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SNOWPACK AND THE SUBNIVEAN ENVIRONMENT FOR DIFFERENT ASPECTS OF AN OPEN MEADOW IN JACKSON HOLE, WYOMING, U.S.A.*

NANCY A. AUERBACH AND JAMES C. HALFPENNY
Institute of Arctic and Alpine Research, University of Colorado
Boulder, Colorado 80309-0450, U.S.A.

ABSTRACT

Snowpack characteristics of an open meadow habitat were examined by students of the Teton Science School's Winter Ecology Course. Characteristics evaluated are inherent in snowpacks throughout circumpolar regions. Snowpits were sampled for 9 yr on a north-facing slope, a valley bottom, and a south-facing slope (situated in the same locations all years). Snow was deepest on the north-facing slope and shallowest on the valley bottom each year. Snowpack thermal index values less than 200 in some years in the valley bottom and on the south-facing slope indicated a possible failure to provide temperature buffering of the nivean environment. Despite lower air temperatures, ground temperatures of the north-facing slope snowpits appear to be higher than the other two aspects, especially in colder years. Temperature gradient snow (TG, depth hoar, or pukak) was well developed in all years for all aspects. We speculate that the depth of formation of cohesionless TG crystals has been sufficient for small mammal movement beneath the snow in all years. Snowpacks with little temperature buffering capability (indicated by low thermal indices), however, may discourage usage of certain locations by mobile mammals in some years. Fluctuating ground temperatures may also influence plant species composition and distribution beneath the snowpack.

INTRODUCTION

The subnivean environment is a protective zone in which many organisms can spend winter (Formozov, 1946; Billings, 1959; Marchand, 1987; Halfpenny and Ozanne, 1989). The layers of snow blanketing the ground moderate air temperature fluctuations and protect animals and plants from extremes and rapid changes in temperature. Snow also provides protection from chilling winds and radiation loss.

Snow on the ground changes form or undergoes metamorphism due to temperature conditions within the snowpack. The abiotic forces create a varied snowpack with a wide range of subnivean environmental characteristics. In a meadow ecosystem, we compared the long-term snowpack records of three aspects (north-facing, valley bottom, and south-facing) for indicators of quality of subnivean environment, using characteristics which pertain to organism needs. Characteristics evaluated were snowpack depth, thermal index, ground and surface temperature, and temperature gradient snow (TG, depth hoar, or pukak) formation.

STUDY SITE

An open meadow near the Teton Science School, in Grand Teton National Park, Wyoming, U.S.A., was chosen for the study site. The meadow is located at approximately 43°N latitude and 110°W longitude and 2134 m elevation. Sagebrush, grasses, and various forbs grow in the meadow, which slopes gradually into the center, and is surrounded by a forest of aspen (*Populus tremuloides*) and lodgepole pine (*Pinus contorta*). Long

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winters in the Tetons are characterized by low temperatures and deep snowpacks. Measured at the nearby town of Jackson, Wyoming, average winter (October through April) temperature is −5.7°C and monthly precipitation averages 3.2 cm water equivalent (Figure 1). Snowpack depth typically ranges between 50 and 80 cm.

METHODS

Three snowpits were sampled in a 77-m transect running north to south across the meadow. Snowpits were located on the north-facing slope of the meadow, the valley bottom, and on the south-facing slope. Sampling was conducted at about 1430 h on about 4 January by students of the Winter Ecology Class at the Teton Science School each winter from 1981 to 1989.

Pits were dug through the snow to ground level, and all sampling was conducted on the smoothed, shaded, north-facing side of the pit. Layers within the snow profile were determined, and heights to tops and middles of the layers were measured from the ground. Temperature and density of the snow, as well as type and size of snow crystals (LaChapelle, 1969; Colbeck, 1987) were recorded from snow in the middle of each layer. The thermal index (summation of the thickness divided by the density of each layer of the snow profile) was also calculated for each snowpit (Marchand, 1982).

RESULTS

In all years the snowpack on the north-facing slope (nf) was deeper than that on the south-facing slope (sf), which was deeper than in the valley bottom (Figure 2). The total depth on the north-facing slope ranged from 37 to 188 cm. The snowpack on the valley bottom ranged from 28 to 76 cm. In deep snow years, differences in depth between aspects were more marked. When all years were compared, depth of snowpack on the valley bottom was most variable ($CV_{vb} = 35.7\%$; $CV_{sf} = 29.5\%$; $CV_{nf} = 29.0\%$). Snowpack on the north-facing slope was significantly ($p < 0.05$) deeper than snowpack on the valley bottom ($\bar{X}_{nf} = 84.2$ cm; $\bar{X}_{sf} = 63.9$ cm; $\bar{X}_{vb} = 50.2$ cm).

The thermal index of the snowpack on the north-facing slope was the highest of the three aspects in all years while the valley bottom snowpack thermal index was lowest in all years (Figure 3). For all years, the north-facing slope thermal index was above 200, ranging from 208 to 508. In five of the years, the thermal index of the valley bottom snowpack was below 200, with a record low of 137. In two of the years, the south-facing slope snowpack thermal index was below 200. The thermal index of the snowpack on the valley bottom was most variable among years ($CV_{vb} = 34.4\%$; $CV_{nf} = 27.0\%$; $CV_{sf} = 22.9\%$). The mean thermal index for the north-facing slope was significantly greater ($p < 0.05$) than either of the other aspects ($\bar{X}_{nf} = 385$; $\bar{X}_{sf} = 266$; $\bar{X}_{vb} = 229$).

While not statistically different, surface temperatures above the pit on the north-facing slope were lower than those above the valley bottom pit, which were lower than those above the pit on the south-facing slope ($\bar{X}_{nf} = 13.8$°C; $\bar{X}_{vb} = 10.6$°C; $\bar{X}_{sf} = -8.9$°C). Temperatures at the ground/snow interface showed the reverse trend, with generally higher ground temperatures under the snowpack of the north-facing slope than under the snowpacks of the other two aspects ($\bar{X}_{nf} = -1.7$°C; $\bar{X}_{vb} = -1.9$°C; $\bar{X}_{sf} = -2.4$°C). In colder years, the ground temperature under the north-facing slope pit was substantially higher (as much as 2.2°C) than under the pits on the other aspects. Despite cold surface air conditions, ground under the snow remained relatively warm on the north-facing slope (Figure 4).

Averaged over all years, the thickness of the TG snow (depth hoar or pukak) layer was not statistically different among aspects. In general, the well-developed TG snow layer averaged 21 cm on all aspects. Temperature gradient snow was continuous over large areas.

DISCUSSION

The snowpack moderates environmental effects (air temperatures, wind, radiation) on the subnivean zone where long-term average snowpack conditions may control plant species distribution, community composition, and animal behavior (for reviews see Pruitt, 1960; Marchand, 1982, 1987; Merritt, 1984; Halfpenny and Ozanne, 1989). Snowpack conditions varied among years, but relationships among aspects were consistent. Year-to-year oscillation of snowpack conditions on the valley bottom and south-facing slope resulted in greater thermal instability for subnivean organisms.

Deep snowpacks increase time necessary for temperature changes to propagate through the snow (Schmid, 1984). The thermal index measurement (Marchand, 1982), which takes snow depth into account, provides a useful tool for interpreting variability in conditions in the subnivean environment. Thermal index values which approach or exceed 200 indicate stable thermal conditions (i.e., the snowpack provides a buffering effect against ambient air temperatures and ground/snow interface temperatures will not fluctuate as much as air temperatures). Thermal stability decreases as thermal index values decrease from 200 to 150, and thermal index values of less than 150 indicate the snowpack has little buffering capability. Ground/snow interface temperatures may fluctuate dramatically when the thermal index value is

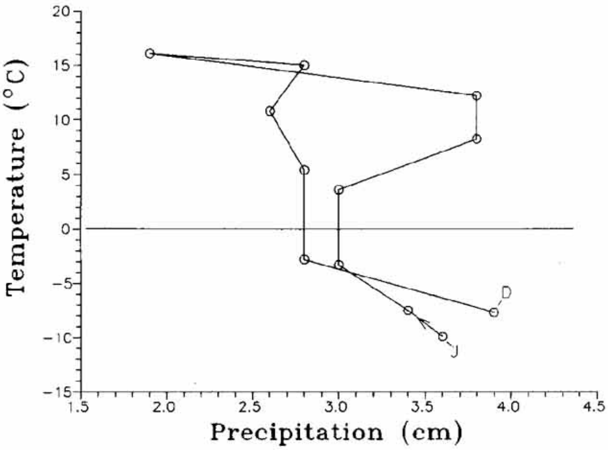

FIGURE 1. Climograph for Jackson Hole, Wyoming. Circles represent consecutive months; J = January, D = December.

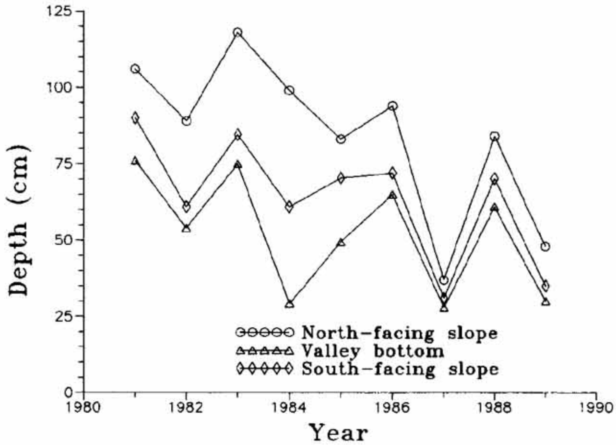

FIGURE 2. Depth of snowpack on all aspects by year.

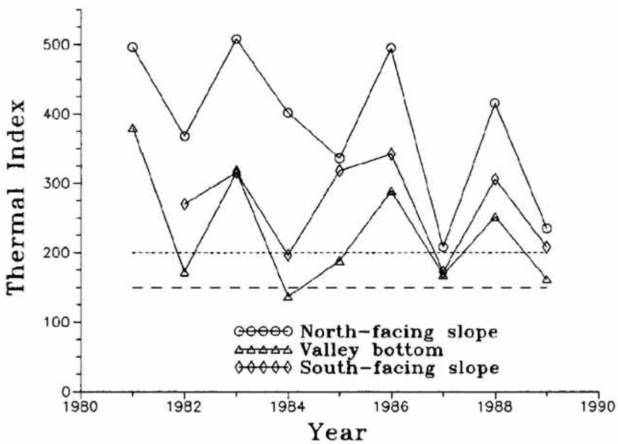

FIGURE 3. Thermal index of snowpack on all aspects by year. The fine dashed line indicates a thermal index of 200 and the coarse dashed line indicates a value of 150. A thermal index value between 150 and 200 indicates thermal stability in the subnivean environment (Marchand, 1982).

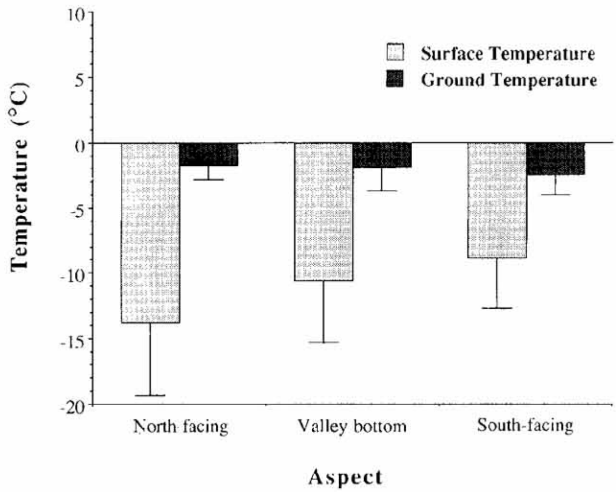

FIGURE 4. Comparison of average temperature conditions by aspect. Shown are the air/snow surface and ground/snow interface temperatures with averages representing 9 yr. Error bars indicate 95% confidence intervals.

below 150. Plants that grow on the valley bottom and south-facing aspects, which had some low thermal index values through the years, must be adapted to withstand more variable conditions during the snow season. Plants which require thermal stability may not be distributed in areas which may have a thinner snopack, and thus more thermal variability.

Over the short term, we speculate that mobile animals such as mice, voles, and shrews have more of a "choice" where they will spend their winter. During years of low snowpack or cold temperatures, animals may emigrate to more suitable subnivean environments. A layer of TG snow at the snow/ground interface is helpful for animals who must burrow through the snow, as they can easily move through the cohesionless TG crystals. While depth of TG snow formation was sufficient for small mammal movement beneath the snow in all years on all aspects, low or fluctuating ground temperatures on the valley bottom and south-facing slope (due to lack of insulation) may have discouraged usage of these locations in some years.

The subnivean environment of the north-facing slope appears to be the most stable from year to year. Vegetation growing on this aspect will be adapted to relatively stable and warm temperatures during the snow season. Suitable snow conditions for the needs of a mobile mammal are provided on the north-facing slope by a deep snowpack, a high thermal index, stable and warm ground/snow interface temperatures, and sufficient TG snow formation for easy mobility.

In summary, over nine winters the snowpack was most variable on the valley bottom, with shallow snow depths and low thermal indices, indicating potential for high ground temperature fluctuation. The subnivean environment on the north-facing slope is the most buffered in a given year, showing more stable conditions, and it also has the most predictable conditions over many years.

Characteristics evaluated here are inherent in snowpacks throughout the world. Therefore, our mid-latitude observations may be comparable to snowpack studies conducted in a range of other areas. We would expect that similar local variability would be present in snowpacks of circumpolar regions and suggest further studies on responses of plants and animals to selective environmental pressures created by various snowpack conditions.

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