1982

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Recommended Citation

Weaver, T. 1982. Root distribution and soil water regimes in nine habitat types of the northern rocky mountains. American Midland Naturalist. 107(2):393-395.

ROOT DISTRIBUTION AND SOIL WATER REGIMES IN NINE HABITAT TYPES OF THE NORTHERN ROCKY MOUNTAINS.

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Abstract

Root distribution and the annual cycle of soil water availability were measured in nine habitat types of the Northern Rocky Mountains. Water stress periods became progressively longer under *Abies lasiocarpa* forests, *Populus tremuloides* groves, *Pseudotsuga menziesii* forests, *Festuca idahoensis* grasslands, *Artemisia tridentata*, and *Agropyron spicatum* grasslands. Water stress periods were longer under *Pseudotsuga* forests than under adjacent logged areas. Live feeder root biomass 1) was similar under grassland, shrubland, and forest types, 2) increased within a vegetation type with altitude, and 3) decreased at a site with depth. Seral grasslands had less live feeder root biomass than forests in the same habitat type but climax grasslands and forests had similar root biomasses.

Introduction

Despite their potential usefulness to range managers, sylviculturalists, and hydrologists, descriptions of the annual cycle of soil water in various vegetation types and habitat types of the Rocky Mountains are rare. Root biomass data are even less common. Daubenmire (1959, 1968, and 1972) and McMinn (1952) have compared the soil water regimes of major forest and steppe vegetation types near Pullman, Washington. McMinn (1960) and Dyrness and Youngberg (1966) have compared soil water regimes between the *Pseudotsuga menziesii* types of Vancouver Island and *Pinus ponderosa* types of central Oregon respectively. Parts of the annual cycle of soil water have been described for desert scrublands near Frenchman, Nevada and Richland, Washington (Rickard 1963, 1967) and for *Populus tremuloides*, *Pseudotsuga menziesii*, *Quercus gambelii* and herbaceous vegetation types near Salt Lake City, Utah (Johnston *et al* 1969).

This paper 1) contrasts the annual cycles of soil water under nine types of climax vegetation and four seral types and 2) contrasts the total quantities and vertical distributions of feeder root biomass under most of the same vegetation types. The climax steppe vegetation types are *Agropyron spicatum-Bouteloua gracilis*, *Festuca idahoensis-Agropyron spicatum*, *Festuca idahoensis-Symphoricarpos albus*, *Artemisia tridentata-Festuca idahoensis*, and *Festuca idahoensis-Agropyron caninum* (Daubenmire 1970, Mueggler 1973). The climax forest vegetation types are *Pseudotsuga menziesii-Symphoricarpos albus*, *Pseudotsuga menziesii-Calamogrostis rubescens*, *Abies lasiocarpa-Vaccinium scoparium*, and *Populus tremuloides (Crataegus)-Symphoricarpos albus* (Daubenmire 1968, Pfister *et al* 1972). Logged (= deforested) stands with complete herbacious cover adjacent to the first three forest types were contrasted with them. The low summer water stresses of 'dry' *Poa pratensis* lawns on a *Festuca idahoensis-Agropyron spicatum* habitat type is noted. Since habitat types are land units recognized by and named for the potential natural (climax) vegetation which can occupy them (Daubenmire

1969), nine habitat types are considered. The four anthropogenic communities studied are examples of seral vegetation occupying four of these habitat types. Because they are easily recognized and relatively uniform in environmental conditions habitat types serve as ideal units for detailed study and management.

Species names follow Hitchcock and Cronquist (1973).

Methods

Soil water data were gathered in from one to four accessible stands of each vegetation type. These stands were visited monthly for two years. Soil water determinations were made with a Coleman meter and plaster blocks (Taylor *et al* 1961). The blocks were installed in the soil profile at depths of 10, 25, and 75 cm. Readings were converted to atmospheres. The calibration curve was made by placing a large metal ring on a ceramic plate, filling this 'pan' with a wet silt loam and 28 blocks, inserting the pan and blocks into a pressure membrane apparatus, adjusting the soil water to tensions of 4.0, 6.0, 9.1, 11.8, and 13.2 atm, reading the blocks, and plotting the means and standard deviations against soil water tensions. Tensions less than 10 atm were easily distinguished; those higher than 15 atm were largely indistinguishable.

Roots were sampled at two randomly chosen points in each stand in June of 1973. Each sample consisted of two cores (2 cm diameter) taken approximately 1 m apart and divided into 10 cm segments. Roots were washed from the cores, the few roots with diameters greater than 5 mm excluded, and the proportion of live roots in each sample estimated on the basis of general appearance. The roots were then dried, weighed, ashed, and reweighed to determine their ash free weights. Live feeder root biomass was estimated by multiplying those ash free weights by the estimated percentage of live roots.

The stands studied lay within 30 km of Bozeman along an orographically induced precipitation gradient. Their locations are given in Appendix Table 1. The low *Agropyron* stands north of Belgrade (1370 m) receive about 360 mm of precipitation per year (cf Belgrade Airport). Foothill stands (1450-1710 m) of *Pseudotsuga*, *Populus*, *Artemesia*, and *Festuca* receive slightly more precipitation than the 502 mm per year recorded in Bozeman. The *Abies* and the upper *Pseudotsuga*, *Populus*, *Artemisia*, and *Festuca* stands (1770-2330 m) probably receive more precipitation than the 883 mm per year recorded at the Bozeman 12 NE station.

Results and Discussion

Annual Cycle of Soil Water.

Table 1 illustrates the normal pattern of precipitation in the study area: light rains fall in September and October, little precipitation falls from November to March, most of the annual precipitation falls between early March and late June, and precipitation is low in July and August.

Table 2 shows the deviation of precipitation at the Bozeman (MSU) Station from the normal: 1971 was preceeded by a normal fall (Sept-Dec +6%) and had a normal spring (Jan-April +6%), and a dry summer (May-August -32%); 1972 was preceeded by a dry summer (-32%) and fall (-20%), was dryish in the spring (-15%) and early summer (-16%), and had a normal fall (+2%). Temperatures were within 1.5°C of the long term monthly averages except for August 1971 (+3°C), March 1972 (+6°C), and June 1972 (+2°C).

The soil water regimes of the vegetation types studied are summarized in Fig. 1. The water regime of each vegetation type is represented by a separate chart. The charts are arranged approximately in order of decreasing moistness of the vegetation types represented: moist forests are first, then drier forests, and finally grasslands. The actual sampling dates are shown. Soil water was measured on these dates and recorded (Fig. 1) for the period between that sample date and the following sample date. This procedure indicates the trends of soil water availability but shows both the beginning and end of a drought season slightly later than they actually occur.

The data for any vegetation type show two general trends. First, soils at field capacity in May become progressively drier during the summer and are rewet by ~~the~~ fall rains, spring snow melt water, and spring rains. The *Agropyron* data illustrate this well. This cycle of soil water was also observed under wet forests of the southern Appalachians (Helvey and Hewlett 1962) and may be characteristic of temperate forests. It is especially pronounced under the dry summer conditions characteristic of the Northern Rocky Mountains (Table 2) where many vegetation types exhaust their supplies of growth water and must lie dormant for greater or lesser periods.

The second general trend is for soils to dry or to be wet from the top downward. This is well illustrated by the *Agropyron-Bouteloua* data or *Pseudotsuga-Symphoricarpos* data. Apparent exceptions (e.g. *Pseudotsuga-Calamagrostis*) are possibly artifacts of summer showers occurring just before sampling dates. The tendency to dry from the top downward has been observed by Metz and Douglass (1959), Daubenmire (1972), and others.

The differences between soil water regimes of different vegetation types are primarily in the length of the dry season and the depth of exhaustion of soil water. A comparison of the data in Fig. 1 with those of Daubenmire (1959, 1968, 1972) and McMinn (1952) shows the similarity of soil water regimes under similar climax vegetation types of Washington and Montana.

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Low *Festuca idahoensis-Agropyron spicatum* stands studied by all dried (>15 atm) to 75 cm by 15 June to 1 July and were rewet to at least 30 cm by early November. *Festuca idahoensis-Symphoricarpos albus* stands were moister than *Festuca-Agropyron spicatum* stands in all cases studied though when diagrammatically expressed the *Festuca-Symphoricarpos* data is not distinguishable from the *Festuca-Agropyron spicatum* data. Neigher Daubenmire nor McMinn studied *Artemisia tridentata-Festuca idahoensis* stands which appear to dry at about the same time as *Festuca-Agropyron spicatum* stands, but to be rewet slightly later.

Agropyron-Bouteloua stands located in drier areas or on steep south slopes clearly dried earlier (1 June) and may have rewet slightly later than *Festuca idahoensis-Agropyron spicatum* stands. This observation is consistent with Daubenmire's (1972) data showing an *Artemisia tridentata*-*Agropyron spicatum* stand drying earlier than a *Festuca idahoensis*-*Agropyron spicatum* stand.

Pseudotsuga-*Symphoricarpos* (e.g. Daubenmire 1956) stands occupy rainier areas than grassland stands. All dried later (1 August) than the grassland stands. Transpiration losses lasting at least through November (observable in the raw data) and evaporation of precipitation intercepted by tree crowns slowed the rewetting of forest soils so the soils of nearby steppe stands were rewet to depths of 30 cm months earlier than the forest soils were. A *Pseudotsuga*-*Calamagrostis* stand appeared to dry from the bottom up in two years, dried at least as early as the *Pseudotsuga*-*Symphoricarpos* stands, and was rewet earlier in the fall than *Pseudotsuga*-*Symphoricarpus* stands were. *Pseudotsuga Physocarpos* stands studied by Daubenmire (1959) and McMinn (1952) were the moistest of the *Pseudotsuga* series: they dried in late August and are probably rewet as early as *Pseudotsuga*-*Symphoricarpos* stands are.

Abies, *Thuja*, and *Populus* stands suffered less drought stress than the lower *Pseudotsuga* stands. My *Abies*-*Vaccinium* and *Populus*-*Symphoricarpos* stands experienced soil water stresses exceeding 15 atm in the upper soil horizons for short periods but never had water stresses (greater than) >15 atm at 75 cm. McMinn's (1952) and one of Daubenmire's (1968) *Abies*-*Pachistima* stands suffered essentially no drought stress while Daubenmire's (1968) second stand dried deeply in 1942. Daubenmire's (1968) *Thuja* stands had growth water available throughout the year.

Two grassland types can be nearly as drought free as the *Abies* and *Populus* forests. 1) Soils of a *Festuca idahoensis*-*Agropyron caninum* site at 2480 m were only slightly drier in 1970 and 1971 than soils of a low *Abies*-*Vaccinium* (forested or logged) site. A *Festuca idahoensis*-*Agropyron caninum* site at 2160 m in the Gravelly mountains (Mueggler 1971) was considerably drier than *Abies* forests studied by McMinn 1952, Daubenmire 1968, or myself. These observations support Daubenmire's suggestion that mountain meadow sites are dry relative to other sites at the same altitude because of wind and slope effects. 2) Poa pratensis lawns are rarely permitted to suffer drought stress. Three drier-than-average lawns were observed from July to October of 1972. In them, soil water stresses at 75 cm never reached 2 atm; water stresses at 25 cm exceeded two atmospheres (but not 5 atm), with browning, during one week in one lawn; and at 10 cm, 2 atm was never exceeded in one lawn, less than was exceeded twice in one lawn greater than ($>$15 atm), was exceeded twice in the third lawn ($<$ 6 atm).

The Soil water measurements presented above support rankings of the relative dryness of important habitat types under climax vegetation made by climatic and topographic criteria (e.g. Daubenmire 1956, 1968).

Water use patterns observed under subclimax vegetation on a habitat type may differ considerably from those seen under climax vegetation. Soils of logged Pseudotsuga-Symphoricarpos stands dried slightly later and, due to lack of transpiration and interception, were rewet earlier in the fall than were forested stands. The same is true on Pseudotsuga-Calamagrostis sites. Little difference in rates of water use were observed on Abies-Vaccinium and logged Abies-Vaccinium sites: the logged site was moister in 1971 and drier in 1972. The earlier drying of soils by forest vegetation than by herbaceous vegetation has been widely observed (Thames et al 1955, Metz and Douglass 1959, Penman 1963, and Johnston 1969) and is used in watershed management: high water yields are promoted by management for grasses while flood control is achieved by management for trees. The relatively short periods of drought stress observed under subclimax vegetation suggest that subclimax species of any sere could be less drought resistant than the climax species.

Live Feeder Root Biomass and its Distribution.

Table 3 compares the feeder root biomasses and their distributions in most of the stands studied.

Root biomass decreased with depth under all vegetation types. Live feeder root biomass in well drained stands of Agropyron-Bouteloua, Artemisia-Festuca, Pseudotsuga-

Symphoricarpos, and Abies-Vaccinium were 200-300, 81-161, 75-133, 45-110, 44-59, 22-124, 21-61, 4-20, 5-14, and 5-27 g/m^2 ranges in the first through tenth decimeter soil layers respectively. This phenomenon has been noted in most vegetation types studied.

Cross stand comparisons suggest that all the upland vegetation types studied have similar live feeder root biomasses: low stands of Agropyron, Artemisia, Pseudotsuga, and Abies have approximately 762, 519, 490, and 545 g/m^2 in the upper five decimeters respectively; live feeder root biomasses increase as one moves upward in each type; and high stands have 1582, 973, 1443, and 1197 g/m^2 of feeder roots in the upper five decimeters respectively. (Note in Table 3 that the standard error of the low Agropyron stands root biomass is high and that the upper Artemisia and Abies stands may be relatively dry 'high stands'.) Feeder root biomasses increased similarly with altitude in Populus stands (349 to 536 g/m^2) though feeder root biomasses in the upper 50 centimeters were less than those observed on well drained sites: perhaps root growth on these seasonally wet sites is inhibited by oxygen deficiency. The increase in feeder root biomass with altitude within a vegetation type could be due to increased availability of a limiting factor, probably water. The similarity of feeder root biomasses under different vegetation types seems to suggest that as one moves up a gradient of water availability (altitude) he will find a series of 'community root systems' which are increasingly efficient (gm/HOH/gm/root) extractors of water: a low Pseudotsuga community can extract as much (or more) water as nearby shrub types with a third of the feeder root biomass and a low Abies community can extract as much (or more) water as a high Pseudotsuga stand with a third of its root biomass. This observation is consistant with the fact that trees have lower root-shoot ratios than grasses do (e.g. Bray 1963).

Various workers (Thames et al 1955, Metz and Douglass 1969, Johnston et al 1969) have concluded from water use studies that forest vegetation is deeper rooted than seral meadow vegetation of a similar site. A comparison of adjacent well-drained stands bears this out: between 20 and 70 dm ratios were 832/308 g/m^2, 346/116 g/m^2 and 738/332 g/m^2 for a *Pseudotsuga*-*Calamagrostis* and two *Abies*-*Vaccinium* sites respectively. Little difference is observed in a Populus forest with 91 g/m^2 and an adjacent meadow with 82 g/m^2 - root growth in both may be inhibited by lack of oxygen in the deeper horizons of these seepage sites. The biomass of deep roots in climax grasslands, however, may not be significantly lower than those under climax forests: a ranking of sites by 20-70 cm root biomasses is *Agropyron*-*Bouteloua* (grass, 435 g/m^2), *Abies* (forest, 346 g/m^2), *Pseudotsuga*-*Symphoricarpos* (forest, 280 g/m^2), *Populus* (forest, 203 g/m^2), and *Artemisia*-*Festuca* (shrub, 199 g/m^2) for low altitude sites in their vegetation types and *Abies* (forest, 738 g/m^2), *Pseudotsuga*-*Calamagrostis* (forest, 832 g/m^2), *Artemisia*-*Festuca* (shrub, 493 g/m^2), *Festuca*-*Agropyron* *caninum* (grassland, greater >289+ g/m^2), and *Populus* (forest, 91 g/m^2) for high altitude sites in their vegetation types.

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Table 1 - Average monthly precipitation (mm) at

Belgrade, Bozeman, Bozeman 12 NE and Bangtail Ridge, Montana[1]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Belgrade	18	10	22	28	55	62	27	30	27	27	17	14	338
Bozeman	25	18	42	48	75	77	34	40	41	43	32	24	502
Bozeman 12 NE	73	58	67	75	114	121	50	59	72	70	65	62	883
Bangtail Ridge	114	91	87	125	85	75	29	29	43	80	73	77	909

[1] Average for 1950 to 1969 except for Bangtail Ridge where the average is for 1969 to 1972.

Table 2 - Monthly precipitation (mm) at the Bozeman (MSU) Weather Station.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Ave[1]	25	18	42	48	75	77	34	40	41	43	32	24	502
1970	18	8	56	39	87	38	51	25	57	40	36	16	470
1971	24	26	19	72	57	73	7	17	61	17	20	14	406
1972	22	17	32	48	44	78	30	37	51	66	16	12	452

[1] 1950-1969

Table 3 - Live feeder root biomass (gm dry wt/m^2) by horizon in 14 vegetation types.[1]

Vegetation Type	Stands[2] Samples	Alt. (m)	Soil Depth (cm) 0-10	10-20	20-30	30-40	40-50	50-60	60-70	0-70
Low Stands										
Agropyron - Bouteloua	2-4	1360	299	161	133	110	59	72	61	895
			±120	±26	±6	±34	±29	±26	±27	±161
Artemisia - Festuca	1-2	1570	202	118	58	54	44	22	21	519
			±61	±38	±20	±34	±5	±7	±14	±96
Pseudotsuga - Symphoricarpos	3-6	1650	231	81	88	42	48	52	54	596
			±32	±11	±12	±8	±19	±17	±37	±95
Abies-Vaccinium										
Forested	1-2	1810	245	123	75	45	57	124	45	714
			±33	±5	±3	±28	±38	±46	±7	±52
Logged	1-2		327	318	81	10	8	9	--	754
			±231	±55	±15	--	-	-	--	±40
Populus - Symphoricarpos	4-8	1560	119	91	44	50	45	38	26	413
			±20	±12	±13	±19	±24	±13	±10	±85
High Stands										
Festuca - Agropyron	2-20	2330	902	391	143	51	95	--	--	1582 +
			±.04	±.09	±.01	±.02	±.01	--	--	
Artemisia - Festuca	1-2	1780	430	149	227	49	118	45	54	1072
			±98	±8	±93	±10	±28	±14	±26	±259
Pseudotsuga - Calamagrostis										
Forested	1-2	1830	704	305	196	132	106	137	261	1841
			±149	±128	±61	±6	±23	±11	±160	±217
Logged	1-2		440	457	109	83	61	21	34	1205
			±102	±57	±41	±2	±35	±12	±21	±263
Abies-Vaccinium										
Forested	1-2	2360	245	168	229	335	220	217	97	1411
			±25	±4	±104	±193	±143	±73	--	±580
'Logged'[3]	1-2		272	243	174	86	39	33	0	847
			±192	±18	±12	±51	±71	±44	±25	±185
Populus										
Forested	1-2	1830	355	109	37	12	23	8	11	555
			±85	±1	±18	±4	±2	±8	±0	±81
'Logged'[3]			82	35	21	25	16	9	11	199
			±18	±20	±13	±23	±12	±6	--	±15

[1] Mean values and their standard errors are given.

[2] Number of stands samples followed by total number of samples.

[3] Adjacent meadows.

Appendix Table 1. Locations of stands studied.

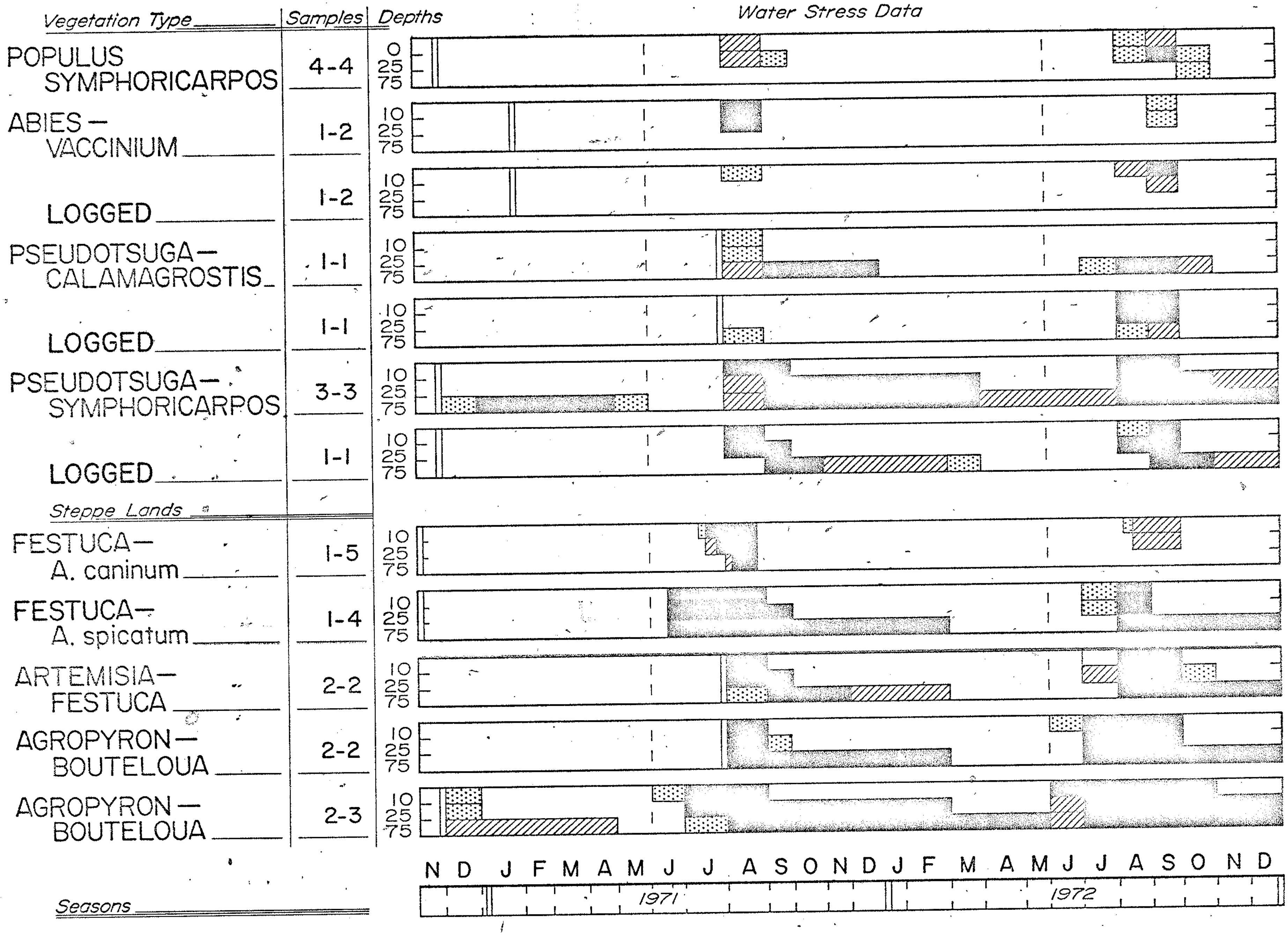
Vegetation Type	Location	Altitude[1]	Slope	Samples Taken[2]
Populus-Symphoricarpos				
Kirk Natural Area	10 km SE of Bozeman	1680	N	1 SM, 1 RT
Bozeman I and II	300 Kagy Lane	1500	0	2 SM, 2 RT
Beck Ranch	6 km NE of Bozeman	1650	0	1 SM, 1 RT
Populus-Poa				
Bridger Bowl	3 km N of Bridger Bowl	1830	0	Forested 1 SM[3], 1 RT Logged 0 SM, 1 RT
Abies-Vaccinium				
Bridger Bowl	3 km N of Bridger Bowl	1830	0	Forested 1 SM, 1 RT Logged 1 SM, 1 RT
Bangtail Station	22 km NE of Bozeman	2360	0	Forested 1 SM[3], 1 RT Logged 1 SM[3], 1 RT
Pseudotsuga-Calamagrostis				
Bridger Bowl	3 km N of Bridger Bowl	1830	0	Forested 1 SM, 1 RT Logged 1 SM, 1 RT
Pseudotsuga-Symphoricarpos				
Kirk Natural Area	10 km SE of Bozeman	1710	N	1 SM, 1 RT
Beck Ranch	6 km NE of Bozeman	1650	N	Forested 2 SM, 2 RT Logged 1 SM, 0 RT
Festuca-Agropyron caninum				
Bangtail Station	22 km NE of Bozeman	2330	0	1 SM, 2 RT
Festuca-Agropyron spicatum				
Walker Ranch	10 km N of Bozeman	1520	0	1 SM, 0 RT
Bozeman *Poa* lawns	1100 S Willson	1500	0	3 SM, 0 RT
Artemisia-Festuca				
Beck Ranch	6 km NE of Bozeman	1570	SW	1 SM, 1 RT
Sheep Creek	7 km N of Bangtail	1770	S	1 SM, 1 RT
Agropyron-Bouteloua				
Walker Ranch	10 km N of Bozeman	1450	SW	2 SM, 0 RT
Theisen Ranch	12 km N of Belgrade	1370	0	2 SM, 2 RT

[1] Altitude in meters.

[2] SM = 1 set of soil moisture samples, RT = 1 set of root samples.

[3] Soil moisture data not presented due to skimpy data.

Figure 1. The annual cycle of soil water availability in 11 vegetation types: a deciduous forest, three coniferous forest, three logged coniferous forests and 4 steppe. The three bars on each graph record measurements made at 10, 25, and 75 cm. Shaded areas indicate periods of soil water stress: stippled = 2 bars +, hatched = 5 bars +, and blackened = 10 bars +. Numerals following stand labels indicate the numbers of stands and sample sites studies. Actual sample dates are shown by Ticks in the box enclosing the figures 1971 and 1972. A double vertical bar in each graph indicates the date study of that site was begun and two dashed lines both at 1 June serve as visual reference points.


Vegetation Type
Samples
Depths
Water Stress Data
POPULUS SYMPHORICARPOS
4-4
0
25
75
ABIES— VACCINIUM
1-2
10
25
75
LOGGED
1-2
PSEUDOTSUGA— CALAMAGROSTIS
1-1
LOGGED
1-1
PSEUDOTSUGA— SYMPHORICARPOS
3-3
LOGGED
1-1
Steppe Lands
FESTUCA— A. caninum
1-5
FESTUCA— A. spicatum
1-4
ARTEMISIA— FESTUCA
2-2
AGROPYRON— BOUTELOUA
2-2
AGROPYRON— BOUTELOUA
2-3
Seasons
N D J F M A M J J A S O N D J F M A M J J A S O N D
1971
1972