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Abstract

This paper presents data and conclusions concerning the vegetation and soils of steep natural slopes of arid regions. Cover by species and soil physical and chemical properties were taken from 10 canyons along the Columbia River north of Pasco, Washington. Vegetative cover was significantly different and averaged 25% on the south-facing and 72% on the north-facing slopes. The mean number of species, but not Shannon's or Simpson's diversity indices, were significantly different. Four species were restricted to the south slopes, 10 were restricted to the north slopes, and 23 were common to both. *Poa sandbergii* and *Agropyron spicatum*, native perennial grasses, dominated the north-facing slopes and *Bromus tectorum*, an alien annual grass, dominated the south-facing slopes. Soils were shallower and rockier on the south-facing slopes. Even though vegetative cover and number of species were different, the similar number of dominant species (Shannon's and Simpson's indices) suggest community functions are nonetheless similar in these contrasting environments.

Key Words: vegetation, slopes, species diversity, dominance.

INTRODUCTION

Canopy cover and species composition of undisturbed vegetation of the shrub-steppe region of south-central Washington have been described by Daubenmire (1970). For the most part, Daubenmire's descriptions are of vegetation types on level to gently sloping land. Quantitative descriptions of vegetation of steep, natural slopes in semi-arid or arid areas are scarce in the published literature. The purpose of this paper is to present our analyses of data on plant species composition and canopy cover of steep north and south slopes.

Differences in vegetation on steep slopes with contrasting exposure have long been recognized and related to differences in microclimate, especially the moisture and heat regimes of the soil layers in close contact with the plants. Few species seem totally restricted to a particular slope aspect but appear to respond to microclimatic differences with shifts in density (Cantlon 1953). Microclimate is in turn influenced by vegetation cover (Ayyad and Dix 1964). Steep south slopes were found to have higher soil and air temperatures than north slopes (Rickard et al. 1971, Rickard et al. 1973), while the number of species, canopy cover, and production were less on steep south slopes than similar north slopes (Rickard 1975). Slope differences in solar radiation caused changes in primary production, protein content, and root-shoot ratios in cheatgrass (*Bromus tectorum*) (Hinds 1975).

The study site was located on the eastern side of the Columbia River, Franklin County, Washington, approximately three miles north of the City of Pasco. Bluffs rising one to two hundred feet drop precipitously into the Columbia River. Deep, parallel canyons have been eroded into the face of the bluff. The canyons run generally east and west so that the sides of the canyons are at the same angles (30-40°) and provide contrasting north- and south-facing exposures. The bluff consists of consolidated alluvium arranged in strata of gravels, pebbles, and cobbles with a sandstone matrix.

The regional climate is characterized by low precipitation, averaging slightly less than seven inches annually, nearly all of which falls in the cool part of the year. Summers are hot and dry and winters cold to cool and wet.

METHODS

Ten canyons large enough to avoid local ridge and valley effects were randomly selected (Fig. 1). In each canyon, two 3 x 4 m plots were set out midway between ridge and valley, one on the north and one on the south slope. Soil samples were taken just outside the lower left-hand corner of each plot. Soil depth measurements and vegetative cover estimates were taken at 1/2 m intervals along the length of the two sides (3 m) and bottom (4 m) of each plot. Thus, a total of 23 cover estimates and soil depth measurements was made per slope. Soil depth was estimated by pushing a metal rod vertically into the soil until it met a solid resistance, usually a rock. These depth measurements are thus biased estimates; bedrock is probably deeper than these values. Vegetative cover was estimated using the Daubenmire (1959) method in which a 20 x 50 cm frame is placed in the ground, short edge against a meter tape, and the percent cover of each species present is placed into one of the following six cover classes: 0 to 5%, 5 to 25%, 25 to 50%, 50 to 75%, 75 to 95%, 95 to 100%. The midpoint of the observed interval was used as the percent cover for that species. The average percent cover, by species, for the 23 plots was calculated and used to represent the slope in subsequent calculations.

The percent cover on each slope was converted to proportional cover by dividing each value by the total. The proportional cover was used to calculate diversity indices according to Hill (1973). The general equation used (Hill 1973) was

$$N_a = (p_1{}^a + p_2{}^a + p_3{}^a \ . \ . \ . + p_n{}^a)^{1/(1-a)}$$

where N_a is a diversity index, $p_1 \ . \ . \ . \ p_n$ are the proportional abundances or covers for the n species, and a is the parameter which determined the diversity index calculated:

a = 0 Number of species

a = 1 exp (H) (H is Shannon's entropy)

a = 2 reciprocal of Simpson's modified index

For a = 1,

$$N_1 = \exp\left(-\sum p_i \ln(p_i)\right) = \exp H \qquad \text{(Hill 1973)}$$

where i progresses from 1 to n.

The Wilcoxon Signed Rank Test was used to test for differences in percent cover for each species, total cover, and the diversity indices, because it assumes only that the samples come from the same but unknown distribution (Woolf 1963).

The soil samples were analyzed for percent gravel (larger than 2 mm); percent sand, silt, and clay; percent organic matter; electrical conductivity; and pH. The percent rock is separate from the percent sand, silt, and clay (which add to 100%). The 10 values from each aspect were averaged to characterize the chemical and physical soil properties.

RESULTS

Thirty-seven species were recorded from twenty slopes (Table 1). Of these, 23 were common to both slopes, 4 were found only on the south slopes, and 10 were found only on the north slopes. *Bromus tectorum*, *Descurainia pinnata*, *Plectritis macrocera*, *Agropyron spicatum*, *Draba verna*, and *Poa sandbergii* were found on at least 9 north slopes, and *B. tectorum* and *Cryptantha circumscissa* were found on at least 9 south slopes. Only *B. tectorum* was found on all slopes examined. There was significantly more *A. spicatum*, *P. sandbergii*, *D. verna*, *Holosteum umbellatum*, and *P. macrocera* on the north slopes and significantly more _B. tectorum_, _Festuca_ sp., and _Gilia leptomeria_ on the south slopes. The south slopes had much less cover (25%) than the north slopes (72%), due to annual grasses (S: 14%, N: 8%), perennial grasses (S: .7%, N: 48%), and annual forbs (S: 3%, N: 10%). Shrubs and perennial forbs had similar cover percentages on the two slope aspects.

Dominance, as indicated by canopy cover, was restricted to two species. On the south slopes, two species, _B. tectorum_ and _Salvia dorii_, provided most of the cover. On the north slopes, _A. spicatum_, _P. sandbergii_, and _B. tectorum_ provided most of the cover. Most species were widely separated and occurred on few slopes (low F value in Table 1), hence, their low percentage cover values. The low F value also decreased significance difference by the Wilcoxon Signed Rank Test, which needs more than 5 dissimilar data pairs.

The diversity indices calculated from these data are shown in Table 2. The south slopes ranged in percent cover from 4.7 to 58, whereas, the north slopes ranged from 43 to 98 percent cover and the means were different at the 1% level. In Table 2, N_0 is the number of species found in the transect. On the south N_0 ranged from 6 to 13 and on the north slope from 9 to 21. The means for N_0 were different at $p < .05$. The value N_1 corresponds to exp (H), where H is Shannon's entropy and ranged from 1.6 to 6.2 on the south slopes and 3.7 to 8.5 on the north slopes. The means for N_1 for the two slope aspects were not different. The value N_2 corresponds to the reciprocal of Simpson's modified index (Hill 1973) and ranged from 1.3 to 4.7 for the south slopes and 2.4 to 6.1 for the north slopes. The means of N_2 were not different.

Soil

As expected, the slopes showed differences in soil properties (Table 3). Average soil depth (penetrability) on the north-facing slopes (32.9 cm) was 3.8 times greater than on the south-facing slopes (8.6 cm) and different at the 5% level.

South-facing slopes were significantly stonier and also had more sand and less silt and clay (Table 3). Organic matter content was slightly higher on the north-facing slope and the pH was slightly lower. There was little soluble salt in the surface and electrical conductivity values were similar when compared between slopes.

DISCUSSION

Total vegetative cover and the number of species were different. The diversity indices, N_1 and N_2, were not different.

Diversity is a measure of how many species are present as examination proceeds down to a certain level of rarity (Hill 1973). It is interesting to note that on the south slopes, B. tectorum, was the dominant species because it alone used most of the community resources, whereas on the north slopes, dominance was shared by *B. tectorum*, *P. sandbergii*, and *A. spicatum*, yet the diversity indices N_1 and N_2 were not different. This may mean that the one abundant species on the slope, *B. tectorum*, is equivalent in community function to the three co-dominant species on the north slopes. With more consideration of rare species as given in the N_1 diversity values, the north slopes have slightly more (S: 4.4, N: 5.3) species though the difference is not statistically different. Overall, dominance, as indicated by N_1 and N_2, appears the same. We can postulate that several factors could account for the contrast in cover and number of species and similarity in numbers of non-rare species.

One factor may be related to the seasonal progression of microclimate. The region is characterized by hot, dry summers and cool to cold wet winters. Because few rains occur during the late spring and summer, soil water reserves are accumulating during the previous winter (Rickard 1967). The deeper the soil, the more water available during the spring and summer when temperatures are adequate for rapid growth. The south slopes warm faster in spring so plant growth begins earlier. However, the growing season on the south slopes is also shorter because the thin soil stores little water. The difference, then, between the slope aspects is the length of growing season, not presence or absence of growing season. Perhaps those species found only on the north slopes require a longer growing period to mature. Further speculating, fewer species can adapt to the more stressful environment of the south slopes, hence the difference in number of species.

Another factor is the much lower rock content of the soil from the north slope, which suggests this soil is not totally derived from the alluvial parent material but is of aeolian origin. Further speculating, the denser north slope vegetation cover would slow the wind so that fine-textured soil material would be deposited onto the north slopes. In essence, this is a positive feedback system; a more mesic environment leads to more vegetation, leads to more soil, leads to a more mesic environment and a denser vegetation, and so on.

Steep slopes are common land forms throughout the semi-arid and arid Western United States. Steep south slopes are often nearly devoid of seed plants. The paucity of plant life is usually attributed to a lack of rooting substrate or extreme stoniness and rapid runoff of precipitation with little opportunity for the water to be stored in the substrate for future root withdrawal. South-facing slopes also provide a more stressful microclimate because the more intense solar radiation leads to higher soil temperatures and evaporation rates.

Presently, most of the vegetative cover on south slopes is provided by the alien annual grass, _B. tectorum_, which suggests these nearly barren south slopes were almost devoid of vegetative cover before the importation of _B. tectorum_. The data gathered in this investigation show that steepness per se is not the cause of slope barrenness. The soil and vegetative cover data suggest that the interactions between vegetation and microclimate lead to a more favorable environment with more plant cover on the north slopes favoring the deposition of fine-textured soil matirial to further increase the thickness of soil.

It is quite possible that steep slopes overlie valuable mineral deposits that may be mined in the future. Restoration of steep slopes in arid regions will require an assessment of the original vegetative conditions. It may be necessary and prudent to accept a nearly barren steep slope as rehabilitated. This is especially important if the legal land restoration criteria insist upon a return to original contour.

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TABLE 1. Mean canopy cover ($\overline{X}$), standard errors (SE), and fraction of slopes on which the species was found (F). Wilcoxon Signed Rank Test used to determine differences at $p < .05$ (*) and $p < .01$ (**). Means and standard errors are descriptive only and were not used in tests for significant differences.

Species	South Facing F	South Facing SE	South Facing $\overline{X}$	North Facing $\overline{X}$	North Facing SE	North Facing F
Grasses						
Perennial						
**Agropyron spicatum	0.3	0.17	0.20	13.66	1.68	1.0
Poa cusickii	0	0	0	5.98	3.69	0.4
**Poa sandbergii	0.5	0.24	0.50	28.11	4.52	1.0
Total perennial grasses*		0.29	0.70	47.75	6.07	
Annual						
*Bromus tectorum†	1.0	4.70	13.75	7.72	2.91	1.0
*Festuca sp.	0.3	0.07	0.09	0.34	0.11	0.5
Total annual grass		4.75	13.84	8.06	2.91	
Total Grasses*		4.76	14.54	55.81	6.73	
Forbs						
Perennial						
Achillea millifolium	0.1	0.01	0.01	0.65	0.41	0.3
Astragalus purshii	0.3	0.19	0.32	0	0	0
Balsamorhiza careyana	0.1	0.60	0.60	0.39	0.37	0.3
Calochortus macrocarpus	0	0	0	0.23	0.19	0.2
Crepis atrabarba	0	0	0	0.02	0.01	0.2
Delphinium sp.	0	0	0	0.97	0.57	0.4
Fritellaria pudica	0	0	0	0.01	0.01	0.1
Lomatium grayii	0.6	1.03	2.27	0.07	0.07	0.1
Lomatium macrocarpum	0.1	0.01	0.01	0.84	0.41	0.5
Phlox longifolia	0	0	0	0.17	0.15	0.2
Total perennial forbs		1.21	3.21	3.35	0.93	
Annual						
Amsinckia lycopsoides	0.6	0.16	0.24	0.12	0.10	0.3
*Cryptantha circumscissa	0.9	0.23	0.90	0.11	0.07	0.4
Descurainia pinnata	0.8	0.18	0.48	0.65	0.21	1.0

†alien species

TABLE 1 (Continued)

Species	South Facing F	South Facing SE	South Facing $\bar{X}$	North Facing $\bar{X}$	North Facing SE	North Facing F
Forbs (Cont.)						
Annual (Cont.)						
**<u>Draba verna</u>†	0.1	0.04	0.04	1.15	0.28	0.9
<u>Epilobium paniculatum</u>	0.2	0.01	0.02	0.01	0.01	0.1
*<u>Gilia leptomeria</u>	0.6	0.10	0.30	0.02	0.02	0.2
**<u>Holosteum umbellatum</u>†	0.1	0.01	0.01	3.59	1.24	0.8
<u>Layia glandulosa</u>	0.2	0.02	0.03	0	0	0
<u>Latuca serriola</u>	0.4	0.20	0.24	0.26	0.13	0.5
<u>Mentzelia albicaulis</u>	0.3	0.04	0.07	0	0	0
<u>Microsteris gracilis</u>	0.4	0.11	0.22	0.51	0.16	0.8
<u>Montia</u> sp.	0	0	0	0.10	0.10	0.1
<u>Phacelia</u> sp.	0.4	0.01	0.17	0.01	0.01	0.1
**<u>Plectritis macrocera</u>	0.4	0.20	0.25	3.23	0.89	0.9
<u>Sisymbrium altissimum</u>†	0.2	0.01	0.02	0.13	0.10	0.2
Total annual forbs*		0.46	2.99	9.89	1.59	
Total Forbs*		1.29	6.20	13.24	1.84	
Shrubs						
<u>Artemisia tridentata</u>	0	0	0	0.07	0.07	0.1
<u>Chrysothamnus nauseosus</u>	0	0	0	0.30	0.30	0.1
<u>Eriogonum niveum</u>	0.3	0.50	0.71	0	0	0
<u>Eriogonum</u> sp.	0.3	0.30	0.42	0.59	0.59	0.1
<u>Grayia spinosa</u>	0.1	0.01	0.01	0.74	0.49	0.2
<u>Lithospermum glabra</u>	0	0	0	0.21	0.13	0.3
<u>Salvia dorrii</u>	0.4	1.24	2.62	1.09	1.02	0.2
Total Shrubs		1.37	3.76	3.00	1.32	
TOTAL COVER ALL SPECIES*		5.02	24.91	72.03	6.09	

TABLE 2. Percent cover and diversity indices (see text for explanation of N_0, N_1 and N_2). Wilcoxon Signed Rank Test used to determine differences at $p < .05$ (*) and $p < .01$ (**). Means and standard errors are descriptive only and were not used in tests for significant differences.

	Slope Number										Mean	Standard Error
	1	2	3	4	5	6	7	8	9	10		
South Facing Slopes												
Percent Cover**	9.1	4.7	58.0	29.0	21.0	29.0	37.0	8.4	26.0	26.0	24.9	5.0
N_0*	9.0	6.0	6.0	11.0	13.0	12.0	10.0	11.0	13.0	9.0	10.0	0.8
N_1	5.3	3.7	1.6	4.2	6.1	5.7	4.1	6.2	3.0	4.1	4.4	0.5
N_2	4.2	2.9	1.3	3.0	4.7	4.0	2.6	4.4	2.0	3.5	3.3	0.4
North Facing Slopes												
Percent Cover**	64.0	64.0	88.0	69.0	98.0	98.0	79.0	72.0	45.0	43.0	72.0	6.1
N_0*	12.0	13.0	16.0	16.0	12.0	21.0	9.0	14.0	12.0	11.0	13.6	1.1
N_1	4.9	4.7	7.0	6.5	3.7	8.5	3.8	5.4	3.8	4.5	5.3	0.5
N_2	3.8	3.1	5.0	4.3	2.4	6.1	2.8	4.0	2.4	3.4	3.7	0.4

TABLE 3. Soil properties of steep north and south slopes. Significant differences based on t-test p < .05 (*) and p < .01 (**).

Soil Properties	South Facing Standard Error	South Facing Mean	North Facing Mean	North Facing Standard Error
*Soil depth (vertical) cm	1.0	8.6	32.9	7.0
**Rock %	5.6	53.3	14.5	5.0
Sand %	2.2	64.4	57.2	7.7
Silt %	2.5	30.8	39.0	3.2
Clay %	1.1	2.8	3.8	1.1
Organic matter %	0.1	0.5	1.1	0.1
pH	0.1	7.7	7.5	0.1
Conductivity mmohs/cm	0.06	0.34	0.36	0.03

FIG. 1. Photographs of two canyons to show contrasting vegetation. Top two are south-facing slopes and bottom two are north-facing slopes. Each vertical pair is from the same canyon.