
Potlatch, ID	red cedar & grand fir	228	red cedar	Fall 1997	N 200, K 100, S 80, Cu 10, B 5
	Douglas-fir	20	red cedar	Fall 1997	N 200, K 100, S 80, Cu 10, B 5
	ponderosa pine	45	red cedar	Fall 1997	N 200, K 100, S 80, Cu 10, B 5
Wallowa, OR	Mixed	66	grand fir	Fall 1995	N 200, K 200, P 100, S 90, B 10, Cu 10, ZN 10, Mo 1
	ponderosa pine	39	grand fir	Fall 1995	N 200, K 200, P 100, S 90, B 10, Cu 10, ZN 10, Mo 1

Table 2. Parameter estimates for equation (1) fit to data from mid and late summer sampling periods.

	Sample Period	
Variable	Mid-summer	Late summer
Y-int	13.8572	13.348
BA	-1.8867	-1.7611
TRT	0.7416	0.6081^{ns}
BAT	0.0022^{ns}	0.0009^{ns}

^{ns} Not significant at $p = 0.1$

Table 3. Understory response estimates derived from equation (1) for mid and late summer sampling periods One white-tailed deer equivalent Animal Unit Month (AUM) is 20% of a cattle AUM.

	Mid-summer				**Late-summer**			
Basal area (ft.^{2}/ac.)	Untreated yields (lbs./ac.)	Response[a] (lbs./ac.)	Cattle AUMs	White-tailed deer equivalents	Untreated yields (lbs./ac.)	Response[a] (lbs./ac.)	Cattle AUMs	White-tailed deer equivalents
25	4171	5075	4	12	3701	2944	3	6
50	1128	1512	1	3	1092	824	1	2
75	525	773	1	2	535	382	0	1
100	305	491	0	1	322	218	0	0
125	200	352	0	1	217	139	0	0
150	142	271	0	1	158	95	0	0
175	106	220	0	1	120	68	0	0
200	82	185	0	0	95	50	0	0
225	66	160	0	0	77	38	0	0
250	54	142	0	0	64	30	0	0

[a] Response is the difference in predicted yields for fertilized areas and control areas