Relationship of Cover Type to Altitude, Aspect, and Substrate in the Bridger Range, Montana

Abstract
Point enumeration data taken from topographic, timber type, and geologic maps were used to relate cover type to elevation, aspect, and substrate in the Bridger Range, Montana. Douglas-fir forests are dominant. Grasses and shrubs attain high cover at low elevations (1678 to 1983 m) and on ESE and SSW slopes. Subalpine fir increases in importance at elevations over 2288 m. Lodgepole pine occurs at all elevations, but only on NNE and ESE aspects. Cover type is clearly related to substrate: Douglas-fir prefers limestone and gneiss; grasses prefer sandstone; lodgepole pine prefers interbedded sandstone and shale; and subalpine fir rarely occurs on gneiss. Possible ecological relationships and applications are discussed.

Introduction
The Bridger Range is a small, isolated mountain range in south central Montana. It extends from 110°53' to 111°6' west longitude, 45°40' to 46°10' north latitude, and from 1525 to 2948 m. Its topography, geology, and vegetation cover types have been mapped by U.S. Geological Survey (1949-1953), McMannis (1955), and U.S. Forest Service (1960-1962). Weather stations at Bozeman, Bangtail Ridge, and Bridger Ridge represent the area (U.S. Weather Bureau, 1971-1972; and Arlin Super, pers. comm.). The objects of this paper are 1) to summarize this information, and 2) to relate the cover types to altitude, aspect, and substrate.

Methods
Vegetational cover, altitude, slope, aspect, and substrate were measured at 555 regularly spaced points in the Bridger Range. 1) The range was delineated by a line following the 1678 m (5500 ft) contour on its north, west, and south sides and on the east side by Bridger and Bracket Creeks, which separate the Bridger Range from the Bangtail Range. 2) Four points were sampled in each section (square mile), including one at its NE corner, one midway between the NE and SE corners, one midway between the NE and NW corners, and one at the center of the section. 3) Altitude, aspect, and slope were recorded for each point from U.S. Geological Survey topographic maps. Altitude was recorded to the nearest 30 m (100 ft). Aspect was recorded in classes centered on N, NE, E, SE, S, SW, W, and NW; for much of the discussion these were pooled by twos into classes centered on NNE, ESE, SSW, and WNW. Slopes were recorded in the following classes: 0-8 percent, 8-16 percent, 16-32 percent, 32-64 percent, and 64-100 percent. 4) The cover at each point was categorized as bare ground, grass-shrubland, Douglas-fir forest, lodgepole pine forest, or subalpine fir forests. Timber
types were determined from U.S. Forest Service timber type maps. When points fell
in areas of nonforest or noncommercial forest, aerial photographs were consulted to
determine the cover type. Most of the vegetation considered is similar to Daubenmire's
(1968, 1970) *Agropyron satsum- Poa secunda, A. satsum-Festuca idahoensis,
Artemisia tridentata-F. idahoensis, Pseudotsuga menziesii-Symphoricarpos albus, P.
menziesii-Calamagrostis rubescens, Abies lasiocarpa-Vaccinium scoparium, and tundra
associations.

Substrates were determined from McMannis' (1955) geologic map
of the Bridger Range under his guidance; they included gneiss, limestone, sandstone,
and interbedded sandstones and shales.

**Climate of the Bridger Range**

Mean (1970-1972) daily maximum temperature, mean daily minimum temperature,
and mean precipitation are summarized by month in Figure 1 for stations at 1481,
2242, and 2590 m (4856, 7352, and 8500 ft). Precipitation and summer temperature
data are unavailable for the 2590 m "Bridger Ridge" site. The short 1970-1972 rec-
ord was used because no longer record exists for either the 2590 m or the 2242 m
"Bangtail Ridge" site; the longterm weather record at Bozeman (MSU) shows the
1970-1972 period was near normal except that September precipitation was approxi-
mately 150 percent of normal, February temperatures were 4.4°C above normal, Au-
gust temperatures were 2.8°C above normal, and October temperatures were 3.3°C
below normal.

In the grassy (*Festuca idahoensis-Agro
yron satsum*) foothills zone (Bozeman,
1481 m), temperatures in January ranged from -10° to 0°C (mean daily minimum
and mean daily maximum), July temperatures were in the 11° to 28°C range, and
the moist spring (5 cm/month) was followed by a dry summer and winter (1.9 cm/
month). High in the Douglas-fir zone (Bangtail Ridge, 2242 m), January temperatures

![Figure 1. Climatic data at three Bridger Range weather stations: Bozeman (1481 m, heavy solid line), Bangtail Ridge (2242 m, broken line), and Bridger Ridge (2590 m, light solid line). In the temperature graph, lines show average temperatures and vertical bars indi-
cate average daily maxima and minima for each month. Horizontal lines indicate months
with less than 3 frost days. Data for precipitation and summer temperature are unavail-
able for Bridger Ridge.](image)
were in the −12° to −6°C range; July temperatures were in the 8° to 20°C range, and
except for the dry summer (3 cm/month), rainfall generally exceeded 5.7 cm per
month. January temperatures high in the subalpine-fir zone (Bridger Ridge, 2590 m)
were also in the −12° to −6°C range. Climates of a nearby Idaho-fescue grassland
(2166 m) and a nearby whitebark pine stand (2257 m) are discussed by Mueggler
(1977) and I(eaver and Dale (1974), respectively: temperatures are similar to those
reported here; precipitation patterns include the May-June high and the July-August
low seen in the Bridgers, but precipitation in the whitebark pine stand is significantly
greater than in the other local vegetation types.

0.55° to 0.73°C per 100 m is a commonly cited average lapse rate (e.g., Oosting,
1956; Bamberg and Major, 1968). In the Bridgers, average temperature dropped 0.89°C
with a 100 m increase in altitude agreeing with Peattie's (1936) observation that
small mountain ranges are cooler at a given altitude than larger ones. The lapse rate
was steeper at the daily maximum temperature (1.0°/100 m) than at the daily mini-
mum temperature (0.42°/100 m).

Effective precipitation may be greater on the east than on the west side of the
Bridger range: total precipitation is likely to be similar on both sides, but 1) tempera-
tures and evaporation rates are usually higher on west than on east slopes (Geiger,
1965); and 2) the western side is bordered by the broad Gallatin Valley and the east-
ern side is sheltered by a narrow valley and the Bangtail Ridge.

Relationship of Slope, Aspect, Substrate, and Cover to Altitude

Three alitudinal zones are used in the descriptions and analyses presented below: low
(1678-1982 m = 5500-6500 ft), middle (1982-2288 m = 6500-7500 ft), and high
(2288-2593 m = 7500-8500 ft). These comprised 41, 39, and 19 percent of the study area
respectively; the 2 percent which lay above 2593 m was pooled with the 2288-2593
m stratum. Median slopes in these zones were approximately 24, 48, and 64 percent
respectively. Aspects were evenly divided at 1678-1982 m: 26 NNE, 28 ESE, 24 SSW,
and 23 percent WNW. Corresponding figures at 1982-2288 m and 2288-2593 m
were 28, 29, 22, and 21 percent; and 24, 28, 30, and 18 percent. Sandstone, sandstone-
shale, gneiss, and limestone covered 25, 35, 30, and 10 percent of the low zone; 11
49, 20, and 20 percent of the middle zone; and 9, 15, 44, and 32 percent of the high
zone, respectively.

The amount of bare ground increased strikingly with altitude; we measured 1, 1,
10, and 69 percent at 1678-1982, 1982-2288, 2288-2593, and above 2593 m, respec-
tively. Of the 22 bare ground sites above 2288 m, two were on sandstone, two were
on sandstone-shale, and 18 were on limestone. Half of those faced ESE, 25 percent
faced SSW, 17 percent faced NNE, and 8 percent faced WNW. One bare WNW-
fac ing sandstone site and one bare ESE-facing sandstone-shale site lay below 2288 m.
Bare sites were included in the calculations of percentages of the area covered by
various vegetation types presented below.

The dominant cover of the Bridger Range is Douglas-fir; at lower altitudes grass-
lands increase in importance and at higher altitudes subalpine-fir increased in im-
portance (Fig. 2). Essentially all the area below 1678 m is grassland. The vegetation
of the 1678-1982 m zone is 38 percent grass, 47 percent Douglas-fir, 15 percent
lodgepole pine, and 0 percent subalpine fir. In the 1982-2288 m and 2288-2593 m
zones, the corresponding figures are 16, 61, 21, and 2 percent; and 10, 55, 12, and 19 percent. Three of the four vegetated sites above 2593 m were occupied by subalpine fir; the fourth was a lodgepole site.

**Relationship of Vegetational Cover to Aspect**

Vegetational cover is clearly related to aspect (Table 1 and Fig. 1). The grass-shrub type reaches its greatest cover values on southeast slopes (ESE and SSW); Douglas-fir is most important on southwest slopes (SSW and WSW); lodgepole is most important on northeast slopes (NNE and ESE); and until the 2288-2593 m level is reached subalpine fir also tends to occupy northeast slopes (NNE and ESE).

The behavior of the grasses and subalpine fir with changes in aspect mirrors their behavior with respect to altitude: grasses tend to dominate on warm dry sites and subalpine fir tends to dominate on cool moist sites.

At the 1678-1982 m and 1982-2288 m levels lodgepole pine is expected to be subclimax to Douglas-fir (e.g., Whitford and Craig, 1918), and might, therefore, be expected to occupy precisely the same sites Douglas-fir does. The observed segregation of the trees with respect to aspect mirrors relative water availability and suggests three hypotheses: 1) lodgepole pine may be climax on cool moist northeast facing slopes; 2) lodgepole is seral to Douglas-fir on northeast slopes, but not on southwest slopes which are usually too hot and/or dry for its establishment; or 3) lodgepole is seral to Douglas-fir, and probability of finding an early successional stage on a northeast facing slope is considerably greater than finding one on a southwest slope because it is in the northeast that stands are dense enough to carry crown fires regularly. The first hypothesis can be tested by looking for Douglas-fir reproduction in the northeast facing lodgepole stands; in Colorado Moir (1969) defined a lodgepole pine climax...
zone, but felt that it was the result of high temperatures and drought rather than the opposite. The second hypothesis would be supported by Bates (1917), who reported that lodgepole has higher water requirements than either Douglas-fir or Engelmann-spruce, and by Gail and Long (1935), who found it occupying hollows, gulches, and northeast-facing slopes. It would be questioned by Larsen (1930), Stephens (1966), and Despain (1973), who found lodgepole occupying relatively droughty sites. The second and third hypotheses are weakly supported by the near absence of lodgepole (6 percent) in the dry sites between 1678 and 1982 m.

### TABLE 1. Cover type probabilities (percent) by elevation and aspect, figures give the percentage of elevation-aspect sites occupied by each cover type.

<table>
<thead>
<tr>
<th>Altitude (m)</th>
<th>NNE</th>
<th>ESE</th>
<th>SSW</th>
<th>WNW</th>
</tr>
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<tbody>
<tr>
<td>Grass</td>
<td>1678-1982</td>
<td>38</td>
<td>45</td>
<td>40</td>
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<td></td>
<td>1982-2288</td>
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<td>2288-2593</td>
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<td>15</td>
</tr>
<tr>
<td></td>
<td>2593+</td>
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<td>0</td>
<td>0</td>
</tr>
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<td>Douglas fir</td>
<td>1678-1982</td>
<td>29</td>
<td>35</td>
<td>54</td>
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<tr>
<td></td>
<td>1982-2288</td>
<td>49</td>
<td>44</td>
<td>82</td>
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<tr>
<td></td>
<td>2288-2593</td>
<td>38</td>
<td>35</td>
<td>58</td>
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<tr>
<td></td>
<td>2593+</td>
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<td>0</td>
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<td>Lodgepole pine</td>
<td>1678-1982</td>
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<td>18</td>
<td>4</td>
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<td>6</td>
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<td>25</td>
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<td>1678-1982</td>
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<td></td>
<td>1982-2288</td>
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<td>23</td>
<td>16</td>
<td>18</td>
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<tr>
<td></td>
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<td>0</td>
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<td>2593+</td>
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<td>100</td>
<td>75</td>
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</table>

*In English units, the altitudinal zones are: 5500-6500; 6500-7500; 7500-8500, and greater than 8500 ft.*

### Relationship of Vegetational Cover to Substrate

Vegetational cover is as clearly related to substrate as to aspect (Table 2). Limestone sites below 2440 m are dominated by Douglas-fir; Douglas-fir (67 percent) and grasses (25 percent) cover the low sites; Douglas-fir (95 percent) covers the middle altitude sites, and high sites are covered by Douglas-fir (40 percent), subalpine fir (21 percent), and grass (17 percent). Gneiss sites are dominated almost as strongly by Douglas-fir: Douglas-fir (61 percent) and grasses (32 percent) cover low sites; Douglas-fir (80 percent), lodgepole-pine (12 percent), and grass (5 percent) cover middle sites; and high sites are dominated by Douglas-fir (79 percent) and lodgepole pine (14 percent)—not subalpine-fir (3 percent). On sandstone sites grasses are especially important: low sites are 54 percent grass and 33 percent Douglas-fir; middle sites are 50 percent grass and 50 percent Douglas-fir; and high sites are 10 percent grass, 40 percent Douglas-fir, and 20 percent subalpine fir. On interbedded sandstone-shale substrates, lodgepole achieves its greatest importance, though Douglas-fir is still dominant: lodgepole (26 percent), Douglas-fir (39 percent), and grasses (35 percent).
cover low sites; lodgepole (37 percent), Douglas-fir (42 percent), and grasses (17 percent) cover middle altitude sites; and lodgepole (24 percent), Douglas-fir (41 percent), and subalpine fir (18 percent) cover high sites.

One might ask why lodgepole performs especially well on sandstone-shale; why grasses perform especially well on sandstone and so poorly on limestone; why subalpine fir performs poorly on gneiss; and why Douglas-fir performs better on limestone and gneiss than on sandstones and sandstone-shales. We can speculate as follows:

The importance of lodgepole on sandstone-shales might be due to fire or the high water and/or nutrient availability on sites with clay-rich soils, gentle slopes due to rapid weathering and/or slumping of shales, and/or high water tables. Several studies (Vlamis et al., 1959; Williams et al., 1963; Hough, 1943) have shown soils derived from shales and sandstone-shales to be more productive than sandstone, limestone, and granite soils. We doubt that lodgepole requires the relatively high nutrient availabilities associated with these soils because it seems to grow well on poor soils (Whitford and Craig, 1918; Stephens, 1916; and Despain, 1973). Gail and Long (1955) associate the presence of lodgepole pine with false hardpans and a high water table; their suggestion that lodgepole is most common on moist sites is consistent with the fact

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### Table 2. Cover types by altitude and substrate; figures give the percentage of substrate-altitude sites occupied by each cover type.

<table>
<thead>
<tr>
<th>Altitude (m)</th>
<th>All Substrates</th>
<th>Sandstone-Shale</th>
<th>Gneiss</th>
<th>Limestone</th>
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<tbody>
<tr>
<td>Grass</td>
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</tr>
<tr>
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<td>32</td>
<td>60</td>
<td>67</td>
<td>48</td>
</tr>
<tr>
<td>1830-1932</td>
<td>32</td>
<td>52</td>
<td>52</td>
<td>20</td>
</tr>
<tr>
<td>1932-2135</td>
<td>12</td>
<td>50</td>
<td>50</td>
<td>0</td>
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<tr>
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<tr>
<td>2440-2593</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
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<tr>
<td>Douglas-fir</td>
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<td>1678-1830</td>
<td>42</td>
<td>32</td>
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<td>2593+</td>
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<tr>
<td>Subalpine fir</td>
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</table>

1In English units the altitudinal zones are: 5500-6000, 6000-6500, 6500-7000, 7000-7500, 7500-8000, 8000-8500, and 8500+ ft.
that it is also most common on north- and east-facing slopes. The importance of lodgepole-pine on sandstone-shale substrates might not be directly due to requirements of the tree for either water or nutrients, but due instead to the high probability of fires in dense stands occupying these relatively rich sites.

Grass types may do well on sandstones because sandstones form well-drained soils which are too dry for competing cover types. Limestones are also expected to form well-drained soils, but here water storage in the upper horizons is probably reduced by stoniness; stoniness generally favors deep-rooted trees over shallow-rooted grasses (Walter, 1970; Despain, 1973). A lack of phosphorus on limestone sites may also favor Douglas-fir over the grasses (Gessel and Walker, 1958; Wright and Mooney, 1965).

The near absence of subalpine fir on the quartz-feldspar gneisses might be due to a high requirement for base-rich substrates or water. The high requirement for bases is suggested by its calcium-rich needles (Strodtmeyer and Ralston, 1968) and by its inability to compete with whitebark pine on lime-poor soils at high altitudes (Weaver and Dale, 1974). The fact that the gneisses occur exclusively on the west side of the Bridgers suggests that gneiss sites might also be relatively dry.

Because Douglas-fir is the dominant tree of the Bridgers one may think of it as occupying those sites not especially favorable for other cover types: it apparently tends to be excluded from sandstones by competition with grasses and from sandstone-shales by lodgepole competition or fire.

**Statistical Tests**

We used Chi-square tests (5 percent level) to determine the significance of the observed changes. 1) The changes in species dominance with altitude and substrate are significant. The changes in species dominance with aspect are significant below 2288 m, but not significant above 2288 m. 2) Cover types did not change aspect significantly with changes in elevation. 3) Chi-square tests suggest that species do change substrates with elevation, but much of this effect appears to be due to the disappearance of sandstone and sandstone-shales at high elevation. 4) Chi-square analyses also suggest that Douglas-fir in the 1678-1982 and 1982-2288 m zones and grasses in the 1678-1982 m zone change aspect with substrate. At 1678-1982 m Douglas-fir is most frequent on WNW aspects of sandstone and sandstone-shale, while at 1982-2288 m it moves into the SSW ("drier" aspect) on sandstone-shale and the ESE ("wetter" aspect) on sandstones; it appears with equal (high) frequencies at both altitudes on limestone and gneiss. At 1678-1982 m grasses appeared with highest frequencies in the SSW on gneiss, sandstone-shales, and sandstones and in the NWN on limestones. In no altitudinal band did lodgepole pine change aspect with changes in substrate. The amount of subalpine fir was insignificant in the lower altitudinal zones.

**Application**

The strong relationships of vegetation cover to elevation, aspect, and substrate—whatever the causes may be—should be considered in management of mountain timberland. First, it may be difficult to regenerate a vegetation type after logging if it occupies a site unusual (marginal?) for it. It might be difficult, for example, to re-establish Douglas-fir on a low sandstone site. Second, when plantings are made, one
should select seedling stock known to thrive under available conditions: this study suggests that, in the Bridger Range, Douglas-fir has broad tolerance (i.e., can be planted almost anywhere) while lodgepole pine has narrower tolerances (i.e., will perform best on sandy-slates and east-facing slopes).

**Literature Cited**


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