Nitrogen, Sulphur and Potassium Concentrations after Fertilization on Mixed Conifer Stands in Northeast Oregon and Southeast Washington

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SUMMARY. Post fertilization nitrogen, sulphur and potassium foliar nutrient concentrations were examined for several species of conifers. This study found grand fir (Abies grandis) foliar nitrogen uptake and potassium levels were higher than compared species Douglas-fir (Pseudotsuga menziesii), ponderosa pine (Pinus ponderosa) and lodgepole pine (Pinus contorta var. latifolia). Douglas-fir foliar nutrient concentrations were higher than ponderosa pine or lodgepole pine. The addition of nitrogen alone tends to cause a decrease in foliar potassium levels for all the species examined. Increases in nitrogen foliar concentrations were consistently higher on the nitrogen alone treatments than the nitrogen plus sulphur treatments.

Methods

Study Area

The study is located in the Blue Mountains of northeast Oregon and southeast Washington. By design, the eight study sites were established on four ranger districts within the Umatilla National Forest. The four ranger districts are Heppner, Pendleton, Pomeroy and Ukiah. Appendix 1. shows the installation locations in northeast Oregon and southeast Washington.

Design and Treatments

The eight study sites were established in 1991 and consist of six square plots 0.1 acre in size. The plots were grouped into two blocks of three plots based on tree and site similarities. The three treatments include control (C), nitrogen (N), and nitrogen plus sulphur (NS). Nitrogen was applied in the urea form and sulphur in the ammonium sulfate form at a rate of 200 lb/acre (225 kg/ha.) and 100 lb/acre (113 kg/ha.), respectively for each nutrient by treatment. The installations were located in mixed species stands. Five stands were regenerated naturally and three were planted. Five of the stands were thinned 6-10 years previously; the remaining stands were unthinned, but were spaced at the time of plantation establishment. Site characteristics for the eight conifer study sites are given in Table 1.

Table 1. Site characteristics for eight mixed conifer study sites located on the Umatilla National Forest in northeast Oregon and southeast Washington.

Site	Elevation	Age	Veg. Series	Parent Material
Upper Pataha (313)	5500	26	ABLA	Basalt
Unfried (314)	5000	23	ABGR	Basalt
Tollgate #1 (315)	4500	26	ABGR	Basalt
Tollgate #2 (316)	5500	24	ABGR	Basalt
Notch #1 (317)	4780	10	ABGR	Basalt
Notch #2 (318)	4800	10	ABGR	Basalt
Notch #3 (319)	4800	10	ABGR	Basalt
Ukiah (320)	4800	11	ABGR	Basalt

Measurements

Initial measurements were made in the fall of 1991. All live trees larger than 4.5 feet (1.35 m.) in height were tagged and measured for heights, diameters and defect at time of treatment. Every two years diameters will be remeasured on all of the trees and any incidence of damage or mortality along with the probable cause will be noted. Heights will be remeasured every four years after treatment on all trees. Tree volumes were estimated using regional species-specific volume equations (Wykoff et al. 1982).

One year after treatment, dormant season foliage samples were obtained from the two most dominant species represented within each installation. Two dominant or codominant trees from each species on each plot were selected for collection. Foliage was collected from the third whorl from the top of each tree by climbing. Current season foliage was clipped, placed in plastic bags, and stored in ice-cooled containers while in the field. In the laboratory , samples were oven dried at 70 degrees centigrade for 24 hours, needles were separated from stems, and removed needles were redried at 70 degrees centigrade for an additional 24 hours. Foliage was ground in Wiley mill in preparation for chemical analysis.

Foliar nitrogen levels were determined using a standard micro-Kjeldahl procedure (Bremner and Mulvaney 1982). Needles were digested with sulfuric acid and the digestrate was distilled with steam. Total K was measured by atomic absorption spectroscopy. Total S was analyzed using a Leco sulphur analyzer.

Data Analysis

Tree foliar nutrient data was analyzed using the following analysis of variance model:

$Y_{ij} = u + F_i + S_j + e_{ijk}$
where
Y_{ij} = is the observation from the *j*th species on the *i*th treatment
u = the experimental mean
F_i = is the fixed effect of the *i*th fertilizer level (i = 1,2,3)
S_j = is the effect of the *j*th species (j = 1,2,3,4)
e_{ijk} = is the experimental error

General linear contrasts of interest for the model above were obtained using the general linear models procedure (PROC GLM) of the Statistical Analysis System (SAS Institute Inc. 1985).

Results and Discussion

Foliar Nitrogen

The fertilization treatments were successful in getting additional nitrogen into the trees. Uptake of nitrogen fertilizer was evident in consistently higher nitrogen levels for all species in the N and NS treatments relative to the controls. On an average for all sites, the N treatment was more successful in increasing the foliar nitrogen levels than the NS treatment, with the N treatment increasing foliar nitrogen by 47% and the NS treatment increasing by 19%.

Foliar nitrogen levels and the effects of nutrient uptake were different by species. Douglas-fir generally had higher levels than both ponderosa pine or lodgepole pine (except on installation 320 where ponderosa pine nitrogen levels were higher on the C and NS treatments). Positive effects for foliar nitrogen were shown for all species, but grand fir consistently had higher uptake than Douglas-fir, ponderosa pine or lodgepole pine.

Foliar nitrogen concentration on the N and NS treatments were above reported adequate levels for all species (except on the NS treatment for Douglas-fir and lodgepole pine in installations 320 and 317, respectively). Nitrogen concentrations thought to be adequate for different species are given in Table 2., foliar nutrient levels below these values are considered deficient. This study found that Douglas-fir and grand fir foliar nitrogen levels increased above deficient levels on the N and NS treatments, relative to the control treatments which were either below or at reported adequate levels. Ponderosa pine foliar nitrogen levels were above adequate for all treatments, including the control, and increased significantly on both the N and NS treatments. Foliar nitrogen concentrations for lodgepole pine were deficient on the control treatments but increased above adequate levels on the N and NS treatments (except on the NS treatment in installation 317). Average nitrogen concentrations and differences in foliar nitrogen concentrations among treatments by species for the study sites (contrasts between means) are given in Table 3.

Table 2. Nitrogen, sulphur and potassium foliar nutrient deficiency levels for the four study species.

	Foliar Nutrient Concentrations[a]		
Species	N	S	K
Douglas-fir[b]	1.40	0.11	0.60
Grand fir[c]	1.15	0.14	0.58
Ponderosa pine[d]	1.15	0.15	0.48
Lodgepole pine[e]	1.30	0.14	0.50

[a]Data are for upper crown foliage collected in the fall and can be used only as guides to probable response to fertilizers. Nutritional interpretations have not yet been developed for all nutrients in all conifer species of interest. However, available data suggest some similarities among different genera within the Pinaceae. Nutritional interpretations reported might apply widely, if not precisely.
[b]Based on Webster and Dobkowski (1983).
[c]From Powers (1981), Kelly and Lambert (1972), Turner et al. (1977).
[d]Based on Boyer (1978), Powers (1988).
[e]From van den Driessche (1979).

Table 3. Average nitrogen concentrations (%) in current foliage by site, treatment and species.

Site & Treatment	Nitrogen Concentration						Species[a] Contrasts	
		Change			Change		Difference	
		%	P		%	P	%	P
313	GF			LP				
C	1.07			1.28			-16	(0.34)
N	1.41	31	(0.13)	1.43	12	(0.47)	-01	(0.91)
NS	1.79	67	(0.00)	1.36	06	(0.71)	24	(0.05)
314	DF			GF				
C	1.17			1.03			12	(0.40)
N	1.81	55	(0.00)	1.72	67	(0.00)	05	(0.56)
NS	1.42	21	(0.13)	1.38	34	(0.04)	03	(0.83)
315 & 316	GF			PP				
C	1.14			1.41			-19	(0.02)
N	1.51	32	(0.00)	1.60	13	(0.11)	-06	(0.42)
NS	1.43	25	(0.01)	1.53	08	(0.32)	-07	(0.42)
317	DF			LP				
C	1.36			1.06			22	(0.05)
N	2.85	110	(0.00)	1.78	68	(0.00)	38	(0.00)
NS	1.47	08	(0.44)	1.19	12	(0.38)	19	(0.07)
318	DF			PP				
C	1.40			1.20			14	(0.28)
N	1.95	39	(0.01)	1.71	43	(0.01)	12	(0.20)
NS	1.54	10	(0.46)	1.33	11	(0.48)	14	(0.27)
319	DF			PP				
C	1.22			1.19			03	(0.88)
N	1.96	61	(0.00)	1.84	55	(0.00)	06	(0.53)
NS	1.46	20	(0.23)	1.34	13	(0.44)	08	(0.54)
320	DF			PP				
C	1.18			1.26			-06	(0.55)
N	1.74	32	(0.00)	1.56	24	(0.05)	10	(0.20)
NS	1.33	13	(0.64)	1.63	29	(0.01)	-18	(0.04)

Note: Means in rows are species nutrient level contrasts and % **difference**; within each site means in columns are nutrient level contrasts and % **change** for the following treatment contrasts: C vs. N and C vs. NS.
[a]The Species Contrasts column represents the percent difference and significance between two species within each row and by treatment, with the first species as basis for relative comparison.

Foliar Sulphur

The relative trends for treatment success with sulphur were inconsistent and did not show any strong evidence of additional uptake associated with the NS treatments when compared to the controls. However, there were unique tendencies by species due to the effects of sulphur fertilization. Average sulphur concentrations and differences in foliar sulphur concentrations among treatments by species for the study sites (contrasts between means) are given in Table 4.

Table 4. Average sulphur concentrations (%) in current foliage by site, treatment and species.

Site & Treatment	Sulphur Concentration						Species[a] Contrasts	
		Change			Change		Difference	
		%	*P*		%	*P*	%	*P*
313	GF			LP				
C	0.08			0.06			25	(0.15)
N	0.06	-25	(0.20)	0.07	17	(0.58)	-14	(0.71)
NS	0.08	00	(1.00)	0.05	-17	(0.71)	38	(0.05)
314	DF			GF				
C	0.09			0.06			33	(0.09)
N	0.06	-34	(0.12)	0.08	33	(0.34)	-25	(0.42)
NS	0.08	-11	(0.52)	0.10	67	(0.03)	-20	(0.27)
315 & 316	GF			PP				
C	0.08			0.08			00	(0.93)
N	0.10	25	(0.04)	0.07	-13	(0.13)	30	(0.00)
NS	0.10	25	(0.04)	0.07	-13	(0.16)	30	(0.00)
317	DF			LP				
C	0.07			0.06			14	(0.40)
N	0.05	-29	(0.33)	0.05	-17	(0.90)	00	(1.00)
NS	0.10	43	(0.15)	0.07	17	(0.47)	30	(0.12)
318	DF			PP				
C	0.06			0.05			17	(0.80)
N	0.07	17	(0.15)	0.05	00	(1.00)	29	(0.05)
NS	0.08	34	(0.01)	0.07	40	(0.22)	13	(0.10)
319	DF			PP				
C	0.04			0.03			25	(0.27)
N	0.05	25	(0.58)	0.05	67	(0.10)	00	(1.00)
NS	0.05	25	(0.40)	0.04	34	(0.58)	20	(0.17)
320	DF			PP				
C	0.07			0.06			14	(0.72)
N	0.07	00	(1.00)	0.05	-17	(0.47)	29	(0.29)
NS	0.05	-29	(0.16)	0.04	-34	(0.22)	20	(0.86)

Note: Means in rows are species nutrient level contrasts and % difference; within each site means in columns are nutrient level contrasts and % change for the following treatment contrasts: C vs. N and C vs. NS.

[a]The Species Contrasts column represents the percent difference and significance between two species within each row and by treatment, with the first species as basis for relative comparison.

On an average for all sites, grand fir foliar sulphur levels increased by 27% ($P \leq 0.05$ on installations 314, 315 and 316) and Douglas-fir by 9% ($P \leq 0.05$ on installation 318), while ponderosa pine and lodgepole pine showed no significant effects. Furthermore, Douglas-fir and grand fir foliar sulphur concentration levels for all treatments were higher than both ponderosa pine and lodgepole pine (except on installation 313 where grand fir was lower than lodgepole pine on the N treatment).

Foliar sulphur levels observed in this study appear to be deficient for all the species. In addition, subsequent treatment with sulphur did not increase foliar concentrations above adequate levels. This could be due to nutritional imbalances, where the addition of nitrogen to sulphur poor sites could antagonize sulphur nutrient balances. Studies that have worked with sulphur and sulphur to nitrogen ratio suggest that foliar sulphur deficiencies may be diluted or masked due to nitrogen imbalances or additions after fertilization (Turner et al. 1977, Jarrel and Beverly, 1981). However, significant increases in foliar sulphur concentrations were observed for Douglas-fir (installation 318) and grand fir (installations 314, 315 and 316).

Foliar Potassium

Differences in foliar potassium concentrations were expressed among the treatments. When nitrogen was applied alone foliar potassium levels tend to decrease. These results appear to be similar to other studies conducted by the Intermountain Forest Tree Nutrition Cooperative (Mika and Moore 1990), where the addition of nitrogen resulted in a decrease in potassium and a imbalance of nitrogen to potassium. On a average for all sites, when nitrogen alone is applied, potassium concentrations decreased by 19% for Douglas-fir ($P \leq 0.05$ on installations 314 and 320), 13% for ponderosa pine and 31% for lodgepole pine. Grand fir potassium levels decreased by 5% on installation 313, 2% on 314 and increased by 45% ($P \leq 0.05$) on installations 315 and 316. There was no strong evidence that the NS treatment had an effect on the foliar potassium levels across all sites and species. The average potassium levels and differences among treatments by species for the study sites (contrasts between means) are given in Table 5.

Table 5. Average potassium concentrations (%) in current foliage by site, treatment and species.

Site & Treatment	Potassium Concentration						Species Contrasts	
		Change			Change		Difference	
		%	P		%	P	%	P
313	GF			LP				
C	0.99			0.58			41	(0.00)
N	0.94	-05	(0.69)	0.52	-10	(0.62)	45	(0.00)
NS	1.15	16	(0.16)	0.68	17	(0.36)	41	(0.00)
314	DF			GF				
C	0.89			1.01			-12	(0.29)
N	0.67	-25	(0.05)	0.99	-02	(0.87)	-32	(0.01)
NS	0.84	-06	(0.66)	0.96	-05	(0.61)	-13	(0.33)
315 & 316	GF			PP				
C	1.18			1.02			14	(0.48)
N	1.71	45	(0.02)	0.80	-22	(0.34)	53	(0.00)
NS	1.43	21	(0.27)	0.87	-15	(0.52)	39	(0.02)
317	DF			LP				
C	0.79			0.68			14	(0.67)
N	0.65	-18	(0.59)	0.35	-48	(0.19)	46	(0.23)
NS	1.21	53	(0.10)	0.48	-29	(0.42)	60	(0.01)
318	DF			PP				
C	0.81			0.67			17	(0.17)
N	0.64	-21	(0.10)	0.51	-24	(0.15)	20	(0.25)
NS	1.14	41	(0.01)	0.85	27	(0.09)	25	(0.01)
319	DF			PP				
C	0.99			0.70			29	(0.01)
N	0.97	-02	(0.80)	0.68	-03	(0.82)	30	(0.01)
NS	0.98	-01	(0.94)	0.67	-04	(0.76)	32	(0.01)
320	DF			PP				
C	1.08			0.86			20	(0.11)
N	0.78	-28	(0.03)	0.84	-02	(0.87)	-07	(0.64)
NS	0.89	-18	(0.15)	0.82	-05	(0.75)	08	(0.62)

Note: Means in rows are species nutrient level contrasts and % difference; within each site means in columns are nutrient level contrasts and % change for the following treatment contrasts: C vs. N and C vs. NS.
[a]The Species Contrasts column represents the percent difference and significance between two species within each row and by treatment, with the first species as basis for relative comparison.

Foliar potassium levels on all sites and for all treatments were above reported adequate levels for Douglas-fir, grand fir and ponderosa pine. However, the addition of nitrogen did alter the foliar potassium levels for all species. This effect is due to growth dilution (Jarrel and Beverly, 1981), where potassium accumulation within the needles is smaller than the relative increased needle growth response of the nitrogen treatment, resulting in a concentration reduction. Deficient potassium levels did occur for lodgepole pine on the N and NS treatments for installation 317. Table 2. contains reported potassium deficiency levels for the four study species.

Foliar Potassium to Nitrogen Ratio

The effects of nitrogen fertilization on the potassium to the nitrogen balance or ratio (K/N) is consistent with the potassium nutrient status. The results show for all the sites (except for grand fir in installations 315 and 316), when nitrogen is applied alone, the K/N tends to decrease. The effects of the N treatment decreased the K/N for grand fir by 17% ($P \leq 0.05$ on installations 313 and 314), Douglas-fir by 48% ($P \leq 0.05$ on installations 314, 318, 319 and 320), ponderosa pine by 32% ($P \leq 0.05$ on installations 318 and 319) and lodgepole pine by 46% ($P \leq 0.05$ on installation 317). Relative trends on the NS treatment for the foliar K/N by site and between species were inconsistent. When comparing all sites and treatments together, grand fir had the highest K/N level with an average of 0.86, Douglas-fir at 0.61, ponderosa pine at 0.55, and lodgepole at 0.44. The average K/N values and differences among treatments and by species for the study sites (contrasts between means) are given in Table 6.

The addition of nitrogen alone has caused an imbalance in the (K/N). Ingestad (1967, 1979) suggested that for several species an adequate balance or ratio of potassium to nitrogen should be .50. The results from this study show that grand fir K/N is extremely high on the controls treatments. The addition of nitrogen on both the N and NS treatments seems to have lowered the K/N closer to reported grand fir adequate values. A decline was also observed for Douglas-fir, ponderosa pine and lodgepole pine, especially on the N alone treatments where the K/N significantly declined to values below the .50 reported adequate value for these species.

Table 6. Average K/N ratio by site, treatment and species.

Site & Treatment	Ratio			Ratio			Species Contrasts[a]	
		Change			Change		Difference	
		%	*P*		%	*P*	%	*P*
313	GF			LP				
C	0.93			0.46			51	(0.00)
N	0.67	-28	(0.04)	0.38	-17	(0.53)	43	(0.02)
NS	0.66	-29	(0.03)	0.55	20	(0.41)	17	(0.37)
314	DF			GF				
C	0.76			0.98			-22	(0.04)
N	0.39	-49	(0.00)	0.59	-40	(0.00)	-34	(0.05)
NS	0.61	-20	(0.14)	0.69	-30	(0.01)	-12	(0.43)
315 & 316	GF			PP				
C	1.04			0.73			30	(0.13)
N	1.20	15	(0.43)	0.53	-27	(0.34)	56	(0.00)
NS	1.02	-02	(0.96)	0.57	-22	(0.44)	44	(0.02)
317	DF			LP				
C	0.59			0.62			-05	(0.86)
N	0.23	-61	(0.08)	0.20	-68	(0.04)	13	(0.88)
NS	0.83	41	(0.23)	0.41	-34	(0.29)	51	(0.05)
318	DF			PP				
C	0.60			0.56			07	(0.67)
N	0.35	-42	(0.02)	0.30	-46	(0.02)	14	(0.63)
NS	0.75	25	(0.12)	0.64	14	(0.36)	15	(0.27)
319	DF			PP				
C	0.83			0.60			28	(0.02)
N	0.49	-41	(0.00)	0.38	-37	(0.03)	22	(0.24)
NS	0.69	-17	(0.13)	0.50	-17	(0.33)	28	(0.07)
320	DF			PP				
C	0.93			0.69			26	(0.03)
N	0.47	-49	(0.00)	0.54	-22	(0.17)	-13	(0.51)
NS	0.67	-28	(0.02)	0.51	-26	(0.10)	24	(0.13)

Note: Means in rows are species nutrient ratio contrasts and % difference; within each site means in columns are nutrient ratio contrasts and % change for the following treatment contrasts: C vs. N and C vs. NS.
[a]The Species Contrasts column represents the percent difference and significance between two species within each row and by treatment, with the first species as basis for relative comparison.

Conclusions

Results from this study have found that nitrogen, sulphur and potassium foliar nutrient levels and uptake vary substantially between species and treatments. Significant foliar nutrient differences occurred between species with grand fir being the most successful in increasing foliar nutrient levels and lodgepole pine the least. Furthermore, both grand fir and Douglas-fir showed higher nutrient concentration levels than either ponderosa pine or lodgepole pine. Although the success of fertilization was evident by increased foliar concentration for each treatment, the overall treatment effect did not increase nutritional values above adequate levels for all the study species. For instance, deficient nitrogen, sulphur and potassium levels were reported for lodgepole pine even after fertilization. In fact, the addition of nitrogen altered relative sulphur and potassium nutrient levels. This was the circumstance for sulphur, where deficiencies were reported for all species on all sites even after treatment with sulphur. In addition, relative potassium levels decreased after nitrogen fertilization. Growth dilution effects and nutrient imbalances appear to be involved. The results from this study indicate that fertilization generally significantly altered the nutrient budget on these sites.

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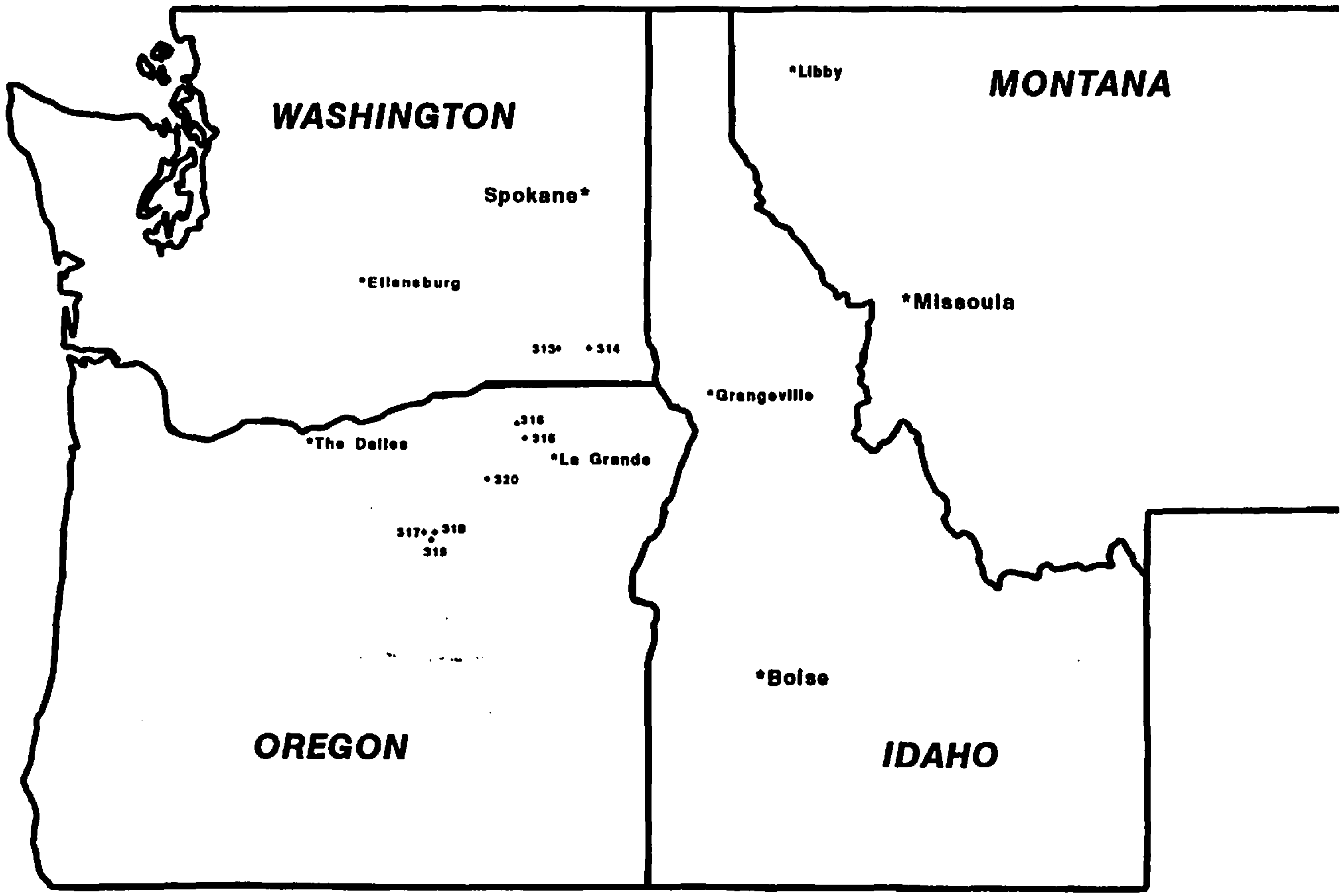
Appendix 1

INTERMOUNTAIN FOREST TREE NUTRITION COOPERATIVE



Mixed Species Umatilla Study Site