1981

Potential Ecological Impacts of Snowpack Augmentation in the Uinta Mountains, Utah

U.S. Bureau of Reclamation

Recommended Citation

U.S. Bureau of Reclamation. Potential Ecological Impacts of Snowpack Augmentation in the Uinta Mountains, Utah. Washington: DC, USGPO, 1981

POTENTIAL ECOLOGICAL IMPACTS OF SNOWPACK AUGMENTATION IN THE UINTA MOUNTAINS, UTAH

FINAL REPORT TO THE WATER AND POWER
RESOURCES SERVICE
1981

MS-230 (3-78)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.
2. GOVERNMENT ACCESSION NO.
3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE
Potential Ecological Impacts of Snowpack Augmentation in the Uinta Mountains, Utah -- Final Report of the Uinta Ecology Project
5. REPORT DATE
April 20, 1981
6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)
Kimball T. Harper et al.
8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS
Department of Botany & Range Science
Brigham Young University, Provo, UT 84602
Under contract to Utah Div. of Water Resource,
231 E. 400 S., Salt Lake City, UT 84111
10. WORK UNIT NO.
11. CONTRACT OR GRANT NO.
Water and Power Resource Service 6-07-DR-20060
12. SPONSORING AGENCY NAME AND ADDRESS
Department of Interior
Water and Power Resources Service
Office of Atmospheric Water Resources Mngt.
Denver, CO 80225
13. TYPE OF REPORT AND PERIOD COVERED
Final Report
May 1, 1976-May 1, 1980
14. SPONSORING AGENCY CODE
Div. Water Res. Contr. No. 76-6892
15. SUPPLEMENTARY NOTES
Results of four years of observations on the effects of late-lying snow on resources of the Uinta Mountains.
16. ABSTRACT

Results of studies on the impacts of late-lying snow on four ecosystems (lodgepole pine and spruce-fir forests, subalpine meadow and alpine herbland) are reported. An increase of 10% in the average snowpack is estimated to retard the 75% snow-free date .7-1.5 days. That amount of additional snow could not be shown to alter tree growth or reproduction in the forests studied. A 10% increase in snowpack tended to increase above-ground herb growth in ecosystems that normally have light snowpacks (lodgepole forest and alpine herbland) and to decrease herb production in zones of heavy snowpacks (spruce-fir forest and subalpine meadow). All changes in herb layer production were small. Species that were adversely or positively affected by late-lying snow are identified.

Baseline silver contents of soils and plant are reported. The vegetational sampling design is evaluated and recommendations for the future are made. It is demonstrated that Landsat imagery is an economical tool for monitoring snowpack retreat. Streamflow and snow melt models are developed for the Uinta Mountains.

17. KEY WORDS AND DOCUMENT ANALYSIS
a. DESCRIPTORS--
Alpine herbland, lodgepole pine forest, snow melt, snow and plant growth, spruce-fir forest, streamflow prediction, subalpine meadow, silver in soils and plants, vegetational sampling, Uinta Mountains, Utah.
b. IDENTIFIERS--
c. COSATI Field/Group COWRR
18. DISTRIBUTION STATEMENT
Available from the National Technical Information Service, Operations Division, Springfield, Virginia 22161.
19. SECURITY CLASS (THIS REPORT)
UNCLASSIFIED
20. SECURITY CLASS (THIS PAGE)
UNCLASSIFIED
21. NO. OF PAGES
22. PRICE

GPO 845-830

POTENTIAL ECOLOGICAL IMPACTS OF SNOWPACK AUGMENTATION IN THE UINTA MOUNTAINS, UTAH

Final Report of the Uinta
Ecology Project

K. T. Harper, Editor

Prepared for the
Utah Division of Water Resources
231 E. 400 S.
Salt Lake City, Utah 84111
and
Water and Power Resources Service
Office of Atmospheric Resources Management
Engineering and Research Center
Denver, Colorado 80225
by
Department of Botany and Range Science
Brigham Young University
Provo, Utah 84602

ACKNOWLEDGEMENTS

During the course of this study, over a score of students have assisted in one way or another. Some of them appear as co-authors of chapters of this report, but others had moved on to graduate school or jobs elsewhere before the final reports were prepared. I am grateful for the contributions each has made to the project.

The sponsor of the research leading to this report was The Water and Power Resources Service of the United States Department of Interior through a contract with the Utah Division of Water Resources. Both Edward Novak (formerly of the Water and Power Resources Service) and Dr. Wally Howell of the Water and Power Resources Service have visited our study areas and offered advice and criticism that were most helpful. I have appreciated their input. Liaison officers from the Utah Division of Water Resources for this project were Paul Summers and Clark Ogden. Their help in the field and in gathering literature was extensive. I have enjoyed the contacts which I have had with them.

Dr. Merrill K. Ridd, Director of the Center for Remote Sensing and Cartography at the University of Utah Research Institute in Salt Lake City, has been most generous with advice, equipment, and laboratory space. The remote sensing aspects of this study could not have been done without his help. Dr. Melvin W. Carter of the Department of Statistics at Brigham Young University has been very helpful in respect to statistical analysis of the data. Lorelei Swingle typed the final report and Naomi E. Hebbert designed the cover.

POTENTIAL ECOLOGICAL IMPACTS OF SNOWPACK AUGMENTATION IN THE UINTA MOUNTAINS, UTAH

CONTENTS

CONTENTS (Continued)

CHAPTER I

INTRODUCTION AND OBJECTIVES

by

K. T. Harper

ABSTRACT

The Uinta Mountains include 13,620 Km^2 of land above 2,135 m. The range includes 26 peaks that rise above 3,965 m. Over 1.8 Km^3 of surface runoff water originates annual on the range.

The commonest rock type in the interior of the Uintas is Uinta quartzite, a hard rock that produces infertile soils on weathering. The higher elevation, least fertile soils are dominated by coniferous forests. Lodgepole pine is the commonest conifer and dominates over 60% of the coniferous forest area. Engelmann spruce is also common at higher elevations. Most coniferous forests on the range are open and have low productivity. The Uintas produce about 1.41×10^5 m^3 of timber per year: lodgepole contributes about 59% of that total and Engelmann spruce about 31%.

The Uintas furnish about 119,709 animal unit months (AUMs) of grazing for domestic livestock. Cattle account for 52% and sheep 46% of the AUMs. The range and water impoundments around its edges furnish about three million days of recreation annually. Camping, fishing, hiking and big game hunting account for 33, 20, 13, and 10% respectively of the visitor days.

Most of the land (66%) is managed by The U.S. Forest Service. Private interests control another 24% of the area above 2,135 m.

This report will consider the impact of late lying snow on the lodgepole pine, subalpine meadow, spruce-fir, and alpine herbland ecosystems. The linkage between snowpack and streamflow is considered. Background levels of silver in plants and soils are reported and the vegetational monitor design for the study is evaluated. The use of satellite photos for monitoring snowpack retreat is also discussed.

PROJECT HISTORY

Early in 1976, the Utah Division of Water Resources entered into a contract with the Bureau of Reclamation (now The Water and Power Resources Service). The purpose of that contract was to provide information for an environmental impact statement for winter cloud seeding to augment snowpack in the Upper Colorado River Basin. The contract also called for formulation and testing of hypotheses related to the potential impact of increased snowpack on regional vegetation. The contractor was also to recommend monitoring procedures for long-term cloud seeding research in the Upper Colorado River Basin with particular emphasis on the Uinta Mountains of Utah. On May 1, 1976, the Utah Division of Water Resources formalized a subcontract with K. T. Harper of Brigham Young University.

Earlier research programs funded by the Service concentrated on the potential impact of winter snow augmentation in the Medicine Bow Mountains of southeastern Wyoming and the San Juan Mountains of southwestern Colorado. The results of those studies have been reported by Knight et al. (1975) and Steinhoff and Ives (1976). The work done by Brigham Young University has focused on the northern slope of the Uinta Mountains, northeastern Utah. The relationship of late lying snow to the plant cover of four major ecosystem was studied during the snow melt and growing seasons of the years 1976-79. Also, the distribution patterns of precipitation in the Uintas and the relationship of snowpack to runoff in nine major watersheds were analyzed.

THE UINTA MOUNTAINS

The Uinta Mountains lie in the northeastern corner of Utah. Unlike other major North American mountain ranges, the long axis of the Uintas is oriented east and west rather than north and south. The range is large in both areal extent and elevation. Over 13,620 km^2 (5.26 x 10^3 mi^2) of land lie above the 2,135 m (7,000 ft) contour in the range. Twenty-six peaks rise above 3,965 m (13,000 ft) in the Uintas. Kings Peak in the center of the range rises to an elevation of 4,117 m (13,498 ft) and is the highest point in Utah.

The Uintas give rise to four of Utah's major rivers: the Bear, Duchesne, Provo and the Weber. About 1.8 km^3 (1.6 x 10^6 acre ft) of surface runoff water are produced annually by the Uintas (Wasatch National Forest 1976 and Jeppson et al. 1968). About 68 percent of that water feeds into the Green River, a major tributary of the Colorado (Jeppson et al., 1968). The Uinta Mountains are thus a major watershed of the Upper Colorado River Drainage Basin.

GEOLOGY

The Uintas are the result of an early Cenozoic uplift of a deep (over 15,250 m) sequence of sedimentary beds that had accumulated in the Uinta trough throughout most of recorded geological time (Hansen 1969). The oldest recorded rocks now exposed in the area (Red Creek Quartzite) are shown to be about 2.3 billion years old by radiometric dating methods (Hansen 1969). The gigantic anticlinal uplift that forms the range rises abruptly from the valley floor of the Kamas Valley on the west, but its upward incline is more gentle at the east end of the range

THE UINTA MOUNTAINS

The Uinta Mountains lie in the northeastern corner of Utah. Unlike other major North American mountain ranges, the long axis of the Uintas is oriented east and west rather than north and south. The range is large in both areal extent and elevation. Over 13,620 km^2 (5.26×10^3 mi^2) of land lie above the 2,135 m (7,000 ft) contour in the range. Twenty-six peaks rise above 3,965 m (13,000 ft) in the Uintas. Kings Peak in the center of the range rises to an elevation of 4,117 m (13,498 ft) and is the highest point in Utah.

The Uintas give rise to four of Utah's major rivers: the Bear, Duchesne, Provo and the Weber. About 1.8 km^3 (1.6×10^6 acre ft) of surface runoff water are produced annually by the Uintas (Wasatch National Forest 1976 and Jeppson et al. 1968). About 68 percent of that water feeds into the Green River, a major tributary of the Colorado (Jeppson et al., 1968). The Uinta Mountains are thus a major watershed of the Upper Colorado River Drainage Basin.

GEOLOGY

The Uintas are the result of an early Cenozoic uplift of a deep (over 15,250 m) sequence of sedimentary beds that had accumulated in the Uinta trough throughout most of recorded geological time (Hansen 1969). The oldest recorded rocks now exposed in the area (Red Creek Quartzite) are shown to be about 2.3 billion years old by radiometric dating methods (Hansen 1969). The gigantic anticlinal uplift that forms the range rises abruptly from the valley floor of the Kamas Valley on the west, but its upward incline is more gentle at the east end of the range

in northwestern Colorado. Deep crustal movements have pushed the crest of the anticline northward until it is asymmetrical with a steep northern face and a more gentle south slope.

Except for a few igneous dikes intruded into the oldest sedimentary rocks in the range, the High Uintas are composed entirely of sedimentary materials (Hansen 1969). For the most part, igneous activities have been absent during the development of the range (Emmons 1907). The ravages of some 70 million years of erosion have stripped off the younger geologic strata from the apex of the Uinta anticline leaving quartzites of the Uinta Mountain group of Precambrian age to dominate most of the landscape above 3,050 m elevation. The generally reddish colored Uinta Mountain Quartzite is hard and deficient in the elements required by plants, thus soils develop slowly on that parent material and are inherently infertile.

The high elevation interior of the range has been further modified by four major glacial events during Pleistocene times (Grogger 1974). During the first and most extensive glaciation, over 2,500 km^2 of the range were buried under ice (Hansen 1969), and valley glaciers advanced beyond the mountain fronts on both the north and south slopes of the Uintas and coalesced to form extensive piedmont glaciers (Grogger 1974). Today the evidence of glaciation in the form of mountain lakes, moraines, cirques, and U-shaped valleys can be seen throughout the High Uintas.

Glaciation has enhanced the depressing effect of hard and nutrient poor rock on plant growth in the Uintas by scouring away or burying such soils as had developed prior to the Pleistocene at high elevations. Shallow, impoverished soils combine with short growing seasons and cold temperatures to make the High Uintas a harsh environment for plant growth. The low plant productivity of the interior of the range is a consequence of the inhospitable environment.

Limestone and shales are currently confined to the edges (particularly the western flank) of the range. Deciduous forest of aspen and thickets of oak are widespread above 1,900 m on limestones and calcareous shales, but coniferous forest and alpine herblands dominate the interior of the range where soils are derived from quartzite.

VEGETATION

The vegetation of the Uintas above 2,135 m is dominated by forest (Table 1-1) with coniferous forest prevailing above 2,740 m. Roughly 60% of the coniferous forest is dominated by lodgepole pine, the most widespread vegetation type in the Uintas. Large areas of Engelmann spruce and subalpine fir also occur in the range. Ponderosa pine is less common in the area and is largely confined to the east and south slopes of the range. Douglas fir forms stands locally throughout the range, usually on limey outcrops.

Wet drainage bottoms and poorly drained valley bottoms in the forested areas support verdant and moderately productive subalpine meadows and willow thickets, the chosen habitat of the moose which has recently invaded the area and established breeding populations. Above 3,350 m, forests are reduced to tangles of twisted, shrub-sized conifer trees or disappear completely. The gentler slopes at high elevation support alpine herblands that only locally consist of a species complex that merits the name alpine tundra.

The flora of the Uintas is rich consisting of over 1,050 vascular plants, 140 mosses and liverworts, at least 40 species of lichen, 235

Table 1-1. Vegetation of the Uinta Mountains. Only the area above 2,135 m is considered.

Vegetative Type	Percentage of Total Area
Coniferous Forest	34.9
Deciduous Forest (aspen and oak)	31.5
Juniper-Pinyon Forest	2.4
Sagebrush-Grass	16.3
Subalpine and Alpine Herblands	9.8
Barren Land (mostly above 3,350 m)	5.1

Data taken from a map based on Landsat imagery (Ridd 1978).

fungal species, and over 800 known species of algae (Harper et al. 1978). No endangered plants are known in the Uinta Mountains, but six plants that have been legally designated as threatened (Federal Register 40 (125), part V, pages 27880-27883, July 1, 1975) do occur in the area. Species designated as threatened are:

Cryptantha stricta (Osterh.) Payson (Erect *Cryptantha*)
Mertensia viridis var. *cana* (Rydb.) L. O. Williams (Green Bluebell)
M. viridis var. *dilata* (A. Nels.) L. O. Williams (Green Bluebell)
Parrya rydbergii Botsch. (Rydberg's *Parrya*)
Penstemon acaulis L. O. Williams (Stemless *Penstemon*)
P. uintahensis Pennell (Uinta *Penstemon*)

Welsh (1978) continues to recognize these taxa as threatened even though he has recommended removing 36 entities from the endangered and threatened lists published for Utah in 1975 by the Fish and Wildlife Service.

ANIMAL RESOURCES

The invertebrate animals of the Uintas are not well known. The mountain pine bark beetle (*Dendroctonus monticola* - family Scolytidae) may exert a greater economic impact on the Uinta Mountains than any other wild animal occurring there. Vertebrate animals of the area are well known and include 22 species of fish, 8 amphibians, 15 reptiles, 82 mammal species and 186 speices of birds (Harper et al. 1978). Domestic animals that regularly forage on the range include cattle, horses, and sheep.

Big game hunting is a major activity on the Uintas. The range supports the largest of Utah's three moose herds (Wilson 1971 and Babcock 1977) and large elk and deer herds. In 1976, 45 bull moose were harvested on the Uintas (John and Fair 1977). The range also provided a harvest of 791 elk in 1976, roughly one-third of the elk harvested in Utah that year. During the period 1970-76, an average of 1,500 mule deer per year were harvested on the Uintas. The deer harvest was made by an average annual force of 4,300 hunters (John and Fair 1977).

Sage grouse, ruffed grouse, and the blue grouse have sizable populations in the Uinta Mountains. In 1976, in an attempt to enrich the upland game bird resource of Utah, the Division of Wildlife Resources reintroduced the ptarmigan into the alpine zone of Painter Basin on the Uinta North Slope. The population is apparently reproducing in its new home (Hall 1978).

Timber Resources

About 44% of the saw timber now harvested in Utah comes from the Uintas (Setzer and Thorssell 1977). The total volume of timber harvested on the range amounts to over 1.41 x 10^5 m^3 (5 x 10^6 ft^3) per year. Lodgepole pine is the primary contributor to the harvest at 58.6% of the total; Engelmann spruce contributes almost 31% of the total (Harper et al. 1978).

Grazing Resources

The Uintas provide summer forage for domestic grazers for an equivalent of 119,709 animal unit months. The grazing is allotted about equally to cattle (52.1%) and sheep (45.7%). Horses account for 2.2% of the permitted grazing pressure (Harper et al. 1978).

RECREATION

The Uintas are a major recreation ground for the population centers along the Wasatch Front in Utah. If one includes visitors to the Flaming

Gorge Recreation Area and Strawberry Reservoir, both on the edges of the study area, total recreation use on the Uinta Mountains is currently close to 3 x 10^6 visitor days per year. The use distribution among the National Forests that manage the bulk of the Uinta Mountain area is roughly as follows: 50% on the Ashley, 42% on the Wasatch, and 8% on the Uinta. (the Uinta National Forest manages only a small portion of the Uinta Mountains). The three major contributors to the visitor day total appear to be camping (33%), fishing (20%) and hiking (13%). Hunting probably contributes about half as many visitor days as fishing (Harper et al. 1978).

NONBIOLOGICAL RESOURCES

The Uintas are notably devoid of mineral resources. Even the deep gravel deposits around the fringes of the range have been little used because of their remoteness from markets. There is a coal withdrawal on Currant Creek on the south slope. Petroleum has been discovered on all sides of the range but the greatest impact is in the Uinta Basin (Harper et al. 1978).

LAND OWNERSHIP

The Forest Service manages the bulk of the core area of the Uinta Mountains and far more land (about 66% of the total area of concern) than any other agency in the area according to the Bureau of Land Management (1978) Land Status Map. Private interests control 24% of the area, the Bureau of Land Management 4%, Indian Reservation about 3.6%, and the State of Utah about 2% (Harper et al. 1978).

STUDY OBJECTIVES

Under the terms of the subcontract between the Utah Division of Water Resources and Brigham Young University, the following objectives were outlined.

a. Prepare a literature review on ecological impacts of weather modification (especially snow augmentation) on natural environments, agriculture, and other activities of prime concern to man. Emphasis will be placed on identifying impacts that are well understood as well as those that will need further attention in the Uinta Mountains.

b. Assemble available data on kinds and extents of natural ecosystems, local climates, water yield, and current locations and intensities of various human activities in the Uinta Mountains. Current activities of resource management agencies in the Uintas will be noted.

c. Identify major sources of published information and primary contact persons knowledgeable about current activities in or dependent upon the Uintas.

d. Locate an area within the Uinta Range that is suitable and accessible for long term monitoring.

e. Establish a network of permanent vegetation monitoring sites in the alpine tundra, subalpine meadows, spruce-fir forests, and lodgepole pine forest of the Uinta Mountains.

f. Identify the impacts of lateness of snowpack disappearance on phytosociology, total plant productivity of various plant "compartments" such as annuals, perennial forbs, perennial grasses, shrubs, and trees in each ecosystem identified above.

g. Study available streamflow and snow course records to determine the effect of variable snowpack on runoff in selected drainages.

h. Analyze the effects of exposure, seasonal temperature, and water content of the snowpack on melt-date of that pack.

i. Investigate the feasibility of using satellite data and/or occasional aerial survey check flights for establishing characteristics of snowpack retreat.

Of the foregoing objectives items b and c have been responded to elsewhere (Harper et al. 1978). All other items are treated in the chapters of this report. The general locations of the intensive study areas used for this study are shown in Figure 1-1.

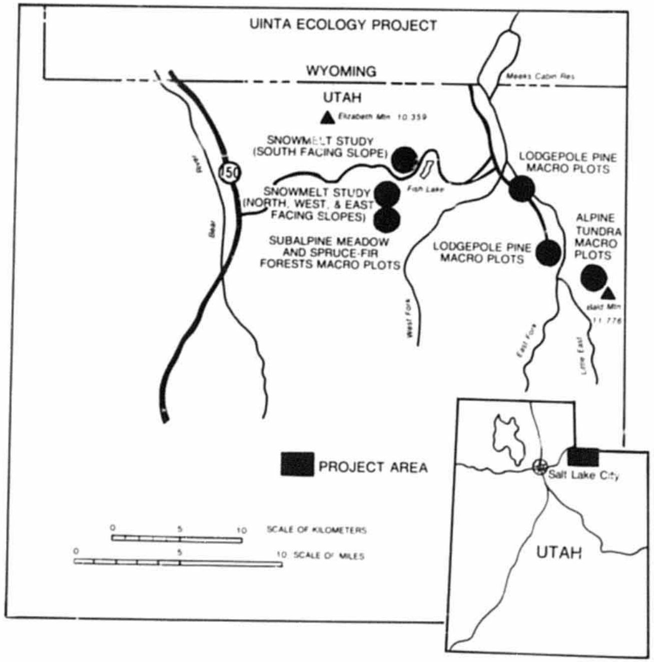


Figure 1-1. Locations of the major study sites used in the Uinta Ecology Project.

LITERATURE CITED

Babcock, W. H. 1977. Continuing investigations of the Uinta North Slope moose herd. Utah Division of Wildlife Resources Publication No. 77-19. 76 pp.

Bureau of Land Management. 1978. Areas of responsibility and land status map: State of Utah. U.S. Dept. of Interior, Geological Survey, Reston, Virginia.

Emmons, S. F. 1907. Uinta Mountains. Bull. Geol. Soc. Am. 18:287-302.

Grogger, P. K. 1974. Glaciation of the high Uintas primitive area, Utah, with emphasis on the North Slope. Ph.D. Dissertation, University of Utah, Salt Lake City. 209 pp.

Hall, D. E. (ed.) 1978. Information needed on ptarmigan. The wildlife report, June 12, 1978, p. 2. Published by the Utah Division of Wildlife Resources, Salt Lake City.

Hansen, W. R. 1969. The geologic story of the Uinta Mountains. Geological Survey Bulletin 1291:1-144.

Harper, K. T., W. K. Ostler, and D. C. Anderson. 1978. Resources of the Uinta Mountains. Submitted to the Utah Division of Water Resources, Salt Lake City, and the U.S. Bureau of Reclamation, Denver, Colorado. 148 pp.

Jeppson, R. W. et al. 1968. Hydrologic atlas of Utah. PRWG35-1, Utah Water Research Laboratory, Utah State University, Logan. 306 pp.

John, R. T. and J. S. Fair. 1977. Big game harvest report - 1976. Utah Division of Wildlife Resources Publication 77-4. 96 pp.

Knight, D. K., et al. 1975. The Medicine Bow Ecology Project. Final Report to U.S. Bureau of Reclamation, Division of Atmospheric Water Resources Management, Denver, Colorado. 397 pp.

Ridd, K. 1978. Vegetation of the Uinta Mountains above 7,000 feet (a map). Department of Geography, University of Utah, Salt Lake City.

Setzer, T. S. and T. S. Thorssell. 1977. Utah timber production and mill residues, 1974. USDA Forest Service, Research Note INT-234. 5 pp.

Steinhoff, H. W. and J. D. Ives. 1976. Ecological impacts of snowpack augmentation in the San Juan Mountains, Colorado. Final report of the San Juan Ecology Project to the U.S. Bureau of Reclamation, Division of Atmospheric Water Resources Management, Denver, Colorado, 489 pp.

Wasatch National Forest. 1976. Environmental statement, North Slope land use plan. USDA Forest Service, Intermountain Region, Ogden, Utah. 161 pp.

Welsh, S. L. 1978. Endangered and threatened plants: reevaluation. Great Basin Naturalist 38:1-18.

Wilson, D. W. 1971. Carrying capacity of the key browse species for moose on the north slope of the Uinta Mountains, Utah. Masters thesis, Utah State University, Logan. 57 pp.

CHAPTER 2

INTERRELATIONSHIPS AMONG PRECIPITATION, VEGETATION AND STREAMFLOW IN THE UINTA MOUNTAINS, UTAH

by

K. T. Harper

R. A. Woodward

and

K. B. McKnight

ABSTRACT

Only a small area on the headwaters of the Weber and Provo Rivers received over 102 cm (40 in) of precipitation during the 1973-78 period. Longer term records confirm that conclusion for the entire Uinta Mountains. Throughout the range, most (> 75%) of the water-year precipitation comes during the October-June period. Winter precipitation is far more reliable than summer precipitation. The north and west sides of the range receive 16-18% more precipitation than the south and east sides. On the average, precipitation shows an increase of about 7.6 cm per 305 m (3.0 in/1000 ft.) increase in elevation in the Uintas.

Surface runoff water is almost wholly attributable to cool season (October-June) precipitation. Although April 1 snowpack accounts for less than half of the cool season precipitation, that snowpack accounts for over 96% of the year-to-year variation in streamflow. Our runoff model predicts that a 10% increase in the average April 1st snowpack will elevate streamflows 13% above average.

Multiple regression analysis shows that streamflow can be expected to decrease 4.8% if all the deciduous forests on the west end of the Uintas are permitted to be displaced by coniferous forests through natural succession. Removal of forest cover and replacement with herbaceous vegetation should increase streamflow significantly. For maximum increases in streamflow, weather modification must be accompanied by vegetation management programs that preserve deciduous forests at the expense of conifers and herblands at the expense of forests.

INTRODUCTION

The Uinta Mountains are a major watershed giving rise to four of Utah's major rivers: the Bear, Duchesne, Provo, and the Weber. About 1.8 Km^3 (1.6 x 10^6 acre feet) of surface runoff water originate annually on the range (Wasatch National Forest 1976 and Jeppson et al. 1968). About 68% of that water feeds into the Green River, a major tributary of the Colorado (Jeppson et al. 1968). The Uintas are thus a major source of water for the Upper Colorado Drainage Basin as well as for the Great Basin portion of Utah.

In 1978, the Soil Conservation Service (SCS) maintained 48 precipitation storage gages in the Uinta Mountains (Whaley and Lytton 1979a). Forty-four of those gages provide total annual precipitation data for the period 1973-78. Twenty-seven of the 44 stations were read on April 1, July 1 and October 1 during the period 1973-78. This combination of stations forms the basis for the following discussion of annual precipitation and the seasonal components thereof in the Uinta Moutains.

In addition to the foregoing precipitation gages, the SCS also maintains 47 snow courses in the Uintas in cooperation with the U.S. Forest Service and the Utah Division of Water Resources (Whaley and Lytton 1979b). Thirty-seven of those courses were read annually on April 1 for the period 1973-79. We here summarize characteristics of the April 1 snowpack of the Uintas for the 1973-79 period based upon those 37 courses.

ANNUAL PRECIPITATION

Although the isohyetal map of Jeppson et al. (1968) shows five separate areas along the crest of the Uintas to receive over 101.6 cm (40 in) of precipitation annually, the SCS precipitation gages show only two stations to receive an average of over 40 inches. Lightening Lake at 3,338 m (10,950 ft) elevation on the headwaters of Rock Creek (tributary to the Duchesne River) receives the largest known annual precipitation in the Uintas with an average of 104.9 cm (41.3 in). The other station with over 102 cm precipitation per year is at 3,020 m (9,900 ft) on Shingle Mill Flat at the headwaters of the Weber river: this station averaged 104.2 cm (41.0 in) for the last ten years, but only 99.7 cm (39.2 in) in the period 1973-78. Trial Lake on the upper reaches of Provo River lies at 2,989 m (9,800 ft) and is midway between Lightening Lake and Shingle Mill Flats: that station averaged 98.8 cm (38.9 in) in the period of concern. Lakefork Basin (at 11,100 ft. or 3,386 m) averaged 88.9 cm (35.0 in) during the same period: this station is slightly east of Lightening Lake and on the headwaters of Lakefork Creek. During this period, two other stations on the upper part of the Weber River watershed received over 95 cm (37 in): Redden Mine at 2,745 m (9,000 ft) and Chalk Creek No. 1 station at 2,776 m (9,100 ft).

The storage gages thus suggest that only the northwest quarter of the Uintas and the highlands just beyond that area to the southeast and on the headwaters of the Duchesne River received over 102 cm annual precipitation in the period 1973-78. Only two other stations outside this area of the Uintas received over 84 cm (33 in) of precipitation per year over the period 1973-78. Those exceptions were the Highline Trail station at 3,200 m (10,500 ft) and the Ashley-Twin Lakes station at 3,200 m (10,500 ft), both near the headwaters of Ashley Creek north of Vernal. Although annual precipitation in the Uintas averages 2.5 - 7.5 cm less per year during the period 1973-78 than duing the decade immediately preceding, the data nevertheless suggest that Jeppson et al. (1968) may have overestimated precipitation at high elevations in the Uintas.

The storage gage data also suggest that maximum annual precipitation is not dropped at the highest elevations in the Uintas. Although there are 16 precipitation storage gage stations above 3,048 m (10,000 ft) in the range, only three of them have a longterm average of over 89 cm (35 in) of precipitation per year. In contrast, seven stations at elevations below 3,048 m (10,000 ft.) have a longterm average of over 88.9 cm (35 in) of precipitation.

ELEVATION AND PRECIPITATION

In order to relate precipitation to elevation, we have regressed average annual precipitation at 44 stations for the period 1973-78 against elevation. The predictive equation for the linear regression is as follows:

$$Y = 1.0 + .025 X$$

Where Y is annual precipitation in cm and X is elevation in m. The model predicts the following precipitation values for specific elevations.

Elevation (m)	Annual Precipitation (cm)
2,134 (7,000 ft)	54.4 (21.4 in)
2,438 (8,000 ft)	62.0 (24.4 in)
2,743 (9,000 ft)	69.6 (27.4 in)
3,048 (10,000 ft)	77.2 (30.4 in)
3,353 (11,000 ft)	84.8 (33.4 in)

Precipitation thus increases 7.6 cm per 305 m rise in elevation (3 in/1000 ft). It should be noted that this model shows wide dispersion around the regression line (r = .521). The regression is none-the-less statistically significant at the .01 probability level.

The average relationship of water content in the April 1 snowpack at various elevations is given in Table 2-1 and Figure 2-1. The data demonstrate great variation from snow course-to-snow course in any given altitudinal class (e.g., the snow course supporting the lightest average snowpack on April 1 in the 2,438 - 2,743 m elevation class received only about 12% as much snow as the course with the heaviest average snowpack in that elevational zone). Nevertheless, when all snow courses within a zone are averaged, there is a general trend toward increasing snowpack with elevation (Figure 2-1). Although Figure 2-1 shows a sizeable decline in snowpack at the highest elevation category, the sample consists of only one snow course. When other snowcourses and years are added to the analysis, the marked decline at the highest elevations is largely eliminated. As might be expected, year-to-year variation in average snowpack tends to be random among elevation classes. Year-to-year variation apparently reflects broad synoptic patterns and is thus quite uniform across the elevational gradient.

Table 2-1. Average characteristics of the snowpack at 37 snowcourses in the Uinta Mountains on April 1, 1973-79. All data are from Whaley and Lytton 1979b.

	Elevation Zone (m)				
Characteristic	2,134-2,438	2,438-2,743	2,743-3,048	3,048-3,353	>3,353
No. Snow courses	11	9	11	5	1
Average Elevation/snow course (m)	2,377	2,593	2,864	3,158	3,444
Ave. April 1 Water Content (cm)	24.3	24.2	31.3	35.3	31.0
Ave. Maximum April 1 water content (cm)[1]	37.3	45.2	57.9	43.9	---
Ave. Minimum April 1 water content (cm)[1]	12.2	5.6	14.7	25.9	---
Ave. April 1 snow density (cm snow/cm water)	3.10	3.24	3.34	3.49	3.75
Ave. temporal coefficient of variation for water content (%)[2]	30.5	41.5	29.7	36.7	32.8
Ave. spatial coefficient of variation for water content (%)[3]	36.9	61.2	45.7	20.8	---

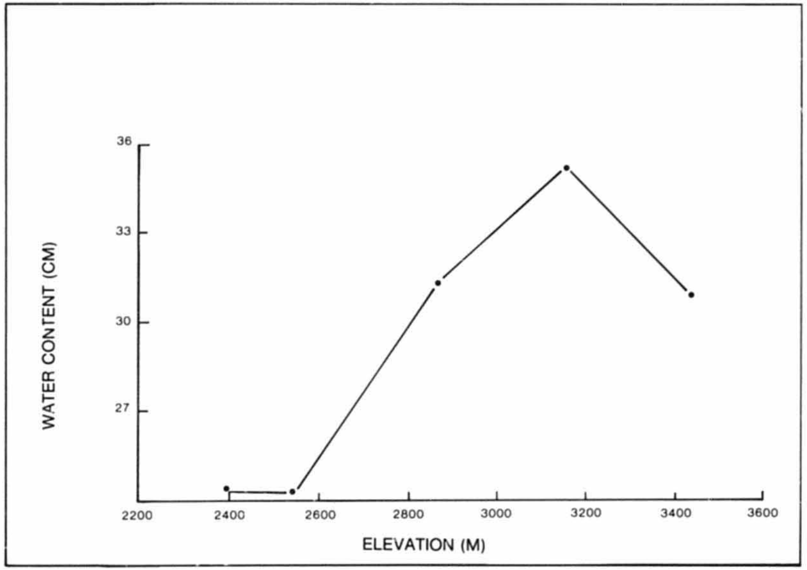
---

[1] Both maximum and minimum April 1 water content values represent the long term average for the snow course having the most or the least snow on the average in each elevation category.

[2] Coefficient of variation is the standard deviation divided by the mean and expressed as a percent. C.V. values were computed for each snow course over years and those values were average by elevation zone. These values thus quantify the average year-to-year variation in water content of the snowpack at individual snow courses.

[3] C.V. values are based on the long-term means and their standard deviations for all courses in an altitudinal class. These values quantity the variation among sites within an altitude class.

Figure 2-1. Water content at selected snow courses in the Uinta Mountains on April 1 averaged by elevation zones. Basic data for this figure are taken from Table 1. As noted in Table 2-1, the sample at 3,444 m consisted on only one snowcourse.



SPATIAL AND TEMPORAL DISTRIBUTION OF PRECIPITATION

It has seemed useful to us to determine how precipitation varies in time and space in the study area. We consider first how precipitation varies in space in the Uinta Mountains. It has long been accepted that the major part of the winter storms that strike northern Utah come from a northwesterly direction as moist air masses from the north Pacific Ocean are driven inlands by the prevailing westerly winds (Eubank 1979). Since the long axis of the Uintas is oriented east and west, we wondered whether the northwestern portion of the range received more precipitation than the south slope which should experience a "rainshadow" effect, if the postulated weather patterns noted above did indeed prevail. By the same logic, one might expect the eastern end of the range to receive less precipitation than the western end.

In order to evaluate the foregoing hypotheses, we grouped SCS precipitation storage gages by their location on the range (i.e., north or south slope; east or west end of the range). The breakdown of stations is shown in Table 2-2. The north-south breakdown was made along the watershed divide running east and west with the Provo and Weber drainages being tallied as part of the north slope. The east-west break was made along a line running north and south at longitude 110°24'30". This line ran just to the west of the Henry's Fork Station and just to the east of the Lakefork Mountain Station (Figure 2-2).

In order to generalize the results of our analyses, separate linear regression analyses relating elevation to precipitation were made for all north slope, south slope, west end and east end stations. The results are shown graphically in Figure 2-3. Sample size for each

Table 2-2. Precipitation storage stations arranged by location in the Uinta Mountains. Number of stations in each portion of the range is shown as are the total number of years of data available for each group of stations. Since some stations were serviced only once a year, sample size varies for total annual and summer (July-September) precipitation. Sample size is shown separately for annual and summer precipitation. All stations used have six or more years of data.

Sample Size By Area And Season

Location in Uintas (Quarter)	No. Stations[1] Annual	Summer	% of Stations > 3,000 m
Northeast	5	4	60.0
Southeast	11	5	54.5
Northwest	18	12	16.7
Southwest	10	6	60.0

[1] Stations used by quarter of the study area listed below:

Northeast

- Burnt Co.
- Henry's Fork
- Hickerson Park
- Highline Trail
- Spirit Lake

Southeast

- Ashley-Twin Lakes
- Atwood Basin
- Chipeta-Whiterocks
- Elkhorn-Ashley G.S.
- Grizzly Ridge
- Kidney Lake
- Kings Cabin
- Mosby Mt.
- Paradise Park
- Reynolds Park
- Windy Park

Northwest

- Blacks Fork Jct.
- Buck Pasture
- Burt Miller Ranch
- Chalk Cr. No. 1
- E. Fork Blacks Fork
- Gold Hill
- Hayden Fork
- Hewinta G.S.
- Lake Cr.
- Lily Lake
- Redden Mine
- Sergeant Lake
- Shingle Mill Flat
- Smith-Morehouse
- Soapstone G.S.
- Steel Cr. Park
- Stillwater Camp
- Trial Lake

Southwest

- Currant Cr.
- Daniels-Strawberry Sum.
- Five Pt. Lake
- LakeFort Basin
- LakeFork Mt.
- Lightening Lake
- Moon Lake
- Rock Cr.
- Shadow Lake
- W. Fork Duchesne

Figure 2-2. Locations of some important snow courses and precipitation storage gages used for this report. The solid vertical line and the broken watershed boundaries were used to separate the courses and gages into four geographic units as listed in Table 2-2. The figure is modified from Whaley and Lytton (1979a, b).

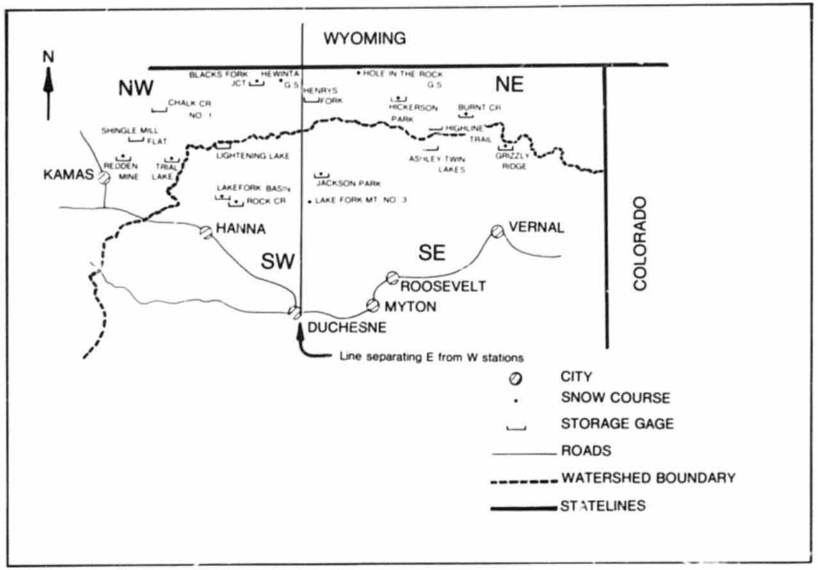
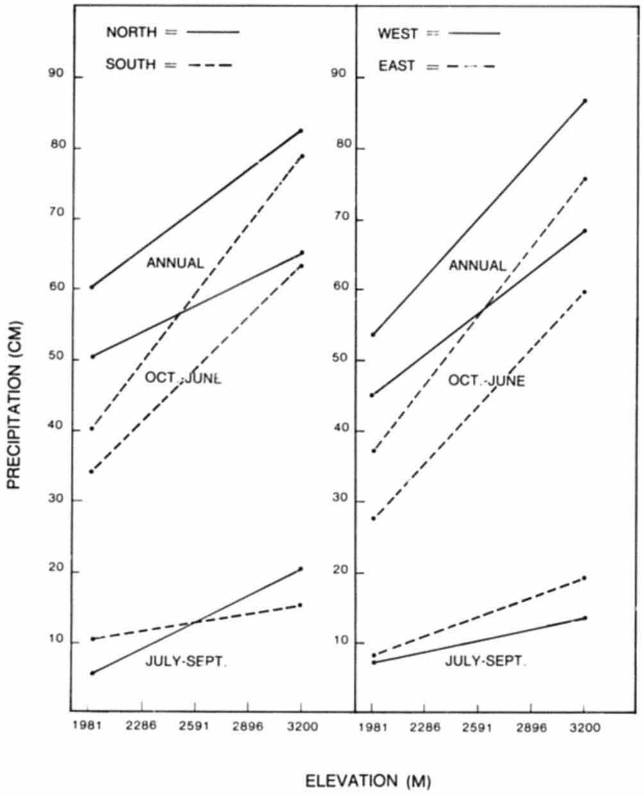


Figure 2-3. Annual, October-June, and July-September precipitation regressed on elevation for north versus south and west versus east portions of the Uintas. Models based on simple, linear regression analyses.



regression analysis can be obtained from Table 2-2. The data for total and cool season (October - June) precipitation support our hypotheses (i.e., the north slope does receive more precipitation than the south and the west end of the range receives more precipitation than the east end). At mid-elevations (2745 m), the models predict that the north slope will receive 16.8% more annual precipitation than the south slope. Similarly, at that elevation, the west end of the range should receive 18.2% more moisture than the east end. At 2746 m, October June precipitation is predicted to be 24.4% higher on the north than the south slope, and 27.9% higher on the west than the east end of the range.

The tendency for the northwest corner of the range to receive larger amounts of precipitation than the rest of the Uintas is also observable in the April 1 snowpack. Using the average values for April 1 snowpacks on 24 snow courses on the west end of the Uintas (Whaley and Lytton 1979b), we have computed the average relationships of snowpack to elevation with a least squares regression model. The deviations of individual snow courses from the regression line are summarized in both absolute and relative terms in Table 2-3. The relativized data are graphically reported in Figure 2-4. The isolines in that figure group snow courses that show similar departues from the regression line based on average tendencies for all snow courses. Figure 2-4 demonstrates that large portions of the watersheds of the Provo and the Weber Rivers receive over 150% as much snow as was predicted by the generalized regression model. April 1 snowpack progressively declines in all directions as one moves away from the Provo and Weber drainages. The decline is especially rapid as the crest of the range is crossed on the headwaters of Rock Creek on the south slope (Figure 2-4).

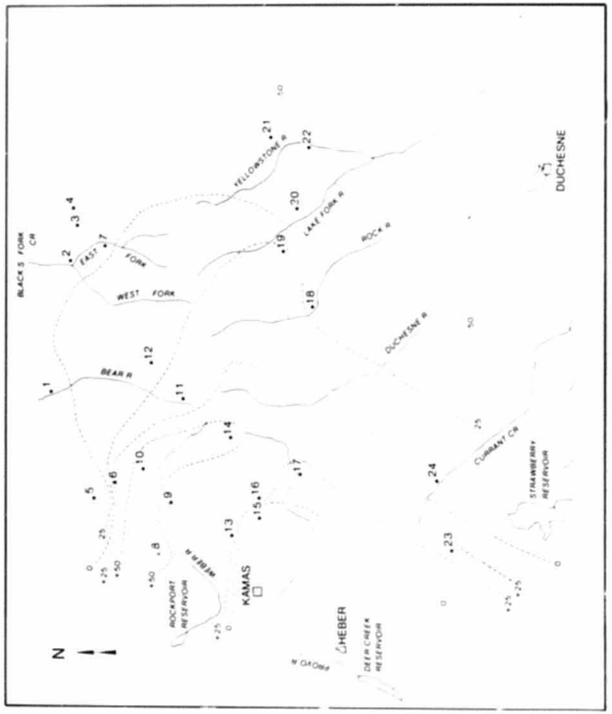
Table 2-3. Location, elevation, average water content of the snowpack on April 1, 1973-79, for each of 24 snow courses on the west end of the Uinta Mountains. Asterisked courses were also used to construct Table 6.

Snow Course Name	Snow Course No.	River Basin	Elevation (m)	Average April 1 Water Cont. (cm)	Deviation from Expected (cm)	% Deviation from Expected
Burt Miller Ranch*	1	Upper Bear	2,408	14.7	-12.4	-45.7
Black's Fork Junction	2	Upper Green	2,722	23.4	- 8.5	-26.6
Steel Creek Park	3	Upper Green	3,018	3[illegible].6	3.4	9.3
Hewinta Guard Station	4	Upper Green	2,896	23.9	-10.5	-30.6
Chalk Creek #3*	5	Weber	2,286	18.5	- 6.8	-26.8
Chalk Creek #2*	6	Weber	2,408	37.3	10.2	37.5
Black's Fork G. S.	7	Upper Green	2,835	23.1	-10.4	-31.0
Sergeant Lake	8	Weber	2,560	45.2	15.8	53.7
Smith-Morehouse*	9	Weber	2,316	31.5	5.7	22.2
Chalk Creek #1	10	Weber	2,774	52.6	20.0	61.3
Hayden Fork*	11	Upper Bear	2,865	39.4	5.4	15.9

Table 2-3. Continued

Snow Course Name	Snow Course No.	River Basin	Elevation (m)	Average April 1 Water Cont. (cm)	Deviation from Expected (cm)	% Deviation from Expected
Stillwater Camp*	12	Upper Bear	2,606	26.2	- 3.9	-13.1
Redden Mine*	13	Weber	2,591	43.4	13.6	45.4
Trial Lake*	14	Provo	2,987	57.9	22.1	61.8
Beaver Creek Ranger Sta.*	15	Provo	2,286	19.1	- 6.3	-24.8
Beaver Creek Divide*	16	Provo	2,438	30.2	2.6	9.6
Soapstone Ranger Station*	17	Provo	2,377	28.4	1.8	6.6
Rock Creek Ranch*	18	Duchesne	2,408	15.7	-11.4	-42.0
Brown Duck Ridge*	19	Duchesne	3,292	43.9	3.6	8.9
Lakefork Mt. #1*	20	Duchesne	3,109	25.9	-11.7	-31.1
Jackson Park*	21	Duchesne	3,444	31.0	-11.6	-27.3
Lakefork Mt. #3*	22	Duchesne	2,469	11.7	-16.4	-58.3
Daniels-Strawberry Summit	23	Duchesne	2,438	36.8	9.2	33.5
Currant Creek*	24	Duchesne	2,377	23.1	- 3.6	-13.4

Figure 2-4. Isolines for percent deviations from expected values for water content of the average April 1 snowpacks at snow courses on the west end of the Uinta Mountains. Snow courses are represented by numbers with the numbers being keyed to snow course names in Table 2-3. Average water content of the 24 snow courses on April 1 was regressed against elevation to give a generalized model of expected snowpack at any given elevation. The actual April 1, 1973-78 water content at each snow course is stated as a percentage of that predicted by the regression model (Table 2-3).



Summer precipitation (July - September) has a strong tendency to reverse the pattern described in the two preceding paragraphs for annual and cool season precipitation (Figure 23). Summer moisture on the south and east sides of the Uinta Mountains either exceeds or equals rainfall on the north and west sides. This pattern is apparently related to a prevalence of summer storms approaching the range from the southeast. As moist air masses from the Gulf of Mexico sweep inland, around the southern end of the Rocky Mountains of New Mexico, and onto the upper Colorado Plateau, they drop their moisture as they rise over the Uintas which block their movement northward (see average monthly precipitation graphs for southeastern Utah in Jeppson et al. 1968).

In relative terms, a larger portion of the average annual precipitation comes as rain in the July through September period on the south as opposed to the north slope of the Uintas (23.6 versus 19.2% respectively at mid-elevations, 2,746 m). These results are derived from the regression equations used to draw Figure 2-3. Using a similar procedure, we find that on the average, 25.8% of the annual precipitation at 2,746 m falls in the July through September period on the east end of the range, but only 18.9% of the total falls in that period on the west end of the Uintas.

Cool season precipitation is far more dependable from year-to-year at any given station than is July-September precipitation. We have analyzed year-to-year variation in cool and warm season precipitation at 18 storage gage stations on the West end of the Uintas for the six year period 1973-78. Average coefficient of variation for cool season precipitation at the 18 stations was 24.8%, but the comparable figure for July-September precipitation for the same stations and years was 55.4%.

We have also analyzed the storage gage and snow course data to determine if precipitation is better correlated with elevation at some locations and in some seasons than at other locations or seasons. The results (Table 2-4) demonstrate that annual precipitation is better correlated with elevation than either of its components (i.e., October - June and July-September precipitation). The data also show that precipitation is far better correlated with elevation on east and south slopes of the Uintas than on west and north slopes. Coefficient of variation values for snow courses (Table 2-1) within elevational zones show that the April snowpack tends to be somewhat more predictable in space as one moves from low to high elevation.

SNOWPACK AND RUNOFF

There is intense interest in cloudseeding to augment winter snowpacks in mountains of western United States, but before the value of weather modification for augmentation of streamflow can be fairly evaluated, the degree to which annual precipitation and its seasonal components are correlated with water yield must be known. In order to evaluate those relationships in the Uinta Mountains, we have intensively studied nine large watersheds on the west end of the range. Those watersheds and their salient characteristics are listed in Table 2-5. Areal extent and vegetative cover of each watershed was determined from a map developed by Kirk Ridd from Landsat imagery. The map is included in a report submitted to the U.S. Bureau of Reclamation and the Utah Division of Water Resources (Harper et al. 1979). Average elevation per watershed was obtained by superimposing elevational contour lines on all watersheds and determining the proportion of total watershed area

Table 2-4. Correlation coefficients relating precipitation in various seasons to elevation in four different portions of the Uinta Mountains. All r-values are positive. Significance level of each r-value is shown (NS=not significant, *=.05 level, **=.01 level). See Table 2-2 for sample size in the various analyses. Data arranged according to decreasing size of the correlation coefficients for total annual precipitation.

		Season	
Location of Stations	Total Annual	October-June	July-September
East End	.799**	.904**	.612 NS
South Slope	.782**	.653**	.522 NS
West End	.525**	.329 NS	.479 *
North Slope	.318 NS	.212 NS	.615*
Average All Stations	.521**	.409*	.541**

between contour lines separated by 305 vertical meters. Finally, the decimal fraction of area in each contour interval was multiplied by the elevational midpoint of the interval and those products were summed across all intervals. Runoff data are from U.S. Geological Survey (1973-78) records.

In combination, these nine watersheds yield 119,484 hectare meters (968,640 acre feet) of runoff water in the average year. This amounts to slightly over 60% of the total annual runoff produced by the Uinta Mountains in the average year (Harper 1978). Average runoff per watershed was 30.6 cm (12.0 in) per year of concern. Lakefork, the most productive watershed, produced 42.9 cm (16.9 in) on a yield per unit area basis, while the least productive watershed, Red Creek, yielded only 4.8 cm (1.9 in) of water per year. Not unexpectedly, Red Creek has the lowest and Lakefork the highest average elevation of the nine watersheds considered (Table 2-5). Nevertheless, the regression of runoff on elevation for these watersheds shows that elevation accounts for only about 53% of the variations in runoff (r = .728). The regional variation in snowpack across these areas (Figure 2-4) strongly tempers the effects of elevation as will be demonstrated in greater detail at a later point in this report.

The watersheds employed in this analysis are more productive of runoff water than the average National Forest watershed in Utah (Croft and Bailey, 1964, give 9.0 in as the average water yield) and about as productive as the average subalpine watershed in Colorado (Leaf 1975, 12-15 in). When the total area above 2,134 m (7,000 ft) is considered, the entire Uinta Range yields only about 14.5 cm (5.7 in) of runoff water per year.

Table 2-5. Area, average elevation, and average annual runoff for the water years (October 1 - September 30) 1973-78 for nine major watersheds of the western Uinta Mountains.

Watershed	Area (km^2)	Average Elevation (m)	Average Annual Runoff (Hectare meters)	Average Runoff/Unit Area (cm)
Yellowstone River	317.4	3,245	11,090	34.9
Lakefork Creek	207.4	3,297	8,897	42.9
Rock Creek	647.2	2,831	13,770	21.3
Duchesne River	896.1	2,637	15,681	17.5
Red Creek	813.2	2,405	3,933	4.8
Provo River	423.2	2,753	17,830	42.1
Weber River	431.5	2,844	18,143	42.0
Bear River	464.7	2,981	15,763	33.9
Black's Fork Creek	398.3	3,128	14,385	36.1

Annual runoff for the water years 1973-78 for the nine watersheds listed in Table 2-5 (streamflow summed across all watersheds) is given in Table 2-6. In that Table, we also listed average annual precipitation across those watersheds as well as various seasonal components of annual precipitation. The results of simple regression analyses reported in Table 2-7 show the effects of various components of annual precipitation on runoff. All regressions are based on the logarithms (base 10) of both independent and dependent variables. The results show that cool season precipitation accounts for more of the variation in annual runoff (coefficients of determination or $r^2 = .969$ to $.931$) than total annual precipitation ($r^2 = .790$). Warm season (July - September) precipitation exerts almost no impact on total annual runoff ($r^2 = .059$).

The most cost-effective precipitation parameter for predicting runoff is April 1 snowpack, since that measure requires but one trip into the survey area while others require at least two and the use of storage gages. Since vandals often disturb storage gages but are far less likely to disrupt snow courses, snowpack data are also likely to be more complete from year-to-year than storage gage records. The relationship between April 1 snowpack and runoff from our nine watersheds is graphed in Figure 2-5. The regression equation given in Figure 2-5 shows that a 10% increase in average snowpack on April 1 could be expected to yield a 13% increase in streamflow. A 20% increase in snowpack should generate a 26.6% increase in runoff.

We note in passing that addition of warm season precipitation to April 1 snowpack water content in a multiple regression analysis reduces the amount of variation in annual runoff that can be accounted for using

Table 2-6. Annual precipitation (total and seasonal components given for each year) and combined runoff from nine watersheds. Precipitation data represent average values for 19 snow courses and 18 storage gages scattered across the nine watersheds. The snow courses used are asterisked in Table 2-3. The storage gages used are listed at the base of this Table.

		Precipitation			
Year	Runoff ($M^3 x 10^9$)	Total Annual (cm)	October-June (cm)	July-September (cm)	Water Content of April 1 Snowpack (cm)
1973	1.3598	86.4	64.6	21.8	26.5
1974	1.3283	65.5	60.2	5.4	27.8
1975	1.6005	83.0	72.9	10.1	32.5
1976	1.0555	61.6	54.0	7.6	26.0
1977	.5601	50.4	34.5	15.9	15.0
1978	1.2653	74.0	66.5	7.5	30.8
Average	1.1949	70.2	58.8	11.4	26.4

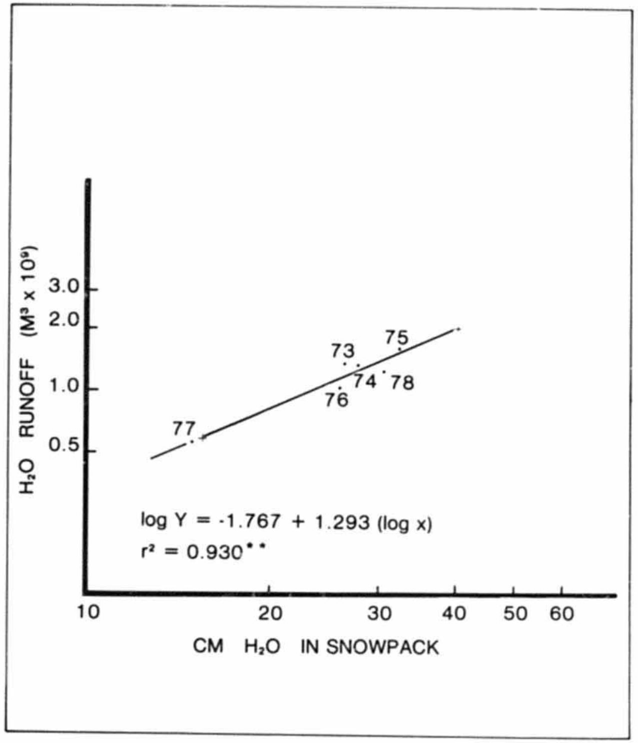
Storage gage stations used were: Black's Fork Jct, Buck Pasture, Burt Miller Ranch, Currant Creek, Daniels-Strawberry Summit, East Fork Blacks Fork Guard Station, Hayden Fork, Hewinta Guard Station, Lake Creek, Lakefork Mt., Moon Lake, Redden Mine, Rock Creek, Smith-Morehouse, Soapstone Guard Station, Stillwater Camp, Trial Lake, and West Fork Duchesne River.

Table 2-7. Results of power regression (logarithm of precipitation in cm versus logarithm of runoff in billions of cubic meters) analyses of the affects of various components of annual precipitation on combined annual runoff from nine watersheds on the west end of the Uinta Mountains (see Table 2-5 for watersheds considered). Basic data for analyses appear in Table 2-6. All correlation coefficients are positive.

Independent Variables	Correlation Coefficients (r)
October-June Precipitation	.985**
October-June Precipitation minus April 1 Snowpack Water Content	.974**
April 1 Snowpack (Water Content)	.965**
Total Annual Precipitation	889**
July-September Precipitation	.243 NS

** - Statistically significant at .01 level
NS - Not significant

Figure 2-5. The relationship between average April 1 snowpack across the nine watersheds listed in Table 2-5 and water-year runoff. The data span water-years 1973-78.



snowpack alone (r^2s of .953 and .965 respectively). This analysis reinforces our earlier conclusion that warm season precipitation has little effect on streamflow, although it does tend to increase forage production (see Chapter 6 of this report for further information on forage production and summer rainfall in the Uintas). Jeppson et al. (1968) have arrived at a similar conclusion for other Utah watersheds. They feel that summer precipitation contributes little to streamflow and should not be included in predictive equations for runoff. They conclude further that "October-April precipitation is as good an index to annual water yield as calender year precipitation, and on some watersheds is a better index." Leaf (1975) draws a similar conclusion for the subalpine watersheds of Colorado.

STREAMFLOW AND VEGETATION

It is generally considered that removal of deep rooted woody plants from watersheds will increase streamflow (Croft and Bailey 1964, Hibbert 1979). Scientific support is less general for the contention that evergreen coniferous trees utilize more water during the annual cycle than deciduous trees and thus reduce streamflow more than deciduous trees, but support does seem to be growing for that contention (Dunford and Niederhof 1944, Swank and Douglas 1974, Verry 1976, Urie 1977, and Jaynes 1978). Since the amounts of herbaceous, deciduous forest, and evergreen coniferous forest varied widely on the nine watersheds that we have intensively studied on the west end of the Uinta Mountains, we have developed a multiple regression model for evaluating the impact of vegetational variables and April 1 snowpack (adjusted for average elevation of the watersheds) on annual water year runoff from each of the nine watersheds. The analysis covers the seven year period 1973-79.

Vegetative cover of each watershed was obtained from maps drawn from Landsat Imagery. Vegetative parameters are given for each watershed in Table 2-8. Annual runoff and April 1 snowpack by watershed are given in Table 2-9. The multiple regression equation for the influence of snowpack and various vegetative (or bare soil or rock) parameters on streamflow appears in Table 2-10. The overall regression analysis is significant at the .01 level of probability and all five independent variables make a statistically significant contribution to the analysis. The model accounts for over 80% of the year-to-year variation in runoff. The most potent predictor of runoff is, as expected, water content of the April 1 snowpack adjusted to mean elevation for each watershed. The coefficients for the other independent variables decrease in magnitude (i.e., contribute less per unit cover to runoff) in the following order: herbaceous > deciduous > barren area > coniferous cover. The order for vegetative variables is as predicted by Jaynes (1978), but reason suggests that barren areas should yield more runoff than any vegetated area. Failure of barren areas to conform to expectations may be attributable to two factors: 1) snow is moved about by wind on the barren areas and snow from one drainage frequently comes to rest in a different drainage than it fell on, and 2) the barren areas consist in part of deep talus accumulations that facilitate deep percolation of melt water from snow. Snow blowing from drain-to-drainage confuses relationships in regression analyses and melt waters that percolate deeply may rise to the surface below stream gaging stations or in a different drainage than they originated in. Both factors probably operate in the study area and

---

Table 2-8. Percent of barren land, conifer, deciduous, and herbaceous cover on nine watersheds in the Uinta Mountains. Other characteristics of these watersheds are given in Table 2-5.

Drainage	% Barren Land	% Conifer	% Deciduous	% Herbaceous
Bear River	7.1	42.3	35.8	13.7
Blacks Fork Creek	10.3	46.6	12.5	0.7
Duchesne River	1.3	21.2	37.0	10.2
Lake Fork Creek	23.5	47.9	1.2	27.4
Provo River	1.0	31.6	49.9	16.4
Red Creek	0.1	1.3	58.6	0.2
Rock Creek	4.9	36.1	16.5	17.1
Weber River	1.0	37.4	52.7	8.9
Yellowstone River	24.1	52.2	3.6	19.3
Average	8.5	35.1	29.1	15.9

Table 2-9. April 1 snowpack values (cm of water adjusted to average elevation of each watershed) and annual runoff (hectare meters/km^2) for nine watersheds in the Uinta Mountains.

Drainage	1973		1974		1975		1976		1977		1978		1979	
	Snowpack	Runoff	Snowpack	Runoff	Snowpack	Runoff	Snowpack	Runoff	Snowpack	Runoff	Snowpack	Runoff	Snowpack	Runoff*
Bear River	20.7	36.9	35.3	41.9	45.2	45.5	35.8	27.6	21.1	15.7	35.6	36.0	-	-
Blacks Fork Cr.	26.7	36.9	32.0	42.3	24.6	48.4	29.2	32.8	21.8	18.6	40.1	37.8	-	-
Duchesne R.	29.7	20.0	25.1	20.4	36.8	24.3	29.0	15.1	14.2	7.8	31.2	17.4	-	-
Lake Fork Cr.	38.9	52.0	32.5	39.4	40.6	58.4	34.3	37.0	15.2	26.0	49.3	44.6	37.6	36.4
Provo R.	40.9	46.1	46.5	50.1	55.4	54.6	44.2	38.4	20.1	15.1	53.8	48.5	-	-
Red Creek	26.2	6.7	13.5	4.9	30.2	6.0	23.6	4.5	2.5	2.3	31.8	4.6	37.1	4.7
Rock Creek	18.8	25.4	17.3	21.0	59.9	29.3	38.4	17.7	13.0	10.3	35.1	23.9	29.9	18.4
Weber R.	47.4	44.0	40.1	50.4	57.7	56.0	46.5	38.9	19.3	16.7	52.1	46.3	-	-
Yellowstone R.	32.5	47.4	18.5	30.2	44.5	46.3	33.0	32.6	14.5	21.4	39.1	31.8	37.6	29.4

* Some 1979 data were unavailable at the time the analysis was made.

Table 2-10. The multiple regression equation relating streamflow to the amounts (percentage coverage) of barren land, and conifer, deciduous, or herbaceous cover and the water content of the April 1 snowpack is given below. The order of entry of the independent variables into the analysis is also given as well as the contribution of each variable to the coefficient of multiple determination. The significance level of each variable is also given.

$$Y = -41.2141 + .5019(X1) + .5480(X2) + .5293(X3) + .8595(X4) + .5930\ (X5)$$

Independent Variable	Symbol for Variable	Contribution to R^2	Significance Level of contribution
Snowpack	X5	.460	.05
Conifer	X1	.273	.05
Deciduous	X2	.021	.05
Herbaceous	X4	.031	.05
Bare Rock	X3	.021	.05
Total R^2		.806	

---

contribute to the unexpectedly weak contribution of barren land to streamflow.

In Table 2-11, we show the results of manipulating various parameters of the multiple regression model (Table 2-10) while all other variables are held constant at the average value for those variable in this set of data. The results show that vegetative manipulation can have important impacts on streamflow. If both conifer and deciduous forest (aspen in our case) were reduced by an absolute value of 10% and herbaceous cover establish in their place, the model predicts that streamflow would increase about 22% (Part B of Table 2-11).

Since deciduous forest is generally successional to evergreen coniferous forest in our area, we have simulated the displacement of deciduous by coniferous forest by manipulating the regression model (Part A, Table 2-11). The results show that streamflow would decline about 4.8% if all deciduous forest were replaced by conifer in the study area. Considering that the model predicts that a 10% increase in April 1 snowpack would generate only 6.5% more streamflow (Part C, Table 2-11), it seems apparent that the forests of our area should be managed to favor deciduous cover, if the gains arising from weather modification are to produce much additional streamflow. If natural forest succession is permitted to proceed to climax, a 10% increase in snowpack due to cloud seeding would yield only 1.7% increase in runoff rather than the potential 6.5%

Considerable evidence exists to demonstrate that vegetational changes have greatly modified streamflow in the West in this century. For the period 1896-1921, annual flow of the Colorado River at Lee's Ferry averaged $20.67 \times 10^9\ m^3$ (16,756,000 acre feet). In contrast,

Table 2-11. The effects of changing the proportions of conifer, deciduous, and herbaceous cover or snowpack on stream runoff as predicted by the multiple regression model given in Table 2-10. All changes in runoff are based on average snowpack and average runoff per unit area for all watersheds and dates and current average vegetation parameters for the 9 watersheds. In Part A of the table, conifer and deciduous cover are mathematically manipulated together. In Part B, herbaceous cover is increased at the expense of conifer and deciduous cover. Park C shows the effect of increased snowpack on stream runoff if the vegetative cover is maintained at its present level.

Part A

% Cover		Change in runoff	
Conifer	Deciduous	(ha m/km^2)	(%)
0	64	1.505	5.1
16	48	.769	2.6
32	32	.033	.1
48	16	-.703	-2.4
64	0	-1.439	-4.9

Part B

% Cover			Change in runoff	
Herbaceous	Conifer	Deciduous	(ha m/km^2)	(%)
16	35	29	0	-
36	25	19	6.681	22.5
56	15	9	13.381	44.1
80	0	0	21.559	71.6

Part C

% Increase in April First Snowpack	Change in Runoff	
	(ha m/km^2)	(%)
5	0.98	3.3
10	1.955	6.5
15	2.933	9.8
20	3.910	13.0

annual flow at that point for the period 1930-64 averaged only 16.15 x 10^9 m^3 (13,090,000 acre feet) (a decline in annual flow of about 22%). Although Hibbert (1979) is willing to attribute that decline to climatic change, a number of researchers have ruled out decreased precipitation as the only cause for the decrease in streamflow. Yevdjevich (1961) considered the decline to be due to man-made changes on the watersheds. Julian (1961) concluded that there had been a slight increase in annual temperature on the upper reaches of the Colorado during the period of record that could have increased evapotranspiration losses, but he also held that man-made changes were involved in reduced streamflow at Lee's Ferry. Christiansen (1967) reconsidered the issue and concluded that an increase in evapotranspiration due to improved plant cover on watersheds was most likely responsible for declining streamflow. He noted that overgrazing was widespread early in the century, but since that time rangelands of the upper reaches of the Colorado have been less heavily grazed and have acquired a progressively heavier plant cover. It should be added too that fire control in the forested areas of the region has improved dramatically in the period of concern.

Jeppson et al. (1968) have analyzed flow in 13 streams from throughout Utah (five in the Colorado River Basin and eight in the Great Basin) for the historic period (period variable depending upon records available for individual streams, but generally the second decade of the century through 1965). They conclude that "in practically all of these plots of running averages, a general downward trend appears superimposed upon the several fluctuations for the runoff, whereas the precipitation does not show the same decreasing trend throughout the period of record." Thus Jeppson et al. (1968) show that the same declining trends

in streamflow exist in Utah's Great Basin as have been noted for the Colorado River Basin, but those trends do not appear to be based on declining precipitation. There is abundant evidence that both grazing management and fire control have steadily improved in this century in Utah (Harper 1968).

There is impeccable data to support the conclusion that a heavy herbaceous cover reduces runoff and streamflow (Croft and Baily 1964). There is likewise good data to show that deciduous forest (primarily aspen) is favored by fire (Harper 1968). There is also evidence that deep rooted woody plants have increased at the expense of herbs on many Utah rangelands (Pederson and Harper 1978 and Cottam 1961). All of those trends should reduce streamflow. Thus an abundance of data support our contention that vegetation management must be used in conjunction with weather modification if maximum benefits are to be achieved.

It must be pointed out that the regression model given in Figure 2-5 predicts a greater increase in streamflow than the model given in Table 2-10. The difference apparently lies in the fact that the multiple regression model (Table 2-10) spreads the runoff response among five variables. Of the two regression models, the simple regression model of Figure 2-5 is undoubtedly the more robust and reliable.

LITERATURE CITED

Christiansen, J. E. 1967. Indications of changing relations between precipitation and streamflow with time. International Conference on Water for Peace, Conference Proceedings, 624 pp. Washington, D.C.

Cottam, W. P. 1961. Our renewable wildlands -- a challenge. University of Utah Press, Salt Lake City. 182 pp.

Croft, A. R. and R. W. Bailey. 1964. Mountain water. Special publication of the Intermountain Region, USDA Forest Service. 64 pp.

Dunford, E. G. and C. H. Niederhof. 1944. Infuence of aspen, young lodgepole pine, and open grassland types upon factors affecting water yield. J. of Forestry 42:673-677.

Harper, K. T. 1968. The ecological perspective, p. 25-43. In M. Treshow and C. M. Gilmour (eds). The future of Utah's Environment. University of Utah Center of Environmental Ecology, Salt Lake City.

Harper, K. T. 1978. The Uinta Ecology Study: biennial report. Report to U.S. Bureau of Reclamation, Office of Atmospheric Resources Management, Engineering and Research Center, Denver, and the Utah Division of Water Resources, Empire Bldg., 231 E. 400 S., Salt Lake City. 24 pp.

Harper, K. T., W. K. Ostler and D. C. Anderson. 1978. The Utah Ecology Project: Resources of the Uinta Mountains. Report to the U.S. Bureau of Reclamation, Office of Atmospheric Resources Management, Engineering and Research Center, Denver, and the Utah Division of Water Resources, Empire Bldg., 231 E. 400 S., Salt Lake City. 148 pp.

Harper, K. T., W. K. Ostler and K. B. McKnight. 1979. The Uinta Ecology Study, Interim Report. Report to the U.S. Bureau of Reclamation, Office of Atmospheric Resources Management, Engineering and Research Center, Denver, and the Utah Division of Water Resources, Empire Bldg., 231 E. 400 S., Salt Lake City. 76 pp.

Hibbert, A. R. 1979. Managing vegetation to increase flow in the Colorado River Basin. General Tech. Report RM-66. USDA Forest Service. 27 pp.

Jaynes, R. A. 1978. A hydrologic model of aspen-conifer succession in the western United States. USDA Forest Service Research Paper INT-213. 17 pp.

Jeppson, R. W., G. L. Ashcroft, A. L. Huber, G. V. Skogerboe, and J. M. Bagley. 1968. Hydrologic atlas of Utah. Publication No. PRWG 35-1 from the Utah Water Research Laboratory, Utah State University, Logan. 306 pp.

Julian, P. R. 1961. A study of the statistical predictability of stream-runoff in the Upper Colorado River Basin. High Altitude Observatory, University of Colorado, Boulder.

Leaf, C. F. 1975. Watershed management in the central and southern Rocky Mountains: a summary of the status of our knowledge by vegetation types. USDA Forest Service Research Paper RM-142. 28 pp.

Pederson, J. C. and K. T. Harper. 1978. Factors influencing productivity of two mule deer herds in Utah. J. Range Manage. 31:105-110.

Swank, W. T. and J. E. Douglass. 1974. Streamflow greatly reduced by converting deciduous hardwood stands to pine. Science 185:857-859.

Urie, D. H. 1977. Ground water differences on pine and hardwood forest of the Udell Experimental Forest in Michigan. USDA Forest Service Research Paper NC-145. 12 pp.

U.S. Geological Survey. 1973-1978. Water resources data for Utah. U.S. Geological Survey Water-Data Report UT-73-1-UT-78-1. Distributed from Rm. 8002, Federal Bldg., Salt Lake City.

Verry, E. S. 1976. Estimating water yield differences between hardwood and pine forest: an application of net precipitation data. USDA Forest Service Research Paper NC-128.

Wasatch National Forest. 1976. Environmental statement, North Slope land use plan. USDA Forest Service, Intermountain Region, Ogden, Utah. 161 pp.

Whaley, B. L. and L. K. Lytton. 1979a. Summary of mountain precipitation measurements for Utah, 1930-1978. Report distributed by Snow Survey Section, Soil Conservation Service, U.S. Dept. of Agriculture, Salt Lake City, Utah. 168 pp.

Whaley, B. L. and L. K. Lytton. 1979b. Summary of snow survey measurements for Utah, 1924-1979. Report distributed by Soil Conservation Service, U.S. Dept. of Agriculture, Salt Lake City, Utah. 321 pp.

Yevdjevich, V. M. 1961. Some general aspects of fluctuations of annual runoff in the Upper Colorado River Basin. Civil Engineering Department, Colorado State University, Fort Collins.

CHAPTER 3

PREDICTING SNOW MELT DATES IN THE UINTA MOUNTAINS

by

R. A. Woodward

P. D. Collins

and

K. T. Harper

ABSTRACT

Equations for predicting snow-free dates at specific sites are useful tools for land managers and users of natural resources. The equations developed here for the Uinta Mountains predict snow-free dates for a broad spectrum of sites to within a few days. April 1 water content of the snowpack, potential direct solar beam radiation on the site during the month of April, and the sum degree days above freezing in April and May are as the independent variables required for the equations. Degree days are obtained from valley weather stations. Thus only April 1 snowpack data need be collected annually at sites for which snow-free dates are to be predicted.

The models developed accurately predict local variations in snow-free dates on sites of different exposures in any given year or on a common site in different years. The models can also be used to predict snow-free dates on a given site when the average snowpack is increased by a specified amount. The models predict snow-free date more accurately on uniform terrain where size of the snowpack varies from place-to-place than on complex terrain where both exposure and snowpack vary among sites.

INTRODUCTION

The ability to predict the day of the year that a particular mountain site will become free from winter snow would be a useful capability for natural resource managers. Late lying snow either renders a big game range useless or seriously impairs its value (Regelin 1977, Haupt 1977). Livestock managers, loggers, and recreationists are also affected by late lying snow; their activities could be better planned if they knew when a mountain site would become snow-free. The effects of vegetational alteration and snowpack augmentation on late lying snow and water yield would also be more predictable if a simple but accurate snowmelt model were available (Troendle 1979, Harr and McCorison 1979, Gary 1979).

Attempts have been made in recent years to develop computer models that will successfully predict the date an area will become free of snow (Solomon et al. 1976, Leaf and Brink 1973). Data necessary to implement some of the proposed models are extensive and difficult to obtain. As a result, the models are often usable at only a few, local sites that are heavily instrumented. In this paper, we examine the effect of several easily quantified variables that significantly influence the date of snowpack disappearance in the Uinta Mountains of Utah. Emphasis is placed on data that do not require continuous monitoring and expensive instrumentation at the site. Snowmelt dates were obtained at numerous sites of variable slope and exposure at Elizabeth Ridge on the North Slope of the Uintas. Models have also been developed for predicting the 75 percent snow-free date on nonforested sites on Elizabeth Ridge.

Table 3-1: Permanent site characteristics of 26 snowmelt study sites on Elizabeth Ridge in the Uinta Mountains, Utah.

Site No.	Exposure (Degrees from N)	Elevation (m)	Slope (%)	Potential Solar Radiation in April (Langley/cm^2/day)
1	NORTH (6)	3,157	10	823
2	NORTH (1)	3,157	9	828
3	NORTH (7)	3,157	13	810
4	NORTH (1)	3,157	15	801
5	NORTH (1)	3,157	9	828
6	NORTH (355)	3,157	16	796
7	NORTH (1)	3,157	12	814
8	SOUTH (175)	3,117	21	912
9	SOUTH (175)	3,117	26	918
10	SOUTH (175)	3,117	26	918
11	SOUTH (175)	3,117	23	915
12	SOUTH (180)	3,117	17	906
13	SOUTH (180)	3,117	15	901
14	SOUTH (164)	3,117	13	897
15	EAST (40)	3,160	9	860
16	EAST (52)	3,160	8	860
17	EAST (46)	3,160	9	860
18	EAST (35)	3,160	7	861
19	EAST (35)	3,160	11	859
20	EAST (35)	3,160	8	860
21	EAST (40)	3,160	21	855
22	WEST (254)	3,166	10	859
23	WEST (254)	3,166	8	860
24	WEST (243)	3,166	11	859
25	WEST (243)	3,166	18	856
26	WEST (243)	3,166	17	857

Table 3-2. Annually variable characteristics of the 26 snowmelt study sites. Sum degree days data represent averages based on seven valley stations. Those stations are identified in the text. Other characteristics for these sites are given in Table 3-1.

Site	Snowpack Water Content on April 1 (cm)			Sum Degree Days for April			Sum Degree Days for May			Snow-Free Date		
No.	1977	1978	1979	1977	1978	1979	1977	1979	1979	1977	1978	1979
1	--	72.0	71.6	258.4	184.2	157.2	292.5	283.8	332.5	--	92	76
2	--	72.0	82.0	"	"	"	"	"	"	--	91	81
3	--	78.0	84.8	"	"	"	"	"	"	--	91	82
4	--	90.0	92.4	"	"	"	"	"	"	--	93	84
5	--	105.6	115.9	"	"	"	"	"	"	--	99	87
6	--	--	--	"	"	"	"	"	"	--	95	85
7	--	69.6	65.0	"	"	"	"	"	"	--	88	75
8	28.3	38.4	31.3	"	"	"	"	"	"	24	76	55
9	28.3	33.6	27.2	"	"	"	"	"	"	24	72	50
10	28.3	30.0	23.0	"	"	"	"	"	"	24	72	51
11	28.3	36.0	31.3	"	"	"	"	"	"	24	73	56
12	28.3	60.0	35.5	"	"	"	"	"	"	24	77	56
13	28.3	42.0	32.0	"	"	"	"	"	"	24	76	56
14	28.3	38.4	41.8	"	"	"	"	"	"	58	79	58
15	--	69.6	79.2	"	"	"	"	"	"	--	95	82
16	--	93.6	102.7	"	"	"	"	"	"	--	100	87
17	--	--	34.9	"	"	"	"	"	"	--	90	73
18	--	57.6	49.9	"	"	"	"	"	"	--	84	68
19	--	72.0	67.9	"	"	"	"	"	"	--	90	74
20	--	72.0	68.8	"	"	"	"	"	"	--	91	75
21	--	105.6	--	"	"	"	"	"	"	--	99	87
22	--	--	31.5	"	"	"	"	"	"	--	83	65
23	--	--	26.1	"	"	"	"	"	"	--	79	58
24	--	--	30.9	"	"	"	"	"	"	--	82	59
25	--	--	24.0	"	"	"	"	"	"	--	84	62
26	--	--	29.9	"	"	"	"	"	"	--	85	66

METHODS

Twenty-six sites were selected for intensive study. Seven sites were established on each of the following exposures: east, north and south. Five additional sites were placed on a west-facing slope. All sites were on Elizabeth Ridge, North Slope of the Uinta Mountains, at an average elevation of about 3,160 m (10,367 ft) above sea level. Characteristics of the sites appear in Tables 3-1 and 3-2. In addition, we have developed statistical models for predicting snow-free dates on an Elizabeth Ridge meadow which is situated a few kilometers south of the 26 snowmelt sites noted above (Figure 1-1).

April 1 snowpack was measured at each site and recorded in cm of water at some sites in 1977 and at all 26 sites in 1978 and 1979. By pooling data across years and exposures, sufficient data were available to develop a model that permits one to predict the 75 percent snow-free date on all exposures at the Elizabeth Ridge sites.

The temperature data used in the equations is from National Oceanic and Atmospheric Administration reports (1977-79 . Five official weather stations situated around the base of the Uinta Mountains were selected as sources of temperature data needed to provide an estimate of the variation in warmth of regional air masses covering the study area in different months and years. The stations used were Coalville, Flaming Gorge, Hanna, Kamas Ranger Station, and Vernal Airport. Degree days were obtained for each station by summing all average daily temperatures above 0°C at each station for each day of April and May. Degree days were obtained for April and May separately for each station and the monthly values were averaged for the five stations to give a rough estimate of the warmth of the regional air mass.

We originally intended to use temperatures at the low elevation, municipal weather stations to predict temperature at higher elevation sites where no stations existed. Analysis showed, however, that temperature data from the United States Soil Conservation Service Snotel network (electronic transmitting stations) in the Uinta Mountains were so poorly correlated with elevation that a significant predictor of temperature change wth elevation could not be derived. Late winter and early spring temperatures were particularly poorly correlated with elevation (coefficient of determination, r^2, values of less than 10%). It is apparent that certain areas act as cold air drainage basins while nearby sites at comparable elevations lie within warm inversion zones. Since site specific temperature data are rarely available for sites in the mountains of this region and temperature cannot be accurately predicted across elevational gradient in the Uintas, we have used temperature data from several reliable, low elevation stations around the Uintas to provide crude estimates of the relative warmth of air masses at higher elevations.

Potential direct solar radiation in Langleys (LY)/cm^2/day was obtained for each study site and time interval of concern from tables published by Frank and Lee (1966). Only latitude, direction of exposure and steepness of slope at each site are needed in order to use Frank and Lee's (1966) tables. Because Frank and Lee (1966) provide tables for only discontinuous exposure and slope steepness classes, it is necessary to extrapolate between tabular values to obtain potential solar radiation values for most slopes. Solar radiation has been shown to significantly affect snow accumulation on different exposures in the Pre-Alps of Switzerland (Meiman et al. 1971).

The snow-free date was quantified for analysis by setting April 1 equal to 1.0 and numbering continuously from April 1 to July 9. Table 3-3 shows the number assigned to each calendar date.

Statistical procedures followed Snedecor and Cochran (1980).

RESULTS

Snow-free dates varied widely from exposure-to-exposure and from year-to-year on the 26 intensively studied snowmelt sites (Tables 3-2 and 3-4). Invariably, south-facing slopes became snow-free first, while north and east exposure always became snow-free later. In 1978, only 18 days separated snow-free dates on the exposures that lost their snow cover first and those that were last to become snow-free, but in 1979, 51 days separated the average snow-free dates on south and north-facing slopes (Table 3-4). That great variation undoubtedly reflects more than differential amounts of potential solar radiation on the different exposures. Prevailing southwesterly winds stripped new snow off the south and west-facing slopes considered here and deposited it in great drifts on north and east-facing slopes. Thus size of the initial snowpacks on April 1 varied remarkably on the different exposures (Table 3-2). Differences in the April 1 snowpack was also partially attributable to differential solar radiation on slopes of different exposures. While differences in potential radiation loads on slopes of differing exposure are minor in April (and even less in May and June), such differences are considerably greater during the period November-March when the snowpacks are accumulating (Frank and Lee 1966).

Multiple regression equations for predicting snow-free date on the various slopes studied appear in Table 3-5. The models account for

Table 3-3. Snow-free [illegible] and the corresponding calendar dates for April 1 through July 9.

Snow-Free Date	Calendar Date	Snow-Free Date	Calendar Date
1	April 1	51	May 21
2	2	52	22
3	3	53	23
4	4	54	24
5	5	55	25
6	6	56	26
7	7	57	27
8	8	58	28
9	9	59	29
10	10	60	30
11	11	61	31
12	12	62	June 1
13	13	63	2
14	14	64	3
15	15	65	4
16	16	66	5
17	17	67	6
18	18	68	7
19	19	69	8
20	20	70	9
21	21	71	10
22	22	72	11
23	23	73	12
24	24	74	13
25	25	75	14
26	26	76	15
27	27	77	16
28	28	78	17
29	29	79	18
30	30	80	19
31	May 1	81	20
32	2	82	21
33	3	83	22
34	4	84	23
35	5	85	24
36	6	86	25
37	7	87	26
38	8	88	27
39	9	89	28
40	10	90	29
41	11	91	30
42	12	92	July 1
43	13	93	2
44	14	94	3
45	15	95	4
46	16	96	5
47	17	97	6
48	18	98	7
49	19	99	8
50	20	100	9

Table 3-4. Average snow-free dates in 1978 and 1979 for south, north, east, and west facing slopes for the 26 study sites on Elizabeth Ridge, Uinta Mountains.

	1978	1979
SOUTH	June 1	May 1
NORTH	July 1	June 20
EAST	July 2	June 16
WEST	no data	May 31

Table 3-5. Results of two multiple regression equations for predicting snow-free date on the array of sites of variable exposure listed in Tables 3-1 and 3-2. The independent variables were April 1 snowpack (cm of water), potential direct solar beam radiation in April (Langleys), sum degree days above freezing (°C) in April, and sum degree days in May.

MODEL 1

Snow-free Date = 200.1 + .4337 (X1) - .0280 (X2) - .1633 (X3)
$N = 50$, $R^2 = 0.830$ ($P<.001$)
Standard Deviation of "Y" Estimate = ± 9.3 Days

Independent Variable	Symbol For Variable	Coefficient	T-Ratio	Significance Level
Snowpack	X1	.4337	5.91	.001
Langleys	X2	-.0280	- .53	> .50
April Degree Days	X3	-.1633	- 7.62	.001

MODEL 2

Snow-Free Date = 405.5 + .2961 (X1) - .0940 (X2) - .5009 (X3) - .5816 (X4)
$N = 50$, $R^2 = .939$ ($P<.01$)
Standard Deviation of the "Y" Estimate = ± 5.6 Days

Independent Variable	Symbol For Variable	Coefficient	T-Ratio	Significance Level
Snowpack	X1	.2961	6.68	.001
Langleys	X2	-.0940	-2.85	.01
April Degree Days	X3	-.5009	-14.89	.001
May Degree Days	X4	-.5816	-12.55	.001

Table 3-6. Snowpack and 74% snow-free date characteristics of 30 randomly chosen samples from the subalpine meadow on Elizabeth Ridge. Average degree days for April and May at five valley weather stations are also reported.

Sample No.	Water Content of April 1 Snowpack (cm)	Year of Record	Degree Days April	Degree Days May	Degree Days April & May	Snow-Free Date*
1	32.5	1977	258.4	292.5	550.9	66
2	32.5	"	"	"	"	66
3	30.0	"	"	"	"	66
4	30.0	"	"	"	"	66
5	40.0	"	"	"	"	67
6	45.0	"	"	"	"	71
7	58.3	"	"	"	"	74
8	60.0	"	"	"	"	76
9	52.5	"	"	"	"	73
10	55.0	"	"	"	"	73
11	52.8	1978	184.2	283.8	468.0	84
12	49.5	"	"	"	"	83
13	45.7	"	"	"	"	83
14	70.4	"	"	"	"	90
15	61.0	"	"	"	"	86
16	100.4	"	"	"	"	99
17	102.9	"	"	"	"	99
18	117.3	"	"	"	"	97
19	79.1	"	"	"	"	97
20	94.4	"	"	"	"	96
21	45.4	1979	157.1	332.5	489.6	68
22	53.0	"	"	"	"	73
23	61.6	"	"	"	"	76
24	58.8	"	"	"	"	75
25	91.9	"	"	"	"	86
26	95.0	"	"	"	"	86
27	114.3	"	"	"	"	86
28	68.7	"	"	"	"	76
29	69.9	"	"	"	"	82
30	85.1	"	"	"	"	82

* See Table 3-3

83.0 and 95.9% respectively of the variation in snow-free dates. Both models are able to account for a highly significant fraction of the variation in snow-free dates among slope exposures and years. Temperature of the general air masses was the most important contributor to snow-free date in both equations, but the water content of the April 1 snowpack also exerted a strong impact on the date of snow disappearance. The potential solar beam radiation variable contributed only 0.8 and 1.2% respectively to the coefficient of multiple determination (R^2) in the first and second model. The weak showing of potential solar beam radiation was expected since by April, the sun is high enough in the sky to minimize differences in radiation among exposures.

Another regression analysis was performed using data available from the subalpine meadow near the intensively studied snowmelt plots reported in Table 3-1. A total of 29 sites on the meadow were monitored for April 1 water content of the snowpack and snow-free date in each of the three years, 1977-79. Ten of the 29 sites were randomly selected from each of three years for which data were available for the analyses reported here (Table 3-6). Since the meadow was essentially uniform topographically, potential solar radiation during the snowmelt season was ignored. Again, degree days for April and May are based on average mean temperature for each month at the five, valley weather stations named in the METHODS section.

Three different regression models were developed in order to test the value of various combinations of independent variables as predictors of snow-free date (Table 3-7). Using just water content of the April 1 snowpack and April degree days derived from an average from five valley stations, 71% of the variation in snow-free date on the meadow in three

---

Table 3-7. Multiple regression models for predicting snow-free date at an array of sites on Elizabeth Ridge meadow sampled in three different years. The independent variables were April 1 snowpack water content, degree days in April, degree days in May, and sum degree days in April and May.

MODEL 1

Snow-Free Date = 62.28 + .3359 (X1) - .0204 (X2)
N = 30, R^2 = .714 ($P<.001$)
Standard Deviation of the "Y" Estimates = ± 5.9 Days

Independent Variable	Symbol Variable	Coefficient	T-Ratio	Significance Level
Snowpack	X1	.3359	6.26	.001
April Degree Days	X2	-.0204	-0.66	>.50

MODEL 2

Snow-Free Date = 183.8 + .2673 (X1) - .1328 (X2) - .3122 (x3)
N = 30, R^2 = .964 ($P<.001$)
Standard Deviation of "Y" Estimate = ± 2.1 Days

Independent Variable	Symbol For Variable	Coefficient	T-Ratio	Significance Level
Snowpack	X1	.2673	13.28	.001
April Degree Days	X2	-.1328	- 9.47	.001
May Degree Days	X3	-.3122	-13.37	.001

MODEL 3

Snow-Free Date = 131.7 + .2407 (X1) - .1338 (X4)
N = 30, R^2 = .836 ($P<.001$)
Standard Deviation of "Y" Estimate = ± 4.5 Days

Independent Variable	Symbol For Variable	Coefficient	T-Ratio	Significance Level
Snowpack	X1	.2407	5.80	.001
April + May Degree Days	X2	-.1338	-4.58	.001

different years could be accounted for. By adding May degree days to the independent variables listed in the preceding sentence, Model 2 (Table 3-7) accounted for over 96% of the variation in snow-free day with a standard deviation of only 2.1 days for the estimated snow-free dates. Model 3, Table 3-7, demonstrates that predictive power is lost by summing April and May degree days as compared to results where those values enter the equation separately (as in Model 2): specifically Model 3 account for about 13% less of the variation in snow-free date than Model 2.

In order to test the generality of Model 2, Table 3-7, five new samples per year were selected from the 87 available samples for the Elizabeth Ridge meadow for the years 1977-79 (Table 3-8). Observed snow-free date for those samples was than correlated with snow-free dates predicted using Model 2. The results (Table 3-8) show good correlation between observed and predicted snow-free dates ($r^2 = .976$).

DISCUSSION

The results demonstrate that snow-free dates in local areas can be predicted with reasonably good confidence without a great deal of sophisticated data collecting equipment. In these studies, only water content of the April 1st snowpack, and site slope and exposure were collected at the site. General radiation loads on the various sites were predicted from Tables (Frank and Lee 1966) using available knowledge of slope and exposure at each site. Since the sites were only a few kilometers apart, differences in cloudiness and snowfall after April 1 were apparently not significantly different from site-to-site. Average degree days for April and May from five low elevation weather station around

---

Table 3-8. Independent data used to test the generality of multiple regression Model 2, Table 3-7. Samples again are from Elizabeth Ridge meadow, but none of the samples were used to construct Model 2.

Sample No.	Water Content of the April 1 Snowpack (cm)	Year of Record	Degree Days		Snow-Free Date*	
			April	May	Observed	Predicted
31	32.5	1977	258.4	292.5	66	66.9
32	30.0	"	"	"	66	66.2
33	48.3	"	"	"	71	71.1
34	58.3	"	"	"	76	73.7
35	60.0	"		"	74	74.2
36	45.7	1978	184.2	283.8	83	83.0
37	57.7	"	"	"	87	86.2
38	65.7	"	"	"	88	88.3
39	75.0	"	"	"	95	90.8
40	101.6	"	"	"	102	97.9
41	45.4	1979	157.1	332.5	72	71.3
42	62.4	"	"	"	79	75.8
43	53.6	"	"	"	73	75.5
44	93.4	"	"	"	87	87.2
45	93.4	"	"	"	90	87.2

* See Table 3-3

the base of the mountains seem to have given a meaningful estimate of general warmth of the regional atmosphere. In combination, those four independent variables (i.e., water content of the April 1 snowpack, potential direct beam solar radiation and degree days for the months of April and May) proved capable of accounting for most of the observed site-to-site and year-to-year variation in snowfree dates on both variable and uniform topography at Elizabeth Ridge.

Accuracy of the snow-free date estimates is much better on uniform topography, but even in complex topographic situations, snow-free dates were predicted within ± 5 or 6 days. It thus appears possible to make good estimates of snow-free dates at specific locations with nothing more than a knowledge of site slope and exposure (needed only once) and April 1 snowpack (needed annually). All other data could be obtained at valley locations. Snow-free date estimates would require May climatic records, but could be generated within minutes after those became available. The method will accurately predict snow-free date well into July.

If one were content with estimates with standard deviations in the order of ± 9 or 10 days, snow-free dates on complex terrain could be estimated by May 1 (see Table 3-5). On uniform topography, one could predict the 75% snow-free date by May 1 with standard deviations for estimates in the neighborhood of ± 5 or 6 days: in this case, one would need only April 1 snowpack size and April degree days (Model 1, Table 3-7).

Using Model 2, Table 3-5, and assuming equal April 1 water content of the snowpack on north, east, south and west exposures, potential solar radiation values of 811, 859, 910 and 859 langleys/cm^2 day respectively on those slopes, and 202 and 303 degree days for April and May respectively, the model predicts the following:

Exposure	Snow-Free Day
North	June 6th
South	May 28th
East	June 2nd
West	June 2nd

The models can also be used to predict how much snow-free date may be depressed if average annual snowpack on a given site were increased by 15% or some other amount. Using Model 2, Table 3-7, and assuming average April 1 snowpack water content on a treeless meadow to be 64 cm, April degree days to be 202 and May degree days to be 303, snow-free date would be delayed 2.6 days given a 15% increase in water content of the April 1 snowpack.

LITERATURE CITED

Frank, E. C. and R. Lee. 1966. Potential solar beam irradiation on slopes: tables for 30° to 50° N latitude. U.S. Dept. Agriculture Research Forest Service Paper RM-18:1-116.

Gary, H. L. 1979. Duration of snow accumulation increases after harvesting in lodgepole pine in Wyoming and Colorado. U. S. Dept. Agriculture, Forest Service Research Paper RM-366:1-7.

Harr, R. D. and F. M. McCorison. 1979. Initial effects of clearcut logging on size and timing of peak flows in a small watershed in western Oregon. Forest Hydrology 15:90-94.

Haupt, H. F. 1979. Effects of timber cutting and revegetation on snow accumulation and melt in north Idaho. U.S. Department Agriculture Forest Service Research Paper INT-224:1-14.

Leaf, C. and G. E. Brink. 1973. Computer simulation of snowmelt within a Colorado subalpine watershed. U.S. Department Agriculture, Forest Service Research Paper RM-99:1-8.

Meiman, J. R., E. Remmenga and H. Keller. 1971. Snow distribution in relation to solar radiation on two Swiss Pre-Alp watersheds. Water Resources Research 7:1636-1640.

National Oceanic and Atmospheric Administration. 1977-1979. Climatological data for Utah (1977, 1978, and 1979). Volume 79 (Nos. 4, 5, 6), Vol. 80 (Nos. 4, 5, 6), and Vol. 81 (Nos. 4, 5, 6). Environmental Data Service, National Climatic Center Asheville, North Carolina.

Regelin, W. L., J. G. Nagy, and O. C. Wallmo. 1977. Effects of snowdrifts on mountain shrub communities. XIIIth Congress of Game Biologists, (March 1977, Atlanta, GA.):414-419. Wildlife Society, Wildlife Management Institute, Washington, D.C.

Snedecor, G. W. and W. G. Cochran. 1980. Statistical methods, 7th ed. Iowa State University Press, Ames, Iowa. 507 p.

Solomon, R. M., P. F. Ffolliott, M. B. Baker, Jr., and J. R. Thompson. 1976. Computer simulation of snowmelt. U.S. Dept. Agriculture, Forest Service Research Paper RM-174:1-8.

Troendle, C. A. 1979. Hydrologic impacts of silvicultural activities. Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers 105(IR1):57-70.

CHAPTER 4

EFFECTS OF HEAVIER SNOWPACKS ON PLANT PARAMETERS OF THE LODGEPOLE PINE-BLUEGRASS HABITAT TYPE IN THE UINTA MOUNTAINS

By

K. T. Harper

Clifford W. Morden

Deborah L. Hunter

and

Karl B. McKnight

ABSTRACT

Response of the plant components of the *Pinus contorta* - *Poa nervosa* (lodgepole pine-bluegrass) habitat type to increased snowpack has been evaluated on the North Slope of the Uinta Mountains, Utah. Twenty-five plots (0.02 ha) were distributed along a gradient of increased snowpack. Elevation of the plots ranged from 2,760 - 2,846 m: April 1 snowpacks held 16.3 cm of water on the average. The group of plots having the heaviest snowpack averaged about 41% more snow on April 1 than the group with the smallest snowpacks. Snow-free day averaged slightly over three days later on the heavy pack sites than on the sites with the lightest snowpacks.

Tree growth rate could not be demonstrated to vary significantly across the gradient of snowpack size. Likewise, understory production and tree reproduction were not adversely affected by heavier snowpacks. There were no qualitative shifts in composition of the understory as size of the snowpack increased, but quantitatively, composition shifted from a perennial graminoid dominated herb layer to one dominated by perennial forbs as size of snowpack increased. There were small, but statistically nonsignificant increases in both herb layer diversity and production on the sites having the heaviest snowpacks.

INTRODUCTION

Commercial lodgepole pine (*Pinus contorta* Dougl. ex Loud.) forest appears to cover about 247,000 hectares in the Uinta Mountains (Choate 1965 and Ridd 1979). Roughly 92% of that acreage occurs in the state of Utah; the remainder lies across the state boundary in adjacent Wyoming. Interpolation between Choate's (1965) and Ridd's (1979) maps suggests that the Uintas support another 47,000 hectares of noncommercial lodgepole. The species occurs over a broad elevational range (2,250-3,350 m), but its most extensive stands occur between 2,440 and 2,900 m. Henderson et al. (1977) conclude that lodgepole pine "is the most common tree species and also the most important commercial timber species in the Uintas - roughly 50 percent of the present volume."

Choate (1965) reported that the species had an average site quality of 51 (51 ft tall at 100 years) in the Uintas with a range from 40-90. Choate (1965) reported an average volume of 19.77 m^3/ha of growing stock in Uinta lodgepole pine stands in 1961. Proctor (1971) shows an annual above-ground forage production of 405 kg/ha for 37 Uinta lodgepole stands.

Lodgepole stands in the Uintas are typically heavily infested with dwarf mistletoe. Foresters consider that trees parasitized by mistletoe suffer a serious reduction in growth rates (Choate 1965). Since over half of the area of lodgepole pine in the Uintas is past rotation age (Choate 1965), the mountain pinebark beetle is a major pest killing thousands of trees each year. Since this beetle rarely attacks stems having a diameter of less than 1.0 dm (Keen 1952), an abundance of stems past rotation age favors large beetle populations and frequent epidemics.

Henderson et al. (1977) recognized seven habitat types in lodgepole pine forests in the Uinta Mountains, thus the lodgepole community is ecologically complex as might be expected for such a widespread species. Winn (1976) provides good checklists and relative abundance values for vertebrate animals associated with several lodgepole pine habitats on the North Slope of the Uintas. Knight et al. (1975) have studied the effects of late lying snow on the understory vegetation of the lodgepole pine-*Vaccinium scoparium* habitat types in the Medicine Bow Mountains of southwestern Wyoming. Knight et al. (1975) found that *Carex geyeri*, *Carex rossii* and possibly *Arnica cordifolia* decreased in cover with late -persisting snow; *Hieracium gracile* and possibly *Erigeron peregrinus* increased in cover with longer snow duration.

OBJECTIVE

It was our objective to determine the effect of late lying snow on above-ground forage production, tree reproduction and tree growth in one lodgepole pine habitat on the North Slope of the Uinta Mountains.

STUDY AREAS

Two stands in the *Pinus contorta* - *Poa nervosa* habitat type (Henderson et al. 1977) were selected for study on the East Fork of Blacks Fork River, Summit County, Utah. One stand ocurred at 2,760 m in the southeast quarter of section 3, T.2 N., R. 12 E. The other stand is located about 6 km south of the first at 2,846 m in the northwest quarter of section 25, T.2 N., R. 12 E. Both stands grow on nearly level alluvial deposits laid down in the relatively distant past by the East Fork of Black's Fork River: Soil surface in both stands is now so high above the stream that roots of the lodgepole trees do not penetrate to watertable. The stands are dense and vigorous (Figure 4-1).

Precipitation storage gages maintained by the Soil Conservation Service (Whaley and Lytton 1979) occur close to each of the lodgepole stands considered. One storage gage (Blacks Fork Junction) is located 2.5 km north of the lower elevation stand and at 2,720 m elevation. Average annual precipitation at that station for the period 1969-78 was 59.4 cm with 21% of the total falling during the July-September period. The other storage gage is located on the edge of the higher elevation stand: average precipitation for the 1969-78 period was 63.3 cm. Again about 21% of the total precipitation fell during the warmer months (July-September).

Both stands had open meadow areas to the west and south. Canyon winds were light but tended in most years to remove some snow from meadows and drop it in small drifts within the forest stands.

METHODS

Twenty-one .02 ha, circular study plots were established within the two lodgepole stands in 1976. Twelve of the plots were placed in the lower elevation stand and nine in the higher elevation stand. Plots were initially placed along two transects in each stand. The assumption was made that plots along the transect closest to the stand edge would accumulate more drifting snow than interior plots. No significant differences in depth of snow developed among plots in the first winter

Figure 4-1. The lodgepole pine forest near the upper stand considered in this study. The fence at left-middle encloses the pasture at East Fork of Blacks Fork Guard Station.

(1976-77) of study. Thus, at the end of that winter, in order to guarantee differences in snowpack, we selected four additional plots in the lower elevation stand in mid-May while patches of late lying snow were still conspicuous. During the 1977-78 and 1978-79 winters, small differences in depth of the April 1 snowpack did develop among stands.

The .02 ha plots are small enough to minimize within-plot environmental and vegetational heterogeneity, but large enough to give a fair sample of the entire plant community at give locations. Within each plot, 25 quadrats were regularly spaced for analysis of the herbaceous and shrubby understory. Each quadrat was circular in shape and had an area of 0.25 m^2. Location of each quadrat was marked to facilitate relocation by a red, 8 cm long, wooden dowel drive 7 cm into the soil at the center of the quadrat (see Harper, 1976, for a more detailed description of quadrat placement procedures). Each of the 25 quadrats were marked at their center with a zinc coated steel peg in the final year (1979) of study to insure that each quadrat could be relocated exactly with a metal detector over a period of many years. Tree reproductions and woody plant cover below a height of two meters were estimated in eleven 4.0 m^2 quadrats uniformly distributed over each plot in 1979. Tree canopy cover (all foliage over 2m above the ground) was also estimated in the 4.0 m^2 quadrats.

The tree population (all tree individuals over 150 cm tall) on each 0.02 ha plot was inventoried. Species, height, and diameter at breast height (DBH) were recorded for each individual. Four trees were also cored in each plot to gain information on tree age and growth rate in the last 10 years (Fig. 4-2). Cores were removed with a Swedish increment corer. Cored trees were selected for vigor and freedom from

Figure 4-2. Coring lodgepole pine trees to determine age and growth rates. Karl B. McKnight, Edward Novak and Clark Ogden from left-to-right.

crowding by other trees. If more than one tree species occurred on a plot, at least one tree per species was cored.

At each 0.25 m^2 quadrat, the following data were recorded: 1) an estimate of the foliage cover of each species that shaded the quadrat, 2) total living cover of all species combined, 3) cover of plant litter, 4) cover of rock of > 5 mm diameter, and 5) composition of the total living cover with the relative contribution of the major lifeform groups being estimated as percentages of the total. Cover for both herbaceous and woody species (in the 4.0 m^2 quadrats) was estimated using a cover-class method (Daubenmire 1968) with the classes delimited as follows: Trace (0-1.0%), 1 (1.1-5.0%), 2 (5.1-10.0%), 3 (10.1 - 25.0%), 4 (25.1 - 50.0 %), 5 (50.1 - 75.0%), 6 (75.1 - 95.0%), and 7 (> 95.0%). Lifeform groups recognized in the relative cover estimates were: trees, shrubs, perennial graminoides, perennial forbs, annuals, and cryptogams (mosses, liverworts and lichens). Total number of species per quadrat and per macroplot was recorded. Frequency values were obtained for all species by dividing the number of quadrats having a given species by all quadrats in the sample.

Production was estimated using a method described by Hutchings and Schmautz (1969). Four 0.25 m^2 quadrats were equally spaced around and about 1.0 m from a central quadrat of equal size. Production of each of the major lifeform groups was then estimated in each peripheral quadrat as a percentage of production of the corresponding group in the central quadrat. The central quadrat was then clipped by lifeform group (current twig and leaf growth of woody plants was taken to a height of 2.0 m) and the tissue was oven dried and weighed. Two clusters of five quadrats each were sampled per plot per year giving a total of ten

estimates of production per plot. Cryptogams were not harvested because of the difficulty of determining what was current year growth.

The first 21 plots were sampled for herbaceous composition in all four years (1976-79). The four deeper snow plots were sampled in 1978 and 1979 only. Woody cover was sampled in 1979 only. All samples were taken in late July or early August of each year.

Surface soils in the light and medium snowpack zones were sampled for various physical and chemical characteristics in 1976. Soil samples for the heavy snowpack zone were not taken until 1980. Samples from each plot were composites taken from about 20 locations scattered over the surface of the 0.02 ha plot. The surface 2.5 cm of each subsample (usually litter) was removed. Subsamples were taken to a depth of 15 cm with a soil sampling tube. Texture was determined by the hydrometer method. Soil reaction was taken with a glass electrode meter. Soil organic matter was obtained by loss on ignition. Exchangeable cations were displaced with normal ammonium acetate and their concentration in the leachate then determined by atomic absorption procedures.

Snowpack parameters were determined from visits on April 1 annually in 1977-79. Plot locations were known precisely even when plots were snow covered, because colored poles were fixed in vertical position at the center of each plot in late October of each year (Fig. 4-3). On the April 1 visit, depth and water content of the snowpack was taken at 3-5 spots per plot with a standard Soil Conservation Service snow tube. After May 1, plots were visited 2 or 3 times per week until all were at least 75% free of snow. Date of the 75% snow-free condition was recorded for each plot.

Figure 4-3. Interior of the lodgepole pine forest showing a "snow-pole" used to mark the center of a macroplot. Macroplots were circular in outline and had an area of 0.02 hectare.

RESULTS

Snowpack

In the spring of 1977, we could measure no significant difference in April 1 snowpack among the 21 study plots. In the two subsequent springs, minor differences in snowpack were measurable among the plots (Table 4-1). In an attempt to insure that significant differences in snowpack conditions did exist among study plots, we sought out four sites at the lower elevation stand with obviously heavier snowpacks on April 4, 1978. Those sites were permanently marked and their plant cover was sampled in 1978 and again in 1979. Snowpack on these last four sites average about 40% heavier than on the sites that accumulated the lightest snowpack. Surprisingly, the 75% snow-free date on the four sites selected for heavy snowpacks did not differ significantly from that for sites having medium sized snowpacks. As will be shown later, that anomally seems related, in part at least, to less tree cover on the sites with heavier snowpacks. It should also be noted in this context that all four of the heavy snowpack plots occurred in the lower elevation stand, while seven of the thirteen medium pack sites occurred at the higher elevation site where mean temperature should have been lower.

Absolute water content of the April 1, 1979, snowpacks in the lodgepole pine forest considered here averaged only about 20 and 27% respectively of the water content of the early snow-free date plots in the subalpine meadow and spruce-fir forest studied on Elizabeth Ridge (see Table 4-1 of this manuscript and the subalpine and spruce-fir manuscripts, Chapters 5 and 6, that appear elsewhere in this report). Since annual precipitation at our lodgepole pine sites averaged about

Table 4-1. Water content of the snowpack on April 1 in 1978 and 1979 in lodgepole pine study plots grouped according to similarity of size of the snowpack. The average 75% snow-free date is given for each group of stands.

	Relative Snowpack Size		
	Light	Medium	Heavy
No. Plots in Group	8[1]	13[1]	4[1]
1978 Results			
Average Water Content on April 4 (cm)	18.8	19.4	25.3
Average 75% Snow-free Date	May 28.9	June 1.1	June 1.3
1979 Results			
Average Water Content on April 1 (cm)	10.7	12.2	15.8
Average 75% Snow-free Date	May 17.3	May 20.8	May 20.0

---

[1] Plots included in the light snowpack category are 1, 3, 4, 6, 7, 9, 17, and 19; plots in the medium snowpack group are 2, 5, 8, 10, 11, 12, 13, 14, 15, 16, 18, 20 and 21, and the plots in the heavy snowpack group are special plots 22, 23, 24, and 25.

84% of annual precipitation at the Elizabeth Ridge study area for the 1977-79 water years, it is clear that much less of the annual precipitation is represented in the April 1 snowpack at the lodgepole plots as opposed to the plots on Elizabeth Ridge. Apparently, more of the early and late winter precipitation falls as rain or melts soon after falling in the lodgepole pine forests than in the higher elevation spruce-fir forests and subalpine meadows.

The results in Table 4-1 suggest that a 10% increase in snowpack delays snow-free date by from 0.57 to 1.08 days in the plots considered here. The average delay in snow-free date caused by a 10% increase in size of snowpack, about 0.8 of a day, is almost the same value observed on our Elizabeth Ridge meadow study area (Ostler et al., Chapter 6).

Impacts Of Snow On Plants

Tree Layer. The data in Table 4-2 demonstrate that the amount of snow in the pack on April 1 has no significant effect on tree growth rates or population densities. Likewise, heavy snowpacks do not suppress tree reproduction in the lodgepole stands considered here. In fact, there were more tree reproductions in the plots having heavy snowpacks than in plots with lighter snowpacks. Canopy cover of the tree seedlings increased significantly with increasing snowpack in this study (Table 4-2). We do not consider, however, that tree reproduction is inhibited by reduction in snowpack per se. We feel instead that the heavier tree canopy cover (and consequent reduced light at ground level) over the light snowpack plots is probably responsible for the observed reduction in tree seedlings there. Less tree cover and fewer trees on the heavy snowpack plots are the likely factors responsible for the three patterns

---

Table 4-2. Characteristics of the tree and tree reproduction layers in plots having different amounts of snow in the April 1 snowpack.

Characteristic of The Vegetation No. Plots Considered	Relative Size of Snowpack Light 8	 Medium 13	 Heavy 4		
	Tree[1] Layer			F - Value for ANOVA and Significance	
No. Trees/0.10 Ha	152	104	139	2.08	NS[3]
Average Tree Height (m)	15.9	16.3	14.4	.79	NS
Average Tree DBH[2] (cm)	10.6	13.0	8.8	3.41	NS
Average Tree Age (yrs)	130.0	145.7	119.3	.61	NS
Average Width Last 10 yrs Growth (mm)	7.5	7.1	7.1	.04	NS
Average Tree Canopy Cover (%)	45.8	41.8	37.6	.70	NS
	Tree Reproduction[4] Layer				
No. Reproductions/0.10 ha By Size Class (All Species Combined)					
3-15 cm Tall	45.5	78.7	28.4	.64	NS
15-30 cm Tall	48.3	69.9	119.3	.62	NS
30-150 cm Tall	19.9	101.4	147.8	1.86	NS
Total	113.7	250.0	295.5	1.93	NS
Average Reproduction Canopy Cover (%)	1.9	6.7	9.0	4.22	*[6]

Table 4-2. Continued.

Average Species Composition of the Reproduction Populations by Height Class	Light			Medium			Heavy		
	Abla[5]	Pien[5]	Pico[5]	Abla	Pien	Pico	Abla	Pien	Pico
3 - 15 cm	0	0	100.0	0	0	100.0	0	20.0	80.0
15-30 cm	11.8	0	88.2	4.9	0	95.1	0	0	100.0
30-150 cm	14.3	14.3	71.4	25.9	1.7	72.4	11.5	3.9	84.6
> 150 cm (trees)	0	0	100.0	0	0	100.0	0	0	100.0

---

1. Trees are considered to be all stems over 150 cm tall
2. DBH - diameter at breast height or 1.37 cm above groundlevel.
3. NS - results of ANOVA (analysis of variance) test for significance of difference among means for the three snowpack categories was not significant.
4. Tree reproductions were considered to be any stems less than 1.5 m tall.
5. Abla - _Abies lasiocarpa_; Pien - _Picea engelmannii_ and Pico - _Pinus contorta_.
6. * F - Value for ANOVA significant at the 5% level.

noted earlier: 1) more snowpack (Table 4-1), 2) earlier than expected snow-free dates (Table 4-1), and 3) more tree reproduction than expected (Table 4-2). These patterns apparently owe their origin to reduced interception of precipitation and light by tree canopies and more ecological space for seedlings in the younger (Table 4-2), more open, lodgepole stands on the heavy snowpack study plots.

Herb-Shrub Layer

Heavier snowpacks are significantly associated with increased understory plant cover and a strong trend toward greater production and floristic richness in the understory vegetation of the lodgepole plots considered (Table 4-3). There is also a statistically significant shift in composition of the understory cover as snowpacks become heavier: perennial, grasslike species (graminoides) produce relatively less of the total understory production, while perennial forbs (broad-leaved herbs) produce proportionally more (Table 4-3).

Performance of a few species varied across the snowpack gradient, but no species seemed incapable of survival in the heaviest snowpack plots (Table 4-4). The four species which do vary significantly across the gradient of increasing snowpack (*Achillea millifolium*, *Cerastium beeringianum*, *Potentilla diversifolia*, and *Ranunuculus inamoenus*) all perform best in the zone of greatest snowpack. In fact, 42 of the 49 species that were classified as prevalent species (Curtis 1959) in one-or-the-other snowpack zones preferred the heaviest snowpack zone (Table 4-4). Species that did not reach maximum frequency in the heavy snowpack zone were: *Carex rossii*, *Descurainia californica*, *Luzula spicata*, *Poa reflexa*, *Polygonum douglasii*, *Thlaspi alpestre*, and *Trisetum*

Table 4-3. Characteristics of the herbaceous and shrubby understory layers of lodgepole pine plots having different amounts of snow in the April 1 snowpack. Only herbs, shrubs and trees less than 1.5 m tall are considered here.

Characteristic of The Vegetation	Relative Size of Snowpack Light	 Medium	 Heavy	F - Value for ANOVA and Its Significance	
No. Plots Considered	8	13	4		
Floristics					
Vascular Species					
Average No. Species/0.02 ha Plot	31.3	31.2	40.5	1.56	NS
Average No. Species/0.25 m^2 Quadrat	4.8	5.8	8.5	2.04	NS
Nonvascular Species					
Average No. Species/0.02 ha Plot	1.9	1.7	1.3	.41	NS
Average No. Species/0.25 m^2 Quadrat	.1	.2	.3	1.23	NS
Biomass					
Average Living Cover (%)	27.2	32.4	51.9	3.59	*
Average Above-ground Production/yr					
1978 (g/m^2)	21.6	23.4	37.5	1.04	NS
1979 (g/m^2)	17.8	11.6	26.3	2.12	NS
Average Composition of Understory Cover					
Trees < 1.5 m (%)	7.9	11.8	10.0	.61	NS
Shrubs (%)	1.8	3.1	3.3	.42	NS
Perennial Graminoides (%)	53.7	35.3	32.7	7.08	*
Perennial Forbs (%)	32.9	48.0	52.4	4.94	*
Annuals (%)	2.4	0.1	0.2	2.77	NS
Cryptogams (%)	.7	1.6	1.4	1.07	NS

Table 4-4. Performance of major understory species in the lodgepole pine type along a gradient of increasing amounts of snow in the pack on April 1. Species whose performance varies significantly across the gradient are asterisked. Cover is the percent of the soil surface covered by foliage of a given species. Plant nomenclature follows Harrington (1962).

	PLANT PARAMETER					
	Frequency			Cover		
	Size of Snowpack			Size of Snowpack		
	Light	Medium	Heavy	Light	Medium	Heavy
Vascular Species						
Abies lasiocarpa	0.5	4.3	7.0	0.3	1.6	3.2
*Achillea millefolium	20.5	56.3	57.0	1.2	2.2	1.9
Agropyron trachycaulum	11.0	8.6	25.0	0.4	0.5	0.6
Agrostis scabra	7.5	5.2	8.0	0.2	0.2	0.1
Allium brevistylum	12.0	9.2	21.0	0.5	0.3	0.5
Antennaria alpina	2.5	2.2	5.0	0.2	0.0	0.1
Arnica cordifolia	6.5	4.9	18.0	0.3	0.2	2.5
Arnica mollis	1.5	10.5	20.0	0.0	0.3	1.1
Calamagrostis canadensis	13.5	10.5	15.0	0.9	0.6	1.5
Caltha leptosepala	2.0	1.8	8.0	0.1	0.1	0.4
Carex albonigra	1.5	2.8	13.0	0.1	0.1	0.4
Carex rossii	12.0	14.2	4.0	0.7	0.8	0.3
*Cerastium beeringianum	1.0	0.6	9.0	0.0	0.0	0.2
Cirsium drummondii	5.0	7.4	7.0	0.2	0.4	0.6
Danthonia intermedia	6.0	7.1	17.0	0.1	0.2	0.6
Deschampsia caespitosa	9.0	14.5	22.0	0.4	0.4	2.5
Descurainia californica	5.0	2.2	3.0	0.1	0.0	0.0
Epilobium lactiflorum	0.0	1.8	7.0	0.0	0.0	0.0
Erigeron peregrinus	7.5	8.0	18.0	0.2	0.4	0.5
Erigeron ursinus	18.0	19.7	31.0	0.9	1.2	1.4
Festuca idahoensis	21.0	13.8	21.0	0.5	0.4	0.4
Fragaria ovalis	15.5	33.8	34.0	1.2	1.7	1.3
Galium boreale	9.0	11.7	30.0	0.3	0.6	1.4
Juncus balticus	3.5	3.1	5.0	0.1	0.1	0.2
Luzula spicata	5.5	3.7	5.0	0.1	0.1	0.1
Osmorhiza obtusa	23.5	24.3	51.0	0.7	1.0	3.6
Phleum alpinum	4.5	2.8	6.0	0.1	0.0	0.1
Pinus contorta (reproductions)	12.5	15.7	14.0	1.3	1.6	1.7
Poa arctica	6.0	9.8	12.0	0.3	0.4	0.4
Poa nervosa	59.0	66.3	60.0	5.0	3.4	4.4
Poa reflexa	4.5	1.8	2.0	0.1	0.1	0.2
Polygonum bistortoides	4.5	9.5	14.0	0.1	0.3	0.1
Polygonum douglasii	1.0	6.2	0.0	0.0	0.0	0.0
*Potentilla diversifolia	1.0	4.0	26.0	0.0	0.2	0.7
Potentilla fruticosa	4.5	4.3	4.0	0.2	0.2	0.2
Potentilla pulcherrima	25.5	21.8	32.0	1.0	2.3	1.3

Table 4-4. Continued.

*Ranunculus inamoenus	0.0	0.0	7.0	0.0	0.0	0.1
Solidago multiradiata	2.5	5.5	8.0	0.1	0.1	0.2
Stellaria longipes	17.5	12.3	28.0	0.1	0.1	0.2
Taraxacum officinale	18.5	15.4	30.0	0.4	0.6	0.6
Thlaspi alpestre	12.5	5.5	5.0	0.1	0.1	0.2
Trifolium longipes	8.0	13.4	22.0	0.4	0.3	0.4
Trifolium parryi	1.5	10.5	5.0	0.0	0.5	0.1
Trisetum spicatum	28.5	25.2	26.0	0.5	0.5	0.5
Vaccinium caespitosum	1.0	4.0	5.0	0.0	0.2	0.2
Viola adunca	10.5	15.1	26.0	0.3	0.4	0.8
Zigadenus elegans	2.0	5.5	10.0	0.0	0.2	0.2
Nonvascular Species						
Bryum turbinatum	2.0	6.2	18.0	0.0	0.1	0.6
Cladonia sp.	2.0	7.4	4.0	0.0	0.1	0.0

spicatum. Trends for this last group of species were not statistically significant for any species, thus the data demonstrate that no species was significantly suppressed by heavier snowpacks.

Despite the fact that there is no qualitative difference in the understory vegetation on plots with light and heavy snowpacks, the Ruzicka (1963) index of similarity shows the understory of those two zones to be only 50% similar. The dissimilarity is almost wholly related to better performance of each species in the heavy snowpack zone. Vegetation of the light and medium zones was 66% similar. Snowpack of the heavy zone averaged 41% heavier than in the light zone in 1978 and 1979, the years in which the vegetation data in Table 4-4 were taken. Snowpacks on the medium zone average 8.6% heavier than on the light zone in 1978 and 1979 (Table 4-1).

Snow and Animal Signs

The commonest wild animal signs seen in the lodgepole pine plots were those for the red tree squirrel (*Tamiasciurus hudsonicus*) and the snowshoe hare (*Lepus americanus*). Domestic sheep also grazed across each lower elevation plot each year. Pocket gophers did not occur on the plots studied. Size of the snowpack could not be demonstrated to significantly affect use of the associated forest by any animal (Table 4-5).

Physical and Chemical Characteristics of Plots

Are the few statistically significant differences observed between snowpack zones attributable to the snowpacks per se or to other characteristics of the forest plots included in each snowpack zone? In order to evaluate that question, various characteristics of the physical and

---

Table 4-5. Percentage of quadrats in each snowpack zone showing evidence of the presence of each animal listed. Data are averaged for 1978 and 1979. None of the reported differences between zones are statistically significant. The test for significance was an analysis-of-variance procedure.

	Size of Snowpack		
Animal	Light	Medium	Heavy
Domestic Sheep	28.0	27.1	30.0
Elk	0.0	1.5	0.0
Moose	1.5	4.6	0.0
Mule Deer	4.5	6.8	7.0
Porcupine	0.0	1.2	0.0
Red Tree Squirrel	47.0	47.6	37.0
Snowshoe Hare	27.5	23.1	18.0

chemical environment were studied in all of the plots. The results demonstrate that a large difference in soil depth exists among the size-of-snowpack zones (Table 4-6), with the heaviest snowpacks occurring on plots having the deepest soils. Slope and exposure of the plots in the three groups do not vary significantly among groups. All macroplots have very gentle slopes toward the north northeast or the east.

Unfortunately, because the heavy snowpack plots were selected later than all other plots, soil chemistry was determined for the plots in the heavy snowpack zone two years after soil samples from the other macroplots were sampled. As a result, procedures for collecting the surface soil samples were not uniform: the large differences noted between soils samples from the 0-2.5 cm layer of light or medium and heavy snowpack zones are thus at least partially attributable to sample collection procedures. More humus material was included in soil surface samples taken from light-medium than heavy snowpack macroplots. Plots in the heavy snowpack zone tend to hold less of most essential minerals than soils in the light-medium snowpack categories (Table 4-6), but the differences are usually not statistically significant.

Chemical analyses for soil from other mountain ranges in Utah (Table 4-7) demonstrate that the soils from the lodgepole pine plots considered here are not likely to be deficient in respect to essential elements with the possible exception of potassium and phosphorus. Furthermore, the fact that there is a tendency for the heavy snowpack plots to support more total living understory cover, a larger number of species per quadrat, and more above-ground understory production than the light-medium snowpack plots suggests that water was more limiting

---

Table 4-6. Physical and chemical characteristics of the lodgepole pine plots in each snowpack zone.

Characteristic	Size of Snowpack Light	 Medium	 Heavy	F-Value for ANOVA & Its Significance	
Exposure (Degrees)	12	78	20	.71	NS
Slope Steepness (%)	3	3	2	.71	NS
Soil Depth (dm)	3.9	4.6	9.5	27.98	**[1]
Soil Texture					
Sand (%)	53.2	56.0	45.0	1.48	NS
Silt (%)	25.2	22.6	23.5	1.00	NS
Clay (%)	21.7	21.4	31.5	3.48	NS
Soil Chemistry					
pH 0-2.5 cm depth	5.6	5.6	6.0	3.00	NS
2.5-15.0 cm	5.9	5.9	6.2	2.19	NS
Exchangeable Calcium					
0-2.5 cm (ppm)	6179	5211	5288	0.50	NS
2.5-15.0 cm (ppm)	2771	2136	3038	1.91	NS
Exchangeable Magnesium					
0-2.5 cm (ppm)	958	942	595	3.64	NS
2.5-15.0 cm (ppm)	485	375	319	1.55	NS
Exchangeable Potassium					
0-2.5 cm (ppm)	495	378	276	2.29	NS
2.5-15.0 cm (ppm)	201	158	168	1.32	NS
"Available" Phosphorus					
0-2.5 cm (ppm)	19.1	25.2	3.2	4.83	*[1]
2.5-15.0 cm (ppm)	4.1	3.1	0.8	5.87	*
Soil Organic Matter					
0-2.5 cm (ppm)	48.9	46.1	7.7	15.27	**
2.5-15.0 cm (ppm)	15.5	10.5	4.2	4.33	*

1. ** - highly significant statistically, * - significant at P<.05.
2. NS - Not significant statistically

BEST DOCUMENT AVAILABLE

Table 4-7. Comparison of soil physical and chemical parameters for the lodgepole study area considered here (2.5-15.0 cm depth) with the same parameters for soils of other Utah mountains. Data for the Henrys and the LaSals are from Pederson and Harper (1979).

Parameter (2.5-15.0 cm)

				Exchangeable			
Mountain Range	pH	Sand (%)	Fines (%)	Calcium (ppm)	Magnesium (ppm)	Potassium (ppm)	"Available" Phosphorus
This Report	5.9	53.3	46.7	2483	401	173	3.1
Henrys	6.7	50.0	50.0	2822	166	420	42.4
Lasals	6.3	48.0	52.0	2090	106	418	14.0
Wasatch Plateau[1]	6.5	21.0	79.0	7350	900	420	40.0

[1] Unpublished data from the files of K. T. Harper, Brigham Young University.

---

than potassium and/or phosphorus, since those elements were in shortest supply in the heavy snowpack plots (Table 4-6). The fact that understory production increases rather than declines in the heavy snowpack zone despite lower levels of essential minerals demonstrates that extra snow in the amounts noted here does not have a suppressing effect on plant growth in the lodgepole pine - nerved bluegrass community type.

DISCUSSION

Landis and Mogren (1976) could detect no change in wood production in subalpine fir and Engelmann spruce, as a consequence of weather modification activities in the San Juan Mountains of Colorado. In agreement with that finding, Blaue and Fechner (1976) could demonstrate no correlation between initiation of growth of Engelmann spruce and quaking aspen and late lying snow. They considered growth initiation in those trees to be triggered by air temperature and perhaps photoperiod: late lying snow had little or no effect on either of those variables. Working at lower elevations, Sweeney and Steinhoff (1976) concluded that late lying snow could delay initiation of growth of Gambel oak, but that both early and late starting plants showed stem elongation for about the same number of days. Oak growth was more influenced by summer precipitation in the past year than by time of initiation in the stem elongation in the year of concern (Sweeney and Steinhoff 1976).

Swanson (1967) has shown that lodgepole pine and Engelmann spruce transpire freely and thus probably carry on active photosynthesis) even though the ground may be covered by a heavy snowpack. Thus, late lying snow should have minimal impact on tree growth. Heavy snowpacks might, however, interfere with tree seedling and herbaceous understory growth. Knight et al. (1975) demonstrate that several herbs and the small shrub, *Vaccinium scoparium*, are significantly inhibited by late lying snow. To our knowledge, the effects of late lying snow on tree reproduction in western forests have not been evaluated.

Our data for the *Pinus contorta* - *Poa nervosa* habitat type on the North Slope of the Uinta Mountains show no adverse impacts on either herbaceous and small shrub production or tree reproduction when size of the snowpack is increase 40% and snow-free date is postponed by 3.0 days. In fact, there is a consistent but statistically nonsignificant tendency for both understory production and tree seedling establishment to be enhanced by additional snow. We have detected no changes in tree growth rates attributable to increased snow.

As Dix and Richards (1976) have predicted, our data showed quantitative (but not qualitative) shifts in composition of the understory with increasing snowpack. The floristic richness of the understory has a tendency to increase with additional snowpack in the area studied.

LITERATURE CITED

Blaue, R. W. and G. H. Fechner. 1976. Phenological development of Engelmann spruce in southwestern Colorado, pp. 367-390 *in* H. W. Steinhoff and J. D. Ives (eds.), Ecological impacts of snowpack augmentation in the San Juan Mountains, Colorado. Final report, San Juan Ecology Project, Colorado State Univ. Publ., Fort Collins. 489 pp.

Choate, G. A. 1965. Forest in Utah. U.S. Forest Service Resource Bulletin INT-4. 61 pp.

Curtis, J. T. 1959. The vegetation of Wisconsin. University of Wisconsin Press, Madison. 657 pp.

Daubenmire, R. F. 1968. Plant communities: a textbook of plant synecology. Harper and Row Publishers, New York. 300 pp.

Dix, R. A. and J. A. Richards. 1976. Possible changes in species structure of the subalpine forest induced by increased snowpack, pp. 311-322 *in* H. W. Steinhoff and J. D. Ives (eds.), Ecological impacts of snowpack augmentation in the San Juan Mountains, Colorado. Final Report, San Juan Ecology Project, Colorado State Univ. Publ., Fort Collins. 489 pp.

Harper, K. T. 1976. Work plan: ecological impact study of weather modification in the Uinta Mountains, Utah. Report to Utah Division of Water Resources, Salt Lake City, and the U.S. Bureau of Reclamation, Office of Atmospheric Resources Management, Denver. 46 pp.

Harrington, H. D. 1962. Manual of the plants of Colorado. Swallow Press, Inc., Chicago, Illinois.

Henderson, J. A., R. L. Mauk, D. L. Anderson, T. A. Davis and T. J. Keck. 1977. Preliminary forest habitat types of the Uinta Mountains, Utah. Mimeographed report from the Department of Forestry and Outdoor Recreation, Utah State University, Logan 84322.

Hutchings, S. S. and J. E. Schmautz. 1969. A field test of the relative weight estimate method for determining herbage production. J. Range Manage. 22:408-411.

Keen, F. P. 1952. Insect enemies of western forest. U.S. Dept. Agr. Misc. Publ. No. 273. 280 pp.

Knight, D. H., C. Kyte, B. Rogers and C. R. Starr. 1975. The impact of snow on herbaceous and shrubby vegetation, Pages 175-214 in D. H. Knight (ed.), The Medicine Bow Ecology Project. Final Report to U.S. Bureau of Reclamation, Office of Atmospheric Water Resources, Denver, Colorado 80225.

Landis, T. D. and E. W. Mogren. 1976. Snow augmentation and wood production in subalpine forest, pp. 391-402 *In* H. W. Steinhoff and J. D. Ives (eds.), Ecological impacts of snowpack augmentation in the San Juan Mountains, Colorado. Final Report, San Juan Ecology Project, Colorado State Univ. Publ., Fort Collins. 489 pp.

Ostler, W. K., K. T. Harper, and K. B. McKnight. 1980. The effects of late lying snow on a subalpine *Danthonia* - *Deschampsia* - *Carex* meadow in Utah. Chapter 6. This Report.

Pederson, J. C. and K. T. Harper. 1979. Chemical composition of some important plants of southeastern Utah summer ranges related to mule deer reproduction. Great Basin Naturalist 39:122-128.

Proctor, D. J. 1971. A phytosociological study of the North Slope of the Uinta Mountains. Unpublished manuscript in the files of the Wasatch National Forest, Salt Lake City, Utah. 506 pp.

Ridd, K. 1979. Vegetation of the Uinta mountains above 7000 feet (A map constructed from landsat imagery). In K. T. Harper et al., The Uinta Ecology Study: interim report. Submitted to Utah Division of Water Resources, Empire Bldg., Suite 300, 231 E. 400 S., Salt Lake City 84111 and the U.S. Bureau of Reclamation, Office of Atmospheric Resources Management, Engineering and Research Center, Denver, Colorado 80225. 76 pp.

Ruzika, M. 1958. Anwendung mathematisch - statisticher methoden in der geobotanik (synthetische bearbeitung von aufnahmen). Biologia, Bratisl. 13:647-661.

Sweeney, J. R. and H. W. Steinhoff. 1976. Effects of snow on oakbrush, pp. 343-366 *In* H. W. Steinhoff and J. D. Ives (eds.), Ecological Impacts of snowpack augmentation in the San Juan Mountains, Colorado. Final Report, San Juan Ecology Project, Colorado State Univ. Publ., Fort Collins. 489 pp.

Whaley, B. L. and L. K. Lytton. 1979. Mountain precipitation summary for Utah. Report released by the Soil Conservation Service, Snow Survey Section, 4012 Federal Building, Salt Lake City 84138. 168 pp.

Winn, D. S. 1976. Terrestrial vertebrate fauna and selected coniferous forest habitat types on the North Slope of the Uinta Mountains. Report Distributed by the Wasatch National Forest, Salt Lake City, Utah. 145 pp.

CHAPTER 5

EFFECTS OF LATE LYING SNOWPACKS ON PLANT RESPONSES IN THE ENGELMANN SPRUCE - BLUEBERRY HABITAT TYPE OF THE UINTA MOUNTAINS

By

K. T. Harper

Karl B. McKnight

W. Kent Ostler

and

Deborah L. Hunter

ABSTRACT

Response of the plant components of the *Picea engelmannii - Vaccinium scoparium* (Engelmann spruce-blueberry) habitat type to late lying snow has been evaluated at Elizabeth Ridge on the North Slope of the Uinta Mountains. Thirty-six plots (0.02 ha) were distributed along a gradient of increasingly late snow-free dates. The forest stand occurred at an elevation of 3,200 m; the April 1 snowpack on some study plots held over 140 cm of water in 1979. The group of plots having the latest melt date became 75% snow-free about 21 days after the average plot in the early snow-free date group. Average water content of the earliest snow-free date plots was about 66 cm in 1979. The latest snowmelt plots averaged over 140 cm of water in the snowpack on April 1, 1979.

Neither tree growth rates nor reproductive success could be shown to be adversely affected by late lying snow. Understory herbs and shrubs did show a decline in both diversity and biomass on the latest melt-date plots, but the trend was not statistically significant. Nevertheless, no species was totally eliminated from the late snow-free date plots, but most of the herbaceous and shrub species preferred plots having earlier melt-dates. Shrub biomass contributed relatively less to total understory production, while forbs (herbaceous dicotyledonous species) contributed relatively more as the snow-free date was delayed.

INTRODUCTION

Choate's (1965) forest map for the Uinta Mountain portion of Utah shows spruce-fir (*Picea engelmannii* - *Abies lasiocarpa*) to be the second most widespread coniferous forest type in that area. We infer from Choate's map that there are roughly 103,200 ha of commercial quality spruce-fir forest in the Uintas. Only lodgepole pine forest covers more acreage in the area. Ridd's (1979) vegetative map of the Uintas shows 25% more coniferous forest land in the Uintas than Choate's (1965) map. Since Choate considers commercial quality forest only, we assume that the difference in amount of coniferous forest between his map and that of Ridd is attributable to noncommercial forest. (Since Ridd's map was taken from landsat imagery, we believe that his figures for total coniferous forest are reliable). Assuming that the noncommercial forest is distributed among the four coniferous forest types recognized in the Uintas by Choate (1965) in direct proportion to the area of commercial forest of each, there should be about 19,740 ha of noncommercial spruce-fir forest in the area of concern. The other three coniferous forest types recognized in the Uintas by Choate are lodgepole pine (247,000 ha), ponderosa pine (37,100 ha) and Douglas fir (20,880 ha).

Henderson et al. (1977) recognize four habitat types in the spruce dominated forests of the Uintas. Our study area lies in their *Picea engelmannii* - *Vaccinium scoparium* habitat type. They consider this habitat type to occur primarily above 3,050 m elevation. The type occurs on all slope aspects but the slopes occupied are usually relatively gentle (less than 15%). Soils supporting this habitat type in the Uintas are usually derived from quartzite and are shallow, cobbly

sandy loams. Site index values vary between 42 and 50 (height in feet at 100 years). Better quality sites in this habitat type are reported to support progressively more lodgepole pine at lower elevations and more subalpine fir at higher elevations (Henderson et al. 1977).

Knight et al. (1975) studied the influence of late lying snow in the *Picea engelmannii* - *Vaccinium scoparium* habitat type. They found *Vaccinium scoparium* to decline under the influence of late lying snow, while 14 other species increased in areas of late lying snow, but only one of the trends of the increaser species (that for *Polytrichum juniperinum*) was statistically significant. Increaser species were *Androsace* sp., *Arnica latifolia*, *Calamagrostis purpurascens*, *Erigeron peregrinus*, *Erythronium grandiflorum*, *Hieracium gracile*, *Poa cusickii*, *P. nervosa*, *P. reflexa*, *Polytrichum juniperinum*, *Ranunculus alismaefolius*, *R. eschscholtzii*, *Sibbaldia procumbens*, and *Thlaspi alpestre*.

Landis and Mogran (1976) were unable to detect a change in growth rate of Englemann spruce due to enhancement of snowpack by cloud seeding activities in the San Juan Mountains of Colorado. Blaue and Fechner (1976) evaluated the effects of late lying snow on Engelmann spruce phenology in the San Juan Ecology Project where artificial augmentation of snowpack was attempted. They found that late lying snow did not affect spruce phenology. Dix and Richards (1976) postulated that long-continued snow augmentation would alter composition of the spruce-fir community in Colorado, but their arguments were not tested with field trials.

OBJECTIVE

We have attempted to determine the effect of late lying snow on above-ground forage production, tree reproduction and tree growth in one spruce-fir habitat type on the North Slope of the Uinta Mountains.

STUDY AREA

This study was conducted on Elizabeth Ridge (SW 1/4 of section 15, T. 2 N., R. 11 E.) on the North Slope. Elevation at the site averages about 3,203 m. The area lies within Summit County, Utah. Elizabeth Ridge is a north-south trending prominence which forms the watershed divide between the Bear River which flows into the Great Basin and Blacks Fork Creek, a tributary of the Green River which ultimately empties into the Colorado River. The area appears to have escaped glaciation during the Pleistocene, because of its location away from large areas where ice might accumulate (Hanson 1975). The study area is situated on the nearly flat top of the ridge. Drainage water moves slowly from east to west across the study area. The soils are derived from late Tertiary alluvium: parent material is uniform across the area.

A large subalpine meadow occupies deeper soils to the west of the forested area studied (Fig. 5-1). The prevailingly westerly winds of winter sweep snow from the meadow and deposit it in large drifts that parallel the forest-meadow border. The sparsely stocked forest stand selected for study was selectively logged in the 1950s, but even prior to logging, the stand appears to have been open and poorly stocked.

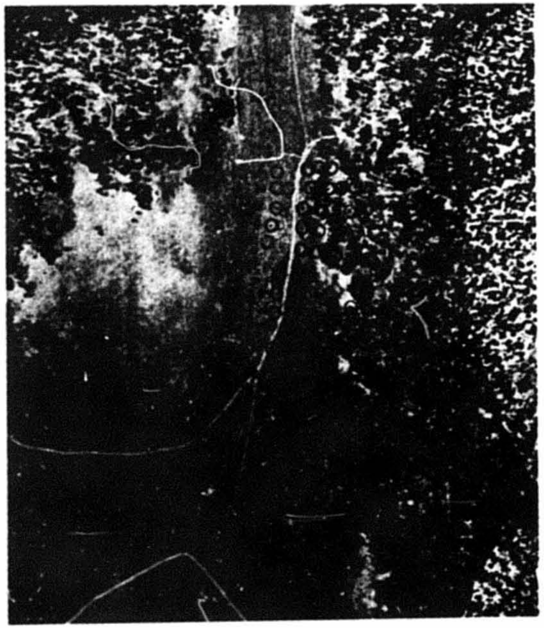


Figure 5-1. Aerial photograph of the Elizabeth Ridge study area showing the spruce-fir forest considered in this chapter and the location of the macroplots used in the study. The subalpine meadow (Chapter 6) and the macroplots used to sample it are also shown. North is at the top of the photo.

Annual precipitation for the water year (Oct. 1- Sept. 30) 1976-77 was about 56 cm. In 1977-78 precipitation was 73 cm at the study area, and in 1978-79 annual water year precipitation again totalled 73 cm.

METHODS

Thirty .02 ha circular study plots were established in a stratified block design across the study area. Plots were located in 1976 after the snowpack had melted. One transect of 10 plots was placed just within the forest and parallel to the forest-meadow ecotone. A second and third transect of 10 plots each roughly paralleled the first with an average distance of about 40 meters between transects. Our initial hope was that depth of snowpack would grade off gradually and uniformly from the forest-meadow edge. Drifts laid down in the 1977-78 winter were unpredictably distributed with large and small drifts bearing little consistent relationship to the three transects. In order to insure large among plot differences in snowpack, six more plots were selected prior to disappearance of the deeper snowpacks in the spring of 1978. These plots were arbitrarily placed at sites of unusually deep snowpacks. See Harper et al. (1979) for exact location of plots in the forest.

Sampling methods and variables sampled were identical to those outlined in the lodgepole pine manuscript (Chapter 4). Vegetation on the initial thirty macroplots was sampled annually for four years, but the last six macroplots were sampled in 1978 and 1979 only.

RESULTS

Snowpack

Snow-free data was retarded as snowpacks increased in size, but the trend was apparently heavily influenced by shade cast by trees. Snow-free dates were early for open-forest stands, while even small snowpacks persisted until late in the season were considerable shade was present (Harper et al. 1978). That relationship is shown in Table 1-1; the water content of snowpacks on macroplots in early and medium snow-free date groups did not differ significantly in the winters of 1976-77 and 1977-78. Nevertheless, the 75% snow-free date for study plots in the early versus medium snow-free categories always showed significant differences.

Variations in snowpack were often very large in small distances (Fig. 5-2). The rather random distribution of light and heavy snowpacks in our sample increase the likelihood that the results are representative of the entire stand.

Snowpacks were unusually light in 1977 and near average in both 1978 and 1979. The snowpacks on the late snow-free sites averaged about 148% larger than the three year average for the group of early melt plots. Snow-free date (75% snow-free) averaged 21 days later on the late as opposed to the early melt-date group of plots. The medium melt-date group averaged about 20% more snow than the early group: melt date was retarded an average of 7.6 days by the additional snow. Using the difference between early and late melt-date groups as the basis for comparison, it is seen that a 10% increase in snowpack can be expected to retard melt data about 1.4 days. At lower elevations and on the

Figure 5-2. Snow depth varied radically over short distances in the Spruce-fir forest. Here Kent Ostler stands at the edge of a drift that was over 3.0 m deep.

Table 5-1. April 1 water content of snowpacks on spruce-fir study plots grouped according to similarity of the 75% snow-free date. The average 75% snow-free date is given for each group. Analysis of variance has been used to test for significance among means for any given variable in study plots assigned to each snow release date group. See Harper et al. (1979) for plots assigned to each group.

	Relative Snow-free Date				
	Early	Medium	Late	Significance of F-Value for ANOVA[1]	
No. Plots/Group	14	16	6	-	
1977 Results					
Ave. Water Content on April 1 (cm)	37.4	42.4	-	0.10	NS[2]
Ave. Snow-Free Date	June 5.9	June 11.4	-	14.13	**[3]
1978 Results					
Ave. Water Content on April 1 (cm)	70.6	91.2	-	0.14	NS
Ave. Snow-free Date	July 1.8	July 9.9	July 22.8	61.47	**
1979 Results					
Ave. Water Content on April 1 (cm)	66.5	75.0	144.3	31.09	**
Ave. Snow-free Date	June 16.1	June 25.4	July 7.0	45.71	**

1. Analysis of Variance
2. NS - not statistically significant
3. ** - statistically different at the .01 probability level.

Table 5-2. Characteristics of the tree layer in groups of plots that become free of snow at significantly different times in the spruce-fir forests of Elizabeth Ridge.

	Relative Snow-Free Date				
	Early	Medium	Late	Significance of F-Value for ANOVA	
No. Plots/Group	14	16	6		
No. Trees[1]/0.10 ha	140.0	87.8	150.0	1.31	NS
Ave. Maximum Tree Height (m)	12.8	12.0	13.7	.57	NS
Ave. Tree DBH[2] (cm)					
Abies lasiocarpa	5.7	8.3	7.6	.41	NS
Picea engelmannii	9.7	10.7	9.9	.83	NS
Ave. Maximum Age (years)					
Abies lasiocarpa[3]	100.1	115.5	110.0	.14	NS[4]
Picea engelmannii	118.8	133.1	185.8	1.43	NS
Ave. width of Last 10 Xylem Rings (mm)					
Abies lasiocarpa	11.2	6.7	8.5	3.71	*[5]
Picea engelmannii	12.6	11.2	11.4	.34	NS
Ave. Tree Canopy Cover (%)	15.4	19.5	24.0	1.03	NS
Composition Tree Population (%)					
Abies lasiocarpa	61.7	45.6	30.0		
Picea engelmannii	38.0	54.4	70.0		
Pinus contorta	0.3	0.0	0.0		

1. Trees are considered to be all individual stems taller than 1.5 m.
2. DBH = diameter at breast height (1.37 m)
3. Plant nomenclature follows Harrington (1962)
4. NS = not statistically significant
5. * = statistically significant at .05 probability level.

subalpine meadow adjacent to our spruce-fir plots, a 10% increase in snowpack retards melt date about 0.8 day (see chapters 4 and 6 of this report). The difference is probably attributable to shading by trees and much smaller snowpacks in the meadow and lodgepole forests respectively. Snowpacks in the spruce-fir stand averaged about 35% larger than those in the adjacent subalpine meadow in 1978 and over 450% larger than in the lodgepole pine plots in at year (see Chapters 4 and 6 of this report).

Impacts of Snow on Plants

Tree Layer. The results show that late lying snow has no significant influence on number, size or growth rate of trees in this study (Table 5-2). Analyses did detect a significant difference in average width of the last 10 xylem rings of *Abies lasiocarpa*, but that difference is probably attributable to a small sample rather than the effects of late lying snow, since width is greater in the zone of latest snow-free dates than in the intermediate zone (Table 5-2). Site quality for spruce averaged about 12.7 m at 100 years in the plots considered here.

Forest composition reveals a trend in which *Abies* declines and *Picea* increases along a gradient of increasing lateness of snowmelt. The trend in relative abundance of the two species can be shown to be highly significant by use of a 2 x 2 contingency table and the Chi-square statistic. Lodgepole pine is confined to the zones of earliest snow-free dates (Table 5-2) in this study, but the sample size is too small to attribute statistical significance to that observation.

Tree Reproduction. The data do not show a tendency for either number or canopy coverage of tree reproductions to decline with delay in the snow-free date (Table 5-3). In fact, both number and canopy cover of reproductions is greater in the late snow release group than in the early release date plots, but the difference is not statistically significant. *Abies* reproductions appear to survive better than *Picea* reproductions, but snow-free date seems not to affect that response. Better survival of *Abies* as opposed to *Picea* reproduction is probably related to the fact that most *Abies* reproductions are vegetatively reproduced from basal branches of established trees that take root wherever snow pushes them onto the soil. In contrast, all *Picea* reproductions appear to be seedlings. The number of reproductions seems adequate to maintain the forest at or above its current level of stocking.

Herb-Shrub Layer

Heavier snowpacks in the spruce-fir stand considered here are significantly correlated with decreasing understory cover. There is also a consistent, but statistically nonsignificant trend toward lower understory production on the plots having the latest snow-free dates (Table 5-4). Composition of the forage produced in the understory shows a consistent (but not significant) trend toward greater relative abundance of forbs and lesser amounts of shrubby plant tissue as the snow-free date is delayed. Grass-like plants tend to remain equally abundant across the gradient of snow-free date. Both annuals and nonvascular plants increase significantly on the macroplots that become snow-free last in this study (Table 5-4).

Table 5-3. Characteristics of the tree reproduction layer in groups of plots that differ in respect to the 75% snow-free date. See Table 5-1 for number of plots in each group and average snow-free date for each group.

	Relative Snow-Free Date			Significance of F-Value for ANOVA	
	Early	Medium	Late		
No. Reproductions per 0.10 ha by Height Class (All Species Combined)					
< 3 cm	1.9	11.4	0.0	1.20	NS
3 - 15 cm	15.2	41.7	15.2	1.16	NS
15 - 30 cm	45.5	47.5	79.6	0.61	NS
30 -150 cm	176.2	261.4	223.5	.53	NS
Total	238.7	361.2	318.3	.81	NS
Cover of Reproduction (%)	5.3	7.9	6.2	.89	NS

Composition of Seedling Population (%)

	Relative Snow-Free Date								
	Early			Medium			Late		
Size Class	Abla	Pien	Pico	Abla	Pien	Pico	Abla	Pien	Pico
< 3 cm	0.0	100.0	0.0	11.1	88.9	0.0	0.0	0.0	0.0
3 - 15 cm	12.5	87.5	0.0	45.5	54.5	0.0	50.0	50.0	0.0
15 - 30 cm	41.7	54.2	4.2	45.9	51.4	2.7	76.2	23.8	0.0
30 -150 cm	69.9	30.1	0.0	67.6	32.4	0.0	71.2	28.8	0.0

1. Abla = *Abies lasiocarpa*

2. Pien = *Picea engelmannii*

3. Pico = *Pinus contorta*

Table 5-4. Characteristics of the herbaceous and shrubby understory layers of the spruce-fir plots having different snow-free dates. Only herbs, shrubs and trees less than 1.5 m tall are considered here.

	Relative Snow-Free Date				
Characteristic	Early	Medium	Late	Significance of F-Value for ANOVA	
		Floristics			
Vascular Species					
Ave. No. Species/0.02 ha	31.2	33.1	31.2	0.81	NS
Ave. No. Species/0.25 m^2	9.0	7.4	5.9	4.80	*
Nonvascular Species					
Ave. No. Species/0.02 ha	6.3	5.9	5.5	0.22	NS
Ave. No. Species/0.25 m^2	1.3	1.0	1.0	1.43	NS
		Biomass			
Ave. Living Cover (%)	56.3	52.9	35.8	20.87	*
Ave. Above-Ground Production/yr					
1978 (g/m^2)	31.5	23.9	21.9	.98	NS
1979 (g/m^2)	40.1	42.3	36.5	.19	NS
Ave. Composition of Understory Production (1978 and 1979 data pooled)					
Shrubs (%)	15.5	8.8	1.9	1.29	NS
Perennial Graminoides (%)	23.6	28.2	24.3	.14	NS
Perennial Forbs (%)	60.9	62.0	73.9	1.82	NS
Ave. Relative Contribution of two plant group to living cover					
Annuals (%)	1.3	0.5	3.0	4.45	*
Cryptogams (%)	2.6	4.7	6.3	8.19	**

Species diversity at the macroplot level was unaffected by snow-free date, but the average number of species per 0.25 m^2 quadrat was progressively suppressed as snow-free date was delayed (Table 5-4). We interpret this result to mean that few if any species are eliminated from local areas by late lying snow, but population size does decline for most species in this forest type when the growing season is significantly shortened.

Performance of only five understory species varied significantly across the snow-free date gradient, and none of those species (i.e., Picea engelmannii seedlings, Epilobium alpinum, Ligusticum filicinum, Saxifraga rhomboidea, and Deschampsia caespitosa) performed best in the latest snow-free category (Table 5-5). Five species (Draba crassifolia, Ranunculus inamoenus, Festuca ovina, Poa nervosa and P. reflexa reached maximum frequencies in the latest snow-free date group, but none of those patterns were statistically significant. Most (21 species) of the prevalent understory species performed best in the earliest snow-free date category, but a sizeable group (13 species) achieved highest average frequency in the medium release-date group (Table 5-5). Every species considered was able to maintain at least a few individuals in the latest snow-release-date group.

The understory community of the early release date zone was 62% similar to that of the latest-release zone as measured by the Ruzicka (1963) similarity index. The understory of the early and medium-release zones was 64% similar. The medium and late-release group understories were 68% similar. Thus, although average snow-free date in the late group was almost two weeks later than in the medium-release date group, composition of the understory was quite similar in the groups.

Table 5-5. Performance of major understory species along a gradient of lateness of snow-free date in the spruce-fir community at Elizabeth Ridge. Species whose frequency varies significantly across the gradient are asterisked. Frequency is the percentage of 0.25 m^2 quadrat in a snow-release date category that support the species in question. Cover is the percent of soil surface covered by foliage of a given species. Nomenclature for plants follows Harrington (1962). Snow-free groups are as in Table 5-1.

	Relative Snow-Free Date			Relative Snow-Free Date		
	Early	Medium	Late	Early	Medium	Late
Species	Frequency			Cover		
Trees						
Abies lasiocarpa	22.9	19.1	18.7	7.4	7.7	4.7
*Picea engelmannii	10.3	22.7	16.0	5.6	5.7	2.8
Shrubs						
Vaccinium scoparium	30.7	25.1	18.0	4.8	4.0	2.6
Forbs						
Achillea millefolium	14.6	16.2	14.7	0.3	0.5	0.4
Antennaria parvifolia	60.7	58.2	49.3	10.8	8.6	7.6
Arnica cordifolia	15.6	7.8	6.7	1.2	0.6	0.5
Artemisia scopulorum	6.9	14.4	8.0	0.2	0.4	0.2
Claytonia lanceolata	5.5	16.7	9.3	0.1	0.3	0.2
Draba crassifolia	6.6	11.3	14.7	0.0	0.1	0.2
*Epilobium alpinum	40.4	18.4	13.3	0.5	0.2	0.4
Erigeron peregrinus	60.0	48.2	42.0	3.2	1.9	1.6
Erigeron ursinus	10.2	10.4	5.3	0.2	0.2	0.1
Hieracium gracile	37.5	20.9	20.7	0.7	0.5	0.3
Lewisia pygmea	55.3	54.7	41.3	0.7	1.1	0.6
*Ligusticum filicinum	15.3	38.0	25.3	1.8	3.9	0.7
Polygonum bistortoides	26.6	38.2	18.7	0.6	0.7	0.3
Potentilla glandulosa	7.8	3.1	4.7	0.1	0.1	0.1
Ranunculus inamoenus	9.1	4.0	11.3	0.1	0.1	0.2
*Saxifraga rhomboidea	0.4	5.8	3.3	0.0	0.1	0.0
Senecio integerrimus	14.4	14.9	5.7	0.3	0.4	0.2
Sibbaldia procumbens	30.9	23.3	19.7	1.1	0.6	0.7
Stellaria umbellata	9.1	5.6	8.7	0.1	0.1	0.1
Trifolium parryi	46.6	40.0	23.3	6.9	3.6	3.2

Table 5-5. Continued

	Relative Snow-Free Date			Relative Snow-Free Date		
	Early	Medium	Late	Early	Medium	Late
Species	Frequency			Cover		
Graminoides						
Agrostis humilis	24.0	18.9	12.0	0.6	0.8	0.7
Carex nigricans	9.1	8.0	4.0	0.5	0.3	0.2
Carex pseudoscirpoides	9.1	16.9	5.5	0.3	0.5	0.1
Carex rossii	16.7	12.7	13.3	0.7	0.3	0.5
Danthonia intermedia	15.3	8.3	2.7	1.3	0.2	0.0
**Deschampsia caespitosa*	59.6	57.6	29.3	5.7	3.7	1.6
Festuca ovina	5.1	4.4	13.3	0.1	0.1	0.2
Juncus drummondii	26.9	16.2	12.0	1.1	0.5	0.4
Luzula spicata	30.2	33.6	25.3	0.3	0.5	0.4
Phleum alpinum	19.6	15.6	13.3	0.3	0.3	0.2
Poa arctica	14.9	19.1	8.7	0.2	0.3	0.2
Poa nervosa	13.1	14.4	19.3	0.3	0.4	0.4
Poa reflexa	16.0	10.0	16.7	0.5	0.2	0.6
Trisetum spicatum	10.6	6.2	5.3	0.2	0.1	0.0
Cryptogams						
Grimmia alpestris	31.3	17.1	21.3	0.4	0.3	0.3
Polytrichum sp.	17.1	23.3	14.0	0.2	0.5	0.3

Snow and Animal Signs

The commonest animal signs observed in the study are were those of the snowshoe hare (Lepus americanus), but pocket gophers (Thomomys talpoides) and mule deer (Odocoileus hemionus) were also common at the site (Table 5-6). Late lying snow appeared not to discourage activity of any of the animals considered here; instead there is trend toward heavier use of the latest melting sites by the hare, the pocket gopher, the red tree squirrel (Tamiasciurus hudsonicus), and the mule deer (Table 5-6). None of the trends were statistically significant, however.

Physical and Chemical Characteristics of Plots

Physical and chemical characteristics are uniform for the plots assigned to the early and medium snow-free-date groups, but are often markedly different in the macroplots assigned to the latest snow-free group (Table 5-7). A slight but statistically nonsignificant increase in soil depth is correlated with increasing snowpack. That pattern may reflect either (or both) increased soil weathering rates on the late snowmelt plots (due perhaps to prolonged periods of soil moisture) or extra inorganic deposition associated with deeper snowpacks (wind deposited sediments give melting snow a dingy color in the area). Since the drifting pattern is controlled by trees, the areas heavily impacted by drifts undoubtedly migrate about as tree's grow and die. That pattern should have a time scale of several score years; thus there should be sufficient time for the vegetation at a drift site to be affected by the snowpack's water content and influence on local growing

Table 5-6. Percentage of quadrats in each snow-free-date zone showing evidence of the presence of each animal listed. Data are an average of the 1978 and 1979 samples. None of the reported differences between zones are statistically significant. The test criterion for significant was the .05 probability level (analysis of variance test).

	Relative Snow-Free Date		
Animal	Early	Medium	Late
	% Frequency		
Domestic Sheep	6.8	5.4	5.0
Mule Deer	2.1	5.7	6.8
Pocket Gopher	2.0	4.0	5.3
Red Tree Squirrel	0.2	2.2	5.4
Snowshoe Hare	33.7	29.7	38.4
Uinta Ground Squirrel	2.9	0.9	2.1

Table 5-7. Physical and chemical characteristics of the plots in each snow-release-date zone.

	Relative Snow-Free Date			Significance of F-Value for ANOVA	
Characteristic	Early	Medium	Late		
Exposure (Degrees)	286	288	289	.02[1]	NS[2]
Slope Steepness (%)	3.7	3.5	3.9	.19	NS
Surface Stone (%)	2.3	4.4	2.0	.72	NS
Soil Depth (dm)	1.7	1.8	1.9	1.00	NS
Soil Texture					
Sand (%)	35.2	36.5	24.2	4.35	**[2]
Silt (%)	31.7	38.3	34.2	3.49	*[2]
Clay (%)	33.1	25.2	41.6	10.97	**
Soil Chemistry					
pH					
0 - 2.5 cm depth	5.2	5.3	5.3	1.55	NS
2.5 -15.0 cm depth	5.1	5.2	5.2	.20	NS
Exchangeable Calcium					
0 - 2.5 cm (ppm)	3419	3599	4147	.82	NS
2.5 -15.0 cm (ppm)	1660	1765	2525	4.33	**
Exchangeable Magnesium					
0 - 2.5 cm (ppm)	455	436	371	1.04	NS
2.5 -15.0 cm (ppm)	313	310	294	0.05	NS
Exchangeable Potassium					
0 - 2.5 cm (ppm)	310	289	352	3.40	*
2.5 -15.0 cm (ppm)	153	172	242	5.11	**

Table 5-7. Continued.

	Relative Snow-Free Date			Significance of F-Value for ANOVA	
Characteristic	Early	Medium	Late		
Available Phosphorus					
0 - 2.5 (ppm)	2.6	3.4	2.2	.86	NS
2.5 -15.0 cm (ppm)	0.4	1.0	0.3	3.70	*
Soil Organic Matter					
0 - 2.5 cm	29.2	36.2	7.5	10.98	**
2.5 -15.0	13.7	15.1	6.5	16.96	**

---

1. F-Value
2. NS = Not statistically significant, * = significant at .05 level, and ** = significant at .01 level.

season, but soil formation processed would be only slighlty affected before changing tree cover forced a change in the size and/or location of snow drifts.

It is interesting that the late melting macroplots have more calcium and potassium in the 2.5-15 cm depth layer of soil than do the plots that accumulated less snow (Table 5-7). That fact reinforces the argument made above concerning the probable impermanence of deep drift sites. If deep drifts were always where they are now, one would have expected the soils of those sites to have been heavily leached or, at least, more leached than sites having lighter snowpacks.

DISCUSSION

The large differences in soil organic matter (Table 5-7) between the snow-free date groups is probably attributable to differences in sampling procedures. Soil samples for the early and medium release-date groups were collected in 1976: samples from the late-release zone were collected in 1980. The samplers appear to have removed different amounts of the humus layer prior to sampling.

In agreement with Landis and Mogren (1976), we have been unable to demonstrate a change in wood production of trees as a result of late lying snow. Likewise we have found no significant changes in tree reproduction due to late lying snow even though our latest melting plots accumulated over twice as much snow as our earliest melt plots.

We have found, as did Knight et al. (1975) that *Vaccinium scoparium* declined as larger snowpacks retarded the snow-free date (Table 5-5).

The trend toward less plant cover on later snow-release sites was not statistically significant, however, in our study. We also found *Poa nervosa* and *P. reflexa* to increase with late lying snow as did Knight et al. (1975). Other species common to this study and that of Knight et al. (1975) behaved differently in response to late lying snow in our area than in Wyoming. Whereas *Erigeron peregrinus*, *Heiracium gracile*, *Polytrichum juniperinum* and *Sibbaldia procumbens* increased on late snow sites in the Medicine Bow Mountains, the species all declined in the late snow-free plots of the Uintas (Table 5-5). The divergent results for these two studies are probably attributable to differences in the spectrum of snow-free dates considered. Knight et al. (1975) had no transects for which snow-free date was later than July 14: our late melt sites did not reach the 75% snow-free condition until July 23 in 1978.

It should be noted that understory plant responses were essentially reversed in the spruce-fir and lodgepole study areas considered in this report. Late lying snow in lodgepole pine forests (*Pinus contorta* - *Poa nervosa* habitat type) tended to increase understory diversity and productivity and almost all herbs performed best in the late snow release zone (see Chapter 4). In contrast, understory production and diversity declined on late-melt sites in the *Picea engelmannii* - *Vaccinium scoparium* habitat type investigated in this study. In addition, most of the prevalent species (87%) performed best away from areas of the latest lying snow. Nevertheless, understory production declined only about 18% on the average between our earliest and latest snow release zones (about 21 days difference in growing seasons). This amounts to a loss of about 0.86% in understory production per day delay in snowmelt. In absolute terms, this amounts to a forage loss of about 3 kg/ha per day delay in snowmelt. Viewed in another way, 3 kg of good quality forage will maintain a mature ewe sheep for about 1.3 days.

It is also of interest to note that soils are more acidic and contain considerably less of each essential plant nutrient in the spruce-fir forest considered here than soils of the lodgepole stands reported on in Chapter 4. The openness and poor growth rates of the spruce-fir forests of this section of the Uintas may be directly attributable to infertile soils.

LITERATURE CITED

Blaue, R. W. and G. H. Fechner. 1976. Phenological development of Engelmann Spruce in southwestern Colorado, pp. 367-390 In H. W. Steinhoff and J. D. Ives (Eds.), Ecological Impacts of Snowpack Augmentation in the San Juan Mountains, Colorado. Final Report, San Juan Ecology Project, Colorado State Univ. Publ., Fort Collins. 489 pp.

Choate, G. A. 1965. Forests in Utah. U.S. Forest Service Resource Bulletin INT-4. 61 pp.

Dix, R. A. and J. A. Richards. 1976. Possible changes in species structure of the subalpine forest induced by increased snowpack, pp. 311-322 In H. W. Steinhoff and J. D. Ives (Eds.), Ecological Impacts of Snowpack Augmentation in the San Juan Mountains, Colorado. Final Report, San Juan Ecology Project, Colorado State Univ., Fort Collins. 489 pp.

Hanson, W. R. 1975. The geologic story of the Uinta Mountains. Geological Survey Bulletin 1291: 1-144. U.S. Government Printing Office, Washington, D.C.

Harper, K. T., W. K. Ostler and K. B. McKnight. 1978. The Uinta ecology study, interim report. Submitted to Utah Division of Water Resources, 231 E. 400 S., Salt Lake City 84111 and U.S. Bureau of Reclamation, Office of Atmospheric Resources Management, Engineering and Research Center, Denver, Colorado 80225. 76 pp.

Harper, K. T., W. K. Ostler and K. B. McKnight. 1979. The Uinta ecology study: interim report. Report submitted to Utah Division of Water Resources, Empire Building, Suite 300, 231 E. 400 S., Salt Lake City 84111 and U.S. Bureau of Reclamation, Office of Atmospheric Resources Management, Engineering and Research Center, Denver, Colorado 80225. 76 pp.

Harrington, H. D. 1962. Manual of the plants of Colorado. Swallow Press, Inc., Chicago, Illinois. 666 pp.

Henderson, J. A., R. L. Mauk, D. L. Anderson, T. A. Davis, and T. J. Keck. 1977. Preliminary forest habitat types of the Uinta Mountains, Utah. Mimeographed Report from the Department of Forestry and Outdoor Recreation, Utah State University, Logan 84322.

Knight, D. H., C. Kyte, B. Rogers and C. R. Starr. 1975. The impact of snow on herbaceous and shrubby vegetation, pp. 175-214 In D. H. Knight (ed.), The Medicine Bow ecology project. Final Report to U.S. Bureau of Reclamation, Office of Atmospheric Water Resources, Denver, Colorado 80225.

Landis, T. D. and E. W. Mogren. 1976. Snow augmentation and wood production in subalpine forest, pp. 391-402 In H. W. Steinhoff and J. D, Ives (eds.), Ecological impacts of snowpack augmentation in the San Juan Mountains, Colorado. Final Report, San Juan Ecology Project, Colorado State Univ. Publ., Fort Collins. 489 pp.

Ridd, K. 1979. Vegetation of the Uinta Mountains above 7000 feet (A map constructed from Landsat imagery). In K. T. Harper et al., the Uinta Ecology Study: Interim report Submitted to Utah Division of Water Resources, Empire Bldg., Suite 300, 231 E. 400 S. Salt Lake City 84111, and U. S. Bureau of Reclamation, Office of Atmospheric Resources Management, Denver, Colorado 80225. 76 pp.

Ruzicka, M. 1958. Anwendung mathematisch - statisticher methoden in der geobotanik (synthetische bearbeitung von aufnahmen). Biolgia, Bratisl. 13:647-661.

CHAPTER 6

THE EFFECTS OF LATE LYING SNOW ON A SUBALPINE DANTHONIA-DESCHAMPSIA-CAREX MEADOW IN UTAH

by

William K. Ostler

K. T. Harper

and

Karl B. McKnight

ABSTRACT

The effects of increasing snowpack on subalpine meadow communities have been investigated. The data show that a 10% increase in snowpack can be expected to delay snow melt by 0.8 day and to suppress aboveground production of plants 2.4%. The effects of a 10% increase in snowpack on number of plant species per unit area and on species composition of the meadow would probably be undetectable. Likewise, flowering phenologies of the plants would be inconsequentially altered by a 10% increase in snowpack. At our study area, suppressed plant production in late snow-release zones appeared to be related to shortened growing season alone. We could not demonstrate a causal relationship between suppressed production and soil chemistry, soil moisture, or plant diseases.

Three very different annual weather patterns affected the study area during the study period. This variation allowed us to sample the dynamic response of subalpine meadow species to different climatic patterns. Both plant cover and production increased with increasing growing season precipitation. Forb cover and forb production appear to be favored over the same parameters for grasses when soil moisture supply is fully recharged by melting snow but growing season precipitation is negligible. Graminoid cover and production increased slowly early in the season in comparison to forbs and were severely restricted in the absence of summer rain.

Plant water stress in late summer was correlated with water content of the April 1st snowpack. Forbs and graminoides appear to respond to moisture stress differently with the latter group being somewhat more tolerant of stress than the former.

Flowering periods for most forbs and graminoides were monitored. Later snow-release dates did not seem to significantly influence the date of initiation of flowering in forbs. The data do suggest, however, that earlier flowering species may be more affected than later flowering species. The total flowering periods of several forbs appear to be lengthened by much delayed snow-release dates; the effect seems to be due to prolonged periods of adequate soil moisture in late-melt zones.

PRIOR BOTANICAL WORK

Despite the large area of the Uinta Mountains, few botanical studies have been made in this rugged area. Early plant floristic studies of portions of the area have been published by Pammel (1903, 1913), Cottam (1930) and Graham (1937). Several ecological studies emerged in the 1950's and 1960's (Murdock 1950, Stutz 1951, Hayward 1945, 1952, Flowers et al. 1960, Christensen and Harrison 1961, and Peterson 1969). Recent floristic collections have been made by S. L. Welsh, S. Goodrich, and M. Lewis. Floristic lists have been published by Lewis (1970), Andersen and Holmgren (1976), and Ostler and Anderson (in Harper et al. 1978). The area is now fairly well known floristically, but quantitative analyses for plant communities are uncommon. This paper deals with the dynamics of a subalpine meadow over a four-year period.

STUDY AREA

The study area is located on the northern slope of the Uinta Mountains in Summit County, Utah (Fig. 1-1). The study area lies at

about 3,200 m elevation on Elizabeth Ridge, a north-south trending prominence which forms the divide between the Great Basin and the Colorado River Basin drainage systems. The area appears to have escaped glaciation during the Pleistocene, because of its isolation from large areas where ice might accumulate (Hanson 1975). The study area is situated on the nearly flat top of the ridge. Drainage water moves slowly from east to west across the area (Fig. 6-1). Soil depth increases down the drainage gradient; thus soils are shallow along the eastern side of the ridge and gradually increase in depth across the .5 km wide study area. The soils are derived from late Tertiary alluvium; parent material is uniform across the study area, but organic matter content of the soil increases down the drainage gradient. Spruce (Picea engelmannii) and fir (Abies lasiocarpa) trees have established on the shallower soils to the east but appear unable to invade the subalpine meadow where soils are deeper and more uniformly moist throughout the year. Ellison (1954) has noted a similar phenomenon on the Wasatch Plateau of Utah. He attributes the phenomenon to an atypical kind of succession in which woody plants invade xeric, creviced rock sites and foster formation of a soil of moderate depth on which herbaceous plants are more competitive than replacements for the woody plants.

We observed the effects of snow on plants in this study by analyzing the response of plants to natural drifts of variable size in an area that is otherwise similar ecologically. Although total elevational change across the study area is less than two meters, the open forest to the east causes the prevailing westerly winds of winter to begin to deposit their burden of snow more than 100 m in front of the forest edge. As a consequence, a large snowdrift parallels the forest-meadow

Figure 6-1. Early spring on the subalpine meadow at Elizabeth Ridge. Note the "snow-poles" in the background: each stands at the center of a 0.02 ha macroplot. Free water from the melting snowbank drains slowly toward the top of the photo (northwest).

border. At the point of maximum depth (which usually lies immediately behind the forest edge), the drift may be over twice as deep as along its leading edge.

Annual precipitation at the study area is not available for the 1975-76 water year (Oct. 1 - Sept. 30), but annual precipitation in the 1976-77 water year was about 56 cm, for 1977-78 the total was 73 cm, and in the 1978-79 water year, precipitation again totaled about 73 cm.

METHODS

Twenty-nine .02 ha circular study plots (macroplots) were established in a stratified block design across the meadow study area. The design allocated about equal numbers of macroplots to areas covered by shallow; moderately deep, and deep snowdrifts. Each macroplot was permanently marked with a steel reinforcing bar at its center. The .02 ha macroplots are small enough to minimize within-plot environmental and vegetational heterogeneity but large enough to give a fair sample of the entire plant community at given locations.

Within each macroplot, 25 subsamples (quadrats) were regularly spaced across the surface of each macroplot. Each quadrat was circular in shape and had an area of 0.25 m^2. To facilitate relocation of quadrats, each was marked by a red, 8 cm long, wooden dowel driven into the soil at the center of the quadrat (see Harper 1976 for a more detailed description of the quadrat placement procedures). In 1979, a zinc coated nail was also driven into the ground at the center of each quadrat to insure that each could be precisely relocated with a metal detector should the need arise.

At each quadrat, the following data were recorded: 1) total living cover, 2) an estimate of the foliage cover of each species that shaded the quadrat, 3) cover of plant litter, 4) cover of rock of greater than 5mm diameter, and 5) composition of the total living cover with the relative contribution of the major lifeform groups being estimated as percentages of the total. Cover for all categories was estimated using a cover-class method (Daubenmire 1968) with the classes delimited as shown in Table 6-1. Lifeform groups recognized in the relative cover estimates were: trees, shrubs, perennial graminoides, perennial forbs, annuals, and cryptogams (mosses, liverworts, and lichens). Total number of species per quadrat and per macroplot was recorded. Frequency values for all species were obtained by dividing quadrats of occurrence for each by total quadrats in the sample. All samples were taken in late July and early August of each year. Frequency and cover estimates for each species were multiplied to provide an index (F X C index) of commonness. This F X C index is modelled after a ubiquity index described by Curtis (1959).

Production was estimated using a method described by Hutchings and Schmautz (1969). Four 0.25 m^2 quadrats were equally spaced around and about 1.0 m from a central quadrat of equal size. Production of each of the major lifeform groups was then estimated in each peripheral quadrat as a percentage of production of the corresponding group in the central quadrat. The center quadrat was then clipped by lifeform group and the tissue was oven dried and weighed. Two clusters of five quadrats each were sampled per macroplot per year giving a total of ten estimates of production per macroplot. The lifeform groups recognized were graminoides, forbs and annuals. Shrubs were absent in the study

---

Table 6-1. Plant cover was estimated using a cover-class method similar to that proposed by Daubenmire (1968). Cover classes recognized are shown below.

Class	Range of Cover Included in the Class
Trace (T)	Less than 1.0%
1	1.1 - 5.0 %
2	5.1 - 10.0 %
3	10.1 - 25.0 %
4	25.1 - 50.0 %
5	50.1 - 75.0 %
6	75.1 - 95.0 %
7	over 95.0 %

area and cryptogams were not harvested because of the difficulty of determining what was current year growth. Annuals never contributed more than 0.5 percent of the production.

Soils were sampled in the fall of 1976. Samples were taken from the 2.5-15 cm layer of soil. Composite samples were assembled from 12-15 subsamples drawn from the entire macroplot. Soils were oven dried at 60°C and sieved to remove gravel and rock particles over 2.0 mm in diameter. Samples were analyzed for texture, pH, available phosphorus, and exchangeable potassium, magnesium, and calcium. Penetrometer readings were taken at the center of alternate 0.25 m^2 quadrats in each macroplot giving a total of 13 estimates of depth to impenetrable material in the soil profile. Slope and aspect of each macroplot was also taken.

All plant species on the meadow were collected and identified. Specimens are on file in the Brigham Young University Herbarium. Plant nomenclature follows Harrington (1962). Species not found in Harrington's flora of Colorado were identified using the flora of Welsh and Moore (1973).

Snow-release dates were obtained by visiting the study area twice weekly during the melt season. This was usually accomplished on cross-country skiis or on an all-terrain vehicle. Snow cover was estimated on each stand at each visit; because small patches of snow often lingered for several days after the remainder of a macroplot became snow-free, the 75% snow-free criterion was used for snow-free date for individual macroplots. In addition, depth and water content of the April 1 snowpack was recorded for each macroplot in 1977, 1978, and 1979. Four-meter-tall poles marked at meter intervals were centered on each macroplot to facilitate plot relocation for the April 1 snow depth measurements (Fig. 6-2). Snow cores were taken each year at each macroplot to provide an estimate of snow water content.

RESULTS

Characteristics of the Study Area

The physical environment of the study area is relatively uniform from one snow-release zone to another (Table 6-2). The terrain is uniform with slopes that average approximately 3%. Exposure and drainage is northwesterly with a mean direction of 281 degrees (corrected for angle of declination). The meadow soils are acidic having a modal pH of 5.2 and are classified as peaty clay loams. Certain meadow characteristics such as soil depth, soil organic matter, and plant moisture stress are negatively associated with April 1 snow depths and snow-release dates. Unexpectedly, several biogenic elements of the top 15 cm of the soil are positively associated with snow depth and snow-release dates (Table 6-2). The soils are nutritionally improverished in essential elements when compared with other mountain soils of Utah (see Table 4-7).

The meadow is dominated by perennial forbs and grasses. Average living cover is 76.3%; litter contributes another 9% to the cover (Table 6-3). There is little exposed rock. Above-ground annual production on the meadow averages 993 kg/ha (890 lb/acre).

The area is a preferred foraging area for both mule deer and sheep. Deer utilize the area throughout the growing season and sheep graze the area in late August or September. Grazing pressure is light.

Figure 6-2. "Snow-poles" were used to locate centers of macroplots. Three poles are visible in this photo.

Table 6-2. Abiotic characteristics of the study area. All soil measurements were taken in 1976. Soil samples are drawn from the 2.5-15 cm depth layer.

	Snow Release Zone		
Characteristic	Early	Middle	Late
No. of macroplots sampled	11	10	8
1977 April 1st water content of snowpack (cm)	31.0 ± 1.4	43.1± 6.1	55.2± 5.1
1978 April 1st water content of snowpack (cm)	49.5 ± 3.8	67.4± 6.5	96.5±13.7
1979 April 1st water content of snowpack (cm)	47.7 ± 2.4	60.3± 5.1	88.7±15.2
1977 snow-free dates (June)	5.0 ± 0.0	8.0± 1.8	13.0± 1.3
1978 snow-free dates (June & July)	22.3 ± 0.5	27.6± 2.0	7.1± 2.3
1979 snow-free dates (June)	10.5 ± 1.8	14.2± 2.2	24.3± 2.8
Slope (%)	3.1 ± 1.5	3.8± 1.4	3.5± 1.4
Exposure (degrees from true north)	300 ±12	297 ±13	292 ± 9
Soil texture			
% Sand	28.4 ± 6.6	35.0± 6.4	34.1± 5.7
% Silt	42.8 ± 4.8	33.0± 4.7	38.7± 8.2
% Clay	28.4 ± 6.6	35.0± 6.4	27.1±11.2
Soil depth (dm)[1]	3.5 ± 0.8	3.0± 0.8	2.1± 0.5
Soil organic matter (%)	19.7 ± 1.8	16.3± 2.2	15.1± 2.8

Table 6-2. Continued.

Soil pH	5.2 ± 0.1	5.2 ± 0.1	5.3 ± 0.2
Soil phosphorus (ppm)	0.2 ± 0.3	0.5 ± 0.6	0.5 ± 0.9
Soil potassium (ppm)	107 ±16	112 ±30	149 ±66
Soil calcium (ppm)	1087 ±121	1089 ±207	1118 ±308
Soil magnesium (ppm)	181 ±35	201 ±58	188 ±68
Moisture stress of <u>Antennaria parvifolia</u> leaves on Aug. 10, 1978 (bars)	11.4 ± 3.2	6.2 ± 1.0	5.6 ± 0.8

---

1. Depth to impenetrable material (usually stone) as determined with a thin metal rod.

Table 6-3. Average vegetational and snowpack characteristics of the study area. All figures are averages of the four years of study. Basic data drawn from Harper (1977) and Harper et al. (1978b).

	Snow Release Zones		
Characteristic	Early	Middle	Late
No. species/0.02 ha	20.7	21.5	24.9
No. species/0.25 m^2	12.0	11.7	11.8
Total living cover (%)	73.2	79.4	67.2
Production (g/m^2)	96.5	107.3	91.7
Composition of above-ground Production			
Forbs (%)	41.7	36.7	47.3
Graminoides (%)	58.3	63.3	52.7
Litter (%)	13.9	12.5	11.0
Rock (%)	0.2	0.5	5.6
Ave. April 1 Water content of snowpack (cm)	42.8	57.0	80.2
Ave. melt date (June)	13	16	25

The Influence of Snow-free Date on Plants

Snow-release dates influence several biotic characteristics of the meadow. Species diversity (species/macroplot) and forb production are positively correlated with later snow-melt dates, while total cover, total production, percent graminoid production and number of species/quadrat are negatively correlated (Table 6-3). These results are similar to those for other studies which have investigated short-term effects of late lying snow (Weaver 1974, Knight et al. 1975).

Total plant cover decreases with increasing snow depth and lateness of release from snow cover, but it does not decrease monotonically (Table 6-3). Other data collected in conjunction with this study suggest that where soil moisture is likely to be deficient for extended periods during the growing season (e.g., in lodgepole pine forest or on subalpine herblands, Chapters 4 and 7), deeper snowpacks will enhance plant cover and production. Where soil moisture is usually adequate throughout the growing season, deeper snowpacks depress plant cover and production apparently through a shortened growing season (Canaday and Fonda 1974, Weaver 1974, Weaver and Collins 1977, Harper 1978, Knight et al. 1979).

Total plant cover showed a decline of 6.0% between the earliest and the latest snowmelt groups (Table 6-3). Since those snowmelt groups were separated by an average of 12 days during the study (Table 6-3), there was a loss of about 0.5% of the total living cover per day delay in snowmelt in this study (Tables 6-3). Weaver (1974) noted that the plant cover in Montana decreased from 75% to 50% with a delay in snow-release of 24 days (approximately 1% decrease per day delay in snow-release). Billings and Bliss's (1959, Table 11) data from the Medicine

---

Bow Mountains of Wyoming indicate that total living plant cover declined about 1.5% per day delay in snowmelt date.

Plant production also appears to be negatively associated with suppressed snow-release dates (Tables 6-3 and 6-5). Our results are based on the 1977, 1978, and 1979 data only because release dates were not obtained for 1976. Table 6-5 shows the predicted decline in plant production with given amounts of additional snow. Weather modification researchers with the U.S. Bureau of Reclamation consider it possible to enhance winter snowpack water content by at least 10%. Given a 10% increase in snowpack, we estimate that there will be a 0.8 day delay in snow melt and plant production will decrease by 2.4% (Table 6-5). Our estimates are in close agreement with those of other studies. Webber, et al. (1976) predicted about a 1.4% decline in production per day delay in snowmelt in the Colorado Rockies. Weaver (1974, Fig. 1) shows approximately a 3% decrease in production per day delay in snow release. Canaday and Fonda's (1974) results indicate that production declined about 1.4% per day delay in snow melt. Knight et al. (1974) present data for mesic subalpine meadows in Wyoming which suggest that above-ground production there may decline as much as 3.8% per day delay in snow release date. Frank (1973) predicted that a 10% increase in snowpack would lengthen the duration of the snowpack less than 1.5 days, but he could not detect a significant correlation between snowpack and herbaceous plant production.

Several workers have concluded that growing season length is the primary factor responsible for decline in above-ground plant production on sites where snow drifts accumulate on mesic mountain meadows (Billings and Bliss 1959, Canaday and Fonda 1974, Webber et al. 1976, Weaver and Collins 1977). Many workers acknowledge the possibility that other factors such as altered soil temperature and growing season air temperature (Weaver 1974, Knight et al. 1975 and Dix and Richards 1976) may delay depletion of soil moisture (Knight et al. 1979), alter microbial decomposition rates (Webber et al. 1976), or increase susceptibility of green plants to pathogens (Dix and Richards 1976) may be associated with late lying snow and alter plant response on late-melt sites, but there is little evidence to support the hypothesis that those variables have a strong effect on yield of the total plant community.

Although Weaver (1974), Weaver and Collins (1977) and Knight et al. (1979) consider shortening of the growing season to be the major avenue by which late lying snow depressed production on mesic meadows in Montana and Wyoming, they suggest that the leaching action of excess water from heavy snowpacks may reduce the supply of certain essential nutrients in the soil and compound the adverse effects of shortened growing season. We recognize that heavy leaching could be a problem on sites consistently covered by heavy snowpacks, but we note that soil nutrients (phosphorus, potassium, calcium and magnesium) were not lower in the soils of our late snow-release zones (Table 6-2). We also found no evidence of increased incidence of plant diseases in the late melt zone. At our site, reduced plant production in areas covered by large drifts seems to be related to a shortened growing season only.

Prevalent vascular plant species on the meadow are shown in Table 6-4. The number of prevalent species listed is equal to the average number of vascular plant species per macroplot. The five most dominant species according to the F x C index are: *Ligusticum filicinum*, *Danthonia*

Table 6-4. Prevalent species in the study area. Prevalents are determined as by Curtis (1959) with the exception that the C X F index here utilizes cover rather than constancy.

Species	Frequency	Cover	Cover X Frequency
Achillea millifolium	6.1	0.2	1.2
Agoseris glauca	9.7	0.3	2.8
Antennaria parvifolia	83.1	7.1	589.5
Artemisia scopulorum	68.3	6.0	408.0
Caltha leptosepala	58.3	2.7	160.1
Epilobium alpinum	48.8	0.5	22.4
Erigeron ursinus	10.6	0.6	6.6
Gentiana calycosa	18.0	0.8	14.9
Lewisia pygmea	64.8	1.2	75.2
Ligusticum filicinum	94.8	12.6	1195.7
Polygonum bistortoides	97.4	4.3	422.1
Potentilla diversifolia	17.3	0.6	9.9
Trifolium parryi	48.0	2.7	129.3
Viola adunca	8.1	0.3	2.5
Agrostis humilis	84.6	4.7	400.4
Carex nigricans	20.6	1.2	24.4
Carex pseudoscirpoidea	89.3	8.9	796.6
Danthonia intermedia	86.5	12.4	1076.6
Deschampsia caespitosa	87.9	10.5	925.3
Eleocharis aciculare	7.6	0.2	1.7
Luzula spicata	22.2	0.3	6.1
Phleum alpinum	20.3	0.5	9.9
Poa arctica	10.9	0.2	1.7

Table 6-5. Predicted impacts of different relative increases in snowpack on plant growth in a subalpine meadow. Values are based on 1977, 1978, and 1979 data. This table is based on an exponential function for cover ($Y = 78.5e^{-.0076x}$, $r = -.43^{*}$, $n = 29$) and production ($Y = 29.6e^{-.024x}$, $r = -.73^{**}$, $n = 29$). Thus plant cover and production is lost less rapidly with small increases in snowpack than with larger increases.

Increase in Snowpack (%)	Delay in Melt-Date	Relative Decline in Plant Cover (%)	Decline in Plant Production[1]
5	0.3 day	.2	.9
10	0.8 day	.6	2.4
15	1.3 day	1.0	3.8
25	2.3 day	1.7	6.7
30	3.0 day	2.3	8.7

1. Grams/m^2

* - Significant at the .05 level.

** - Significant at the .01 level.

---

intermedia, *Deschampsia caespitosa*, *Carex pseudoscirpoidea*, and *Antennaria parvifolia*.

Fourteen vascular species appear to prefer the late snow-release zone; six species achieve their maximum abundance in the early release zone and ten species appear to show little or no preference (Table 6-6). The preference of some species for the late snow-release zone may be related to reduced biotic competition (as a consequence of reduced cover), greater habitat diversity (more microenvironmental sites due to exposed rock) or edge effect from the forest (*Hieracium gracile* is the only species which appears to fit this category). Increased habitat heterogeneity caused by exposed rock and forest-edge influences in the late snow-release zone may be the cause of the increase in number of vascular species per macroplot in that zone (Table 6-5).

Even though there are numerous species in the late-release zone, the average cover of species that prefer that zone is low (only 1.7%, see Table 6-6). The equivalent figure for species that prefer the early-release zone is 5.1%. For species showing no preference for a snow-release zone, average cover is 4.1%. These data support the hypothesis that the late-release zone is a much harsher environment than the other two zones. Weaver (1974) reported a decline in frequency for dominant species along a snow gradient in Montana.

Year-to-Year Dynamics

Production estimates taken in all four years illustrate the dynamics of plant production on the meadow and the influence of annual patterns of temperature and precipitation on plant cover and production (Table 6-7). The vegetation was sampled during the same calender period

Table 6-6. Average response of individual species to the snow release gradient. Each value represents living cover of the species averaged for the years of record.

	Snow Release Zone		
Species	Early	Middle	Late
Achillea millifolium	.1	.1	.4
Agoseris glauca	.5	.1	.1
Antennaria parvifolia	4.5	6.6	5.5
Artemisia scopulorum	8.0	3.9	5.5
Caltha leptosepala	2.0	2.6	1.9
Claytonia lanceolata	.0	.0	.1
Epilobium alpinum	.4	.4	.4
Erigeron peregrinus	4.4	5.3	5.3
Erigeron ursinus	.4	.1	1.0
Gentiana calycosa	.4	1.1	.3
Hieracium gracile	.0	.0	.1
Lewisia pygmea	1.1	1.3	3.4
Ligusticum filicinum	12.2	12.7	8.8
Polygonum bistortoides	5.0	3.4	4.9
Potentilla diversifolia	.9	.3	.2
Senecio integerrimus	.1	.0	.3
Sibbaldia procumbens	.0	.0	.7
Trifolium parryi	3.0	2.1	1.9
Viola adunca	.2	.3	.4

Table 6-6. Continued.

Agrostis humilis	1.7	2.8	2.6
Carex micropteris	.0	.0	.3
Carex nigricans	.2	1.5	2.0
Carex pseudoscirpoidea	7.4	8.2	6.0
Danthonia intermedia	13.4	12.3	3.0
Deschampsia caespitosa	8.8	12.5	14.7
Eleocharis aciculare	.2	.5	.0
Juncus drummondii	.0	.2	.4
Luzula spicata	.1	.1	.3
Phleum alpinum	.3	.6	.5
Poa arctica	.1	.1	.3
Total Cover (All Green Plants Combined)	76.2	82.3	68.2

Table 6-7. Production estimates for the four sampling years. All figures are dry weight estimates of above-ground, annual production in grams/meter^2.

Plant Group	Snow-Release Zone	Year				
		1976	1977	1978	1979	Ave.
Total	Late-release Zone	78.6	95.2	93.7	80.8	87.1
	Middle-release Zone	118.8	124.9	78.8	106.6	107.3
	Early-release Zone	117.3	112.4	56.2	100.2	95.5
	Average	104.9	110.8	76.2	95.9	97.0
Forb	Late-release Zone	36.6	37.2	54.0	37.0	41.2
	Middle-release Zone	42.4	39.6	31.7	43.9	39.4
	Early-release Zone	45.8	45.2	28.3	42.0	40.4
	Average	41.6	40.7	38.0	41.0	40.3
Grasses	Late-release Zone	42.0	58.0	39.7	43.8	45.9
	Middle-release Zone	76.4	85.6	47.1	62.7	68.0
	Early-release Zone	71.5	67.6	27.9	58.2	56.3
	Average	63.3	70.4	38.2	54.9	56.7

every year, but since growing season initiation was dependent upon annual snow-free date, the same calendar date for sampling did not represent the same period of development for plants. During the winter of 1975-76 accumulated snowpack was near the long-term average for the region. During the winter of 1976-77, Utah and the West in general experienced a severe drought with the Unita Range receiving the smallest accumulated snowpack on record, approximately 35% of normal (Whaley and Jones 1977). The light snowpacks melted early, thus snow-free dates were unusually early on our study plots in 1977. During that growing season, however, precipitation was heavy (about 18 cm at our study area) and temperatures were below average. The winter of 1977-78 produced snowpacks that were slightly above normal (110%): subsequent snow-free dates were about 3 weeks later than in 1977 (Whaley and Lytton 1978 and Table 6-2). However, there was essentially no precipitation at the study area during the 1978 growing season. The snowpacks of the 1978-79 winter averaged about 102% of normal at Elizabeth Ridge and the growing season of 1979 was again dry with only about 7 cm of rainfall accumulating in several small storms over that period.

Because of the difference in snow-release dates between 1977 and 1978, the sampling dates were in effect 2 weeks earlier in the latter year. Earlier sampling dates (in terms of plant development) affected the relative stage of development of grasses and forbs in 1978 as compared to 1977. Table 6-7 shows that total above-ground production was down in 1978, but forb production was actually higher in that year than in 1977, with all of the gain accruing in the late-melt zone. Graminoid production in 1978 was most seriously reduced in earlier snow-release zones.

The data suggest that above-ground growth of grasses reaches maximum production later than does that of forbs at Elizabeth Ridge. The summer drought of 1978 with its warmer temperatures actually enhanced forb production in the late-release zone where soils had sufficient moisture to keep plants growing until harvest time. The early snow-melt zones appear to have dried out before the forbs reached peak production, thus severely restricting production. The late maturing grasses were handicapped by 1978 conditions in all snow release zones with the severity of impact being progressively greater, the earlier the release date. The major grasses, *Deschampsia caespitosa*, *Danthonia intermedia* and *Agrostis humilis*, had not produced flowering stalks by sampling time in 1978, but they had flowered by that date in 1977.

Snow Release Dates and Plant Water Stress

Plant water stress was estimated on August 10, 1978, using a plant pressure press (model J-14) made by Campbell Scientific, Logan, Utah. Stress was recorded as the amount of pressure required to force water out of the broken xylem tissue of detached leaves. A species (*Antennaria parvifolia*) which occurred on all stands was used as the test species. Water stress was determined for five individuals at each of the 29 macroplots. A Kruskall-Wallace procedure (Gibbons 1976) was used to determine if plant stress differed significantly between snow-release date zones. Mean stress for each zone differed significantly from all other zones. The means for the early, middle and late-release zones were 11.4, 6.2, and 5.6 bars, respectively (Table 6-8). Weaver (1974) reported similar results in that he found soil water stress to be least on sites where snow melted late and greatest on early snow-release sites.

Table 6-8. Plant moisture stress in bars for *Antennaria parvifolia* on a variety of macroplots in the study area. Each value is an average of five samples/site. The transects noted are shown in Fig. 5-1.

	Snow-Release Zone		
Transect	Early	Middle	Late
1	14.0 ± 2.3	6.6 ± 0.5	5.2 ± 0.5
2	16.3 ± 3.7	8.1 ± 0.5	4.6 ± 1.3
3	12.8 ± 1.2		6.2 ± 0.9
4	12.7 ± 2.9	6.3 ± 1.0	4.0 ± 1.5
5	11.8 ± 2.2	5.3 ± 0.9	4.5 ± 1.5
6	12.2 ± 2.0	6.2 ± 1.1	3.9 ± 0.5
7	10.0 ± 3.0	4.8 ± 0.8	
	5.3 ± 1.3		
8	10.6 ± 2.3	6.1 ± 1.6	5.9 ± 1.1
9	10.1 ± 0.9	6.4 ± 0.6	4.5 ± 1.0
10	6.8 ± 0.7	7.1 ± 0.8	
		6.2 ± 1.2	
Averages	11.4 ± 3.2	6.2 ± 1.0	4.9 ± 1.0

Water stress of 16 other species was also measured in early and late snow-release macroplots (Table 6-9). A paired t-test was used to evaluate the significance of the difference in plant stress between early and late snowmelt plots. The results show that for all species, the late-release zone had significantly lower moisture stress readings (Table 6-9). The absolute differences between samples was variable, however. A possible explanation for the observed differences among species in respect to plant moisture stress on common sites may be rooting depth.

One other feature of Table 6-9 is noteworthy: graminoides and forbs differ markedly. These two lifeform groups were compared using a Mann-Whitney test (Gibbons 1976): the two groups represent significantly different responses. The probability that the average stress of graminoides and forbs on the early and late-snow-release zones represents a common population is .021 and .009 respectively.

Since moisture stress may be affected by soil depth as well as size of snowpack and time of snowmelt, correlations were run to determine the individual affects of soil depth and snowpack water content on plant moisture stress. The analysis correlating plant stress with soil depth gave a significantly negative correlation (r = -.52, Fig. 6-3). Thus soil depth is influencing plant moisture stress in a direction opposite that predicted (normally deeper soils store more water; hence plants growing thereon should show less stress). The correlation between plant moisture stress and snowpack water content for 1978 was highly significant (r = -.85, Fig. 6-4). A multiple regression with soil depth

Table 6-9. Average plant moisture stress in bars for selected species from two macroplots (one each in the early and late snow-release zones).

	Snow-Release Zone	
Species	Early	Late
Forbs		
Achillea millifolium	7.0	2.8
Agoseris glauca	4.6	3.8
Antennaria parvifolia	12.7	4.8
Artemisia scopulorum	5.6	4.5
Erigeron peregrinus	8.1	6.3
Lewisia pygmea	3.7	2.7
Ligusticum filicinum	5.2	3.3
Potentilla diversifolia	9.8	4.5
Trifolium parryi	6.4	4.0
Average	7.0	4.1
Graminoides		
Agrostis humilis	9.1	7.7
Carex nigricans	9.6	7.5
Carex pseudoscirpoidea	13.6	6.7
Danthonia intermedia	9.0	7.5
Deschampsia caespitosa	7.9	3.6
Phleum alpinum	9.6	5.7
Average	9.8	6.5

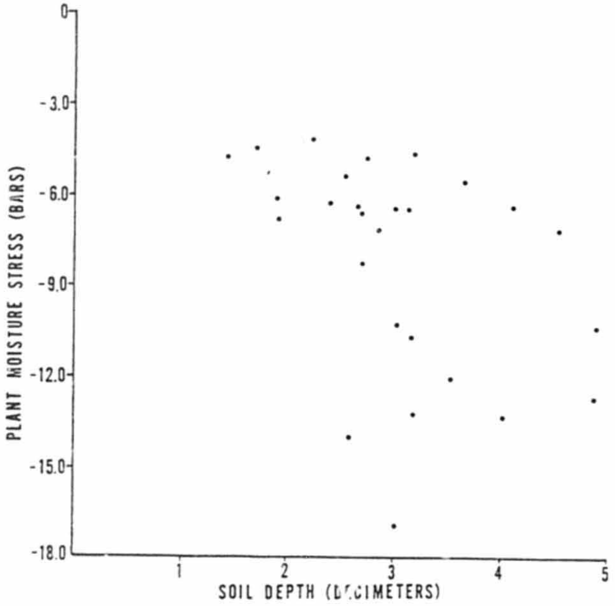


Figure 6-3. The regression of plant moisture stress on soil depth. The relationship is significant at the .01 level.

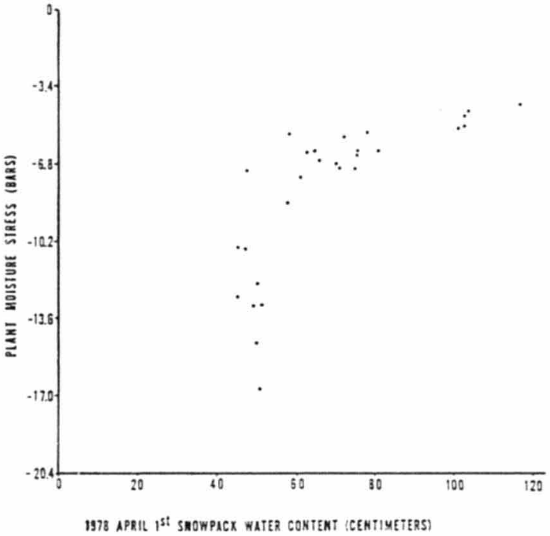


Figure 6-4. The regression of plant moisture stress on water content of April 1, 1978 snowpack. The relationship appears to be a power function; analyzed as such, the relationship is significant at the .01 level.

and April 1st water content as the independent variables shows that soil depth adds little information not available in snowpack water content for predicting plant moisture stress.

Snow-Release Date and Phenology

The study area was visited twice weekly during the growing season in order to document the initiation of flowering of a variety of forbs. Sampling was continued until the middle of August. By mid-August, all except 3 species (Erigeron ursinus, Gentiana calycosa, and Ligusticum filicinum) had initiated flowering. The flowering periods for forb species appear in Fig. 6-5.

The graminoides were not intensively studied, but their blooming periods were noted on several visits throughout the season. Their approximate blooming periods are shown in Fig. 6-6.

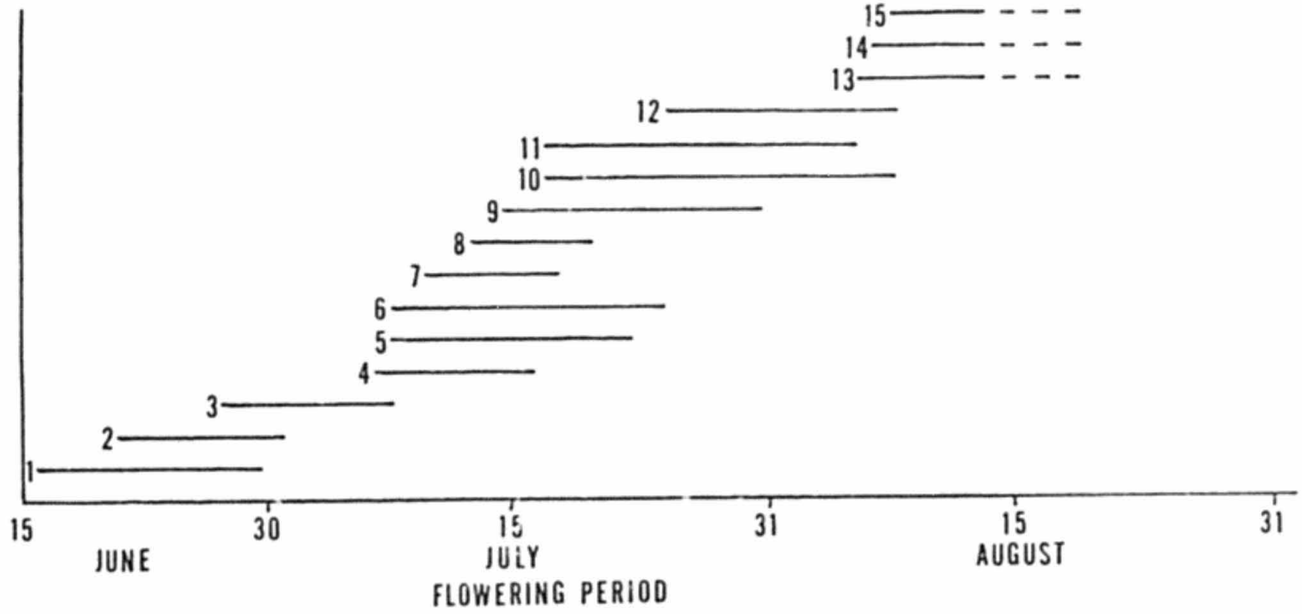
Flower initiation dates and duration of the flowering period of several species in 1977 are reported for the three snow-release zones in Table 6-10. Average floral initiation date was delayed 1.5 days when snow-release date was delayed 8 days. This is a .2 day delay in floral initiation for each day of delay in snow-release. Species which flower early (June and July) seem to be more likely to be delayed by later snow release dates than species which flower later (August). This relationship was not statistically significant, however.

Seven of the 9 species examined showed an increase in flowering period duration in response to later snow-release dates (Table 6-11). The average increase for the 7 species was 6.3 days (4.1 for all 9 species) or approximately .8 days for each day that snow release was delayed. The 2 species which showed a decrease in duration of flowering

---

Figure 6-5. Flowering periods of several forb species in the study area during 1977. Numbers correspond to the following species:

1. Ranunculus alismaefolius
2. Claytonia lanceolata
3. Sibbaldia procumbens
4. Viola adunca
5. Potentilla diversifolia
6. Lewisia pygmea
7. Trifolium parryi
8. Caltha leptosepala
9. Polygonum bistortoides
10. Artemisia scopulorum
11. Erigeron peregrinus
12. Ligusticum filicinum
13. Senecio integerrimus
14. Erigeron ursinus
15. Gentiana calycosa


15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
15
30
JUNE
15
JULY
31
15
AUGUST
31
FLOWERING PERIOD

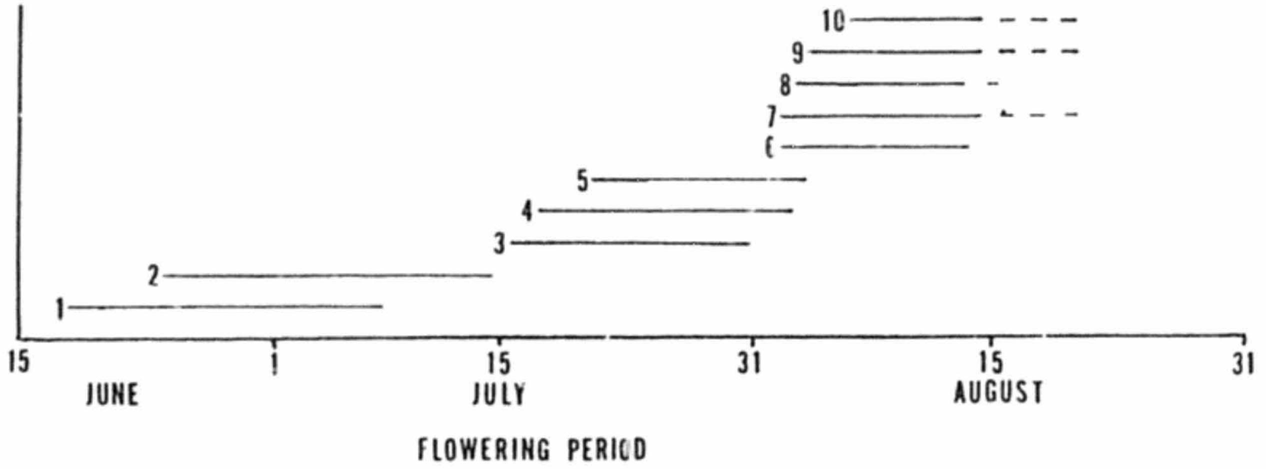


Figure 6-6. Flowering periods of several graminoid species in the study area during 1978. Flowering periods in 1978 were approximately one week later in the 1977 season. Numbers correspond to the following species:

1. *Carex pseudoscirpoidea*
2. *Carex nigricans*
3. *Eleocharis aciculare*
4. *Juncus drummondii*
5. *Luzula spicata*
6. *Deschampsia caespitosa*
7. *Danthonia intermedia*
8. *Agrostis humilis*
9. *Phleum alpinum*
10. *Poa arctica*

Table 6-10. Average initiation dates for flowering of several forb species in the three snow-release zones in 1977.

		Release zones		
Species	Month	Early	Middle	Late
Caltha leptosepala	June	13.3 + 3.2	13.6 + 1.6	14.4 + 1.7
Trifolium parryi	July	2.0 ± 0.0	2.0 ± 0.0	3.6 ± 4.6
Potentilla diversifolia	"	2.0 ± 0.0	4.3 ± 3.6	5.4 + 5.0
Lewisia pygmea	"	9.0 ± 0.0	6.5 ± 5.4	8.0 + 4.2
Artemisia scopulorum	"	9.6 + 1.8	12.0 + 3.2	12.8 + 3.1
Viola adunca	"	13.0 ± 3.5	12.0 ± 4.2	8.7 ± 6.5
Erigeron peregrinus	"	17.5 + 6.0	19.8 + 4.1	25.0 + 6.8
Erigeron ursinus	August	3.8 ± 7.0	8.3 ± 4.0	2.6 ± 5.1
Gentiana calycosa	"	7.5 ± 6.4	5.9 ± 8.3	8.3 + 4.1
Polygonum bistortoides	"	9.0 ± 0.0	10.8 ± 2.9	12.8 ± 3.1
Ligusticum filicinum	"	10.1 + 3.0	10.0 ± 3.2	9.8 + 3.5
Senecio integerrimus	"	13.3 ± 5.6	15.0 + 0.0	16.4 ± 5.0

Table 6-11. Average duration of the flowering period (days) for several forb species in the three snow-release zones in 1977.

	Snow-Release Zone		
Species	Early	Middle	Late
Lewisia pygmea	6.0	13.8	17.8
Viola adunca	7.3	7.0	17.7
*Senecio integerrimus**	15.2	11.7	18.7
Caltha leptosepala	19.9	21.0	24.4
Ranunculus alismaefolius	21.0	19.3	28.0
Potentilla diversifolia	24.0	22.8	26.6
Trifolium parryi	26.0	27.6	30.4
*Erigeron peregrinus**	26.3	21.9	21.3
*Artemisia scopulorum**	31.4	29.5	28.9

* The three latest blooming species of the nine considered.

in the late-release zone are 2 of the 3 latest blooming species of the 9 considered. Late flowering species would be expected to be little affected by additional snow.

SUMMARY AND CONCLUSIONS

Our data demonstrate the effects of increasing snowpack on subalpine meadow communities. Most abiotic variables (slope, exposure, soil texture, and pH) do not differ strongly between snow-release zones in this study. Those variables which do vary were expected to be directly or indirectly influenced by the dependent variable of additional snow. The dependent variables which are negatively correlated with increasing snow and resulting later snow-release dates are soil depth, organic matter, plant moisture stress, total living plant cover, number of species per quadrat and plant production. Four variables, number of species per macroplot, exposed rock, forb production and total flowering period are positively associated with increasing size of the snowpack.

Three very different climatic regimes characterized the study area during the period of record. This variation allowed us to study the dymanics of seasonal response of the subalpine meadow species to different climatic patterns. Both plant cover and production varied favorably in response to increased growing season precipitation. Percent forb cover and forb production appeared to be preferentially favored by early season sampling, while percent graminoid cover and graminoid production showed an opposite trend. Graminoid production was down 38% with approximately a 20 day delay in the snow-release date. Plant phenology was delayed less than snow-release date because of the 'catching up' phenomenon noted by Scott and Billings (1974) and Weaver and Collins (1977).

Duration of flowering periods for most forbs and graminoides were monitored. Late snow-release dates did not seem to significantly delay the initiation of flowering in forbs. The data suggest that earlier flowering species may be more affected in respect to initiation of flowering than later flowering species. The total flowering period of each of several forbs appears to be lengthened by late snow-release dates. This phenomenon probably means that many species cease flowering in the study area because of water stress rather than genetic limitations.

The vegetation of the community is described and prevalent species are noted. Individual species responses to increasing snow show that 14 species prefer the late-release zone while only 6 prefer the early-release zone. Ten species show no preference for snow-release zones. The 14 species which prefer the late release zone contributed much less cover on the average than those which prefer the early zone (1.7 and 5.1% respectively).

LITERATURE CITED

Anderson, B. A. and A. H. Holmgren. 1976. Mountain plants of northeastern Utah. Utah State University, Agricultural Experiment Station Circular 319:1-148. Logan, Utah.

Billings, W. D. and L. C. Bliss. 1959. An alpine snowbank environment and its effects on vegetation, plant development, and productivity. Ecol. 40:388-397.

Canaday, B. B. and R. W. Fonda. 1974. The influence of subalpine snowbanks on vegetation pattern, production and phenology. Bulletin of the Torrey Botanical Club 101:340-350.

Christensen, E. M. and B. F. Harrison. 1961. Ecological study area at Lily Lake in the Uinta Mountains, Utah. Proceedings of the Utah Academy of Sciences, Arts and Letters 38:36-49.

Cottam, W. P. 1930. Some unusual floristic features of the Uintah Mountains, Utah. Proceedings of the Utah Academy of Science, Arts, and Letters 7: 48-49.

Curtis, J. T. 1959. The vegetation of Wisconsin. University of Wisconsin Press, Madison, Wisconsin. 657 pp.

Daubenmire, R. F. 1968. Plant communities: A textbook of plant synecology. Harper and Row Publishers. New York. 300 pp.

Dix, R. L. and J. D. Richards. 1976. Possible changes in species structure of the subalpine forest induced by increased snowpack, p. 311-322 <u>In</u> H.W. Steinhoff and J. D. Ives (eds.), Ecological impacts of snowpack augmentation on the San Juan Mountains, Colorado. Final Report, San Juan Ecology Project, Colorado State Univ. Publ., Fort Collins. 489 pp.

Flowers, S. et al. 1960. Ecological studies of the flora and fauna of Flaming Gorge Reservoir Basin, Utah and Wyoming. University of Utah Anthropology Papers 48:1-256.

Foehner, O. H. 1977. Weather modification: a major resource tool. Proceedings of the 45th Annual Meeting of the Western Snow Conference:1-5.

Frank, E. 1973. Snow amount in relation to streamflow and herbage production in western Colorado. J. of Range Manage. 26: 32-34.

Gibbons, J. D. 1976. Nonparametric methods for quantitative analysis. Holt, Rhinehart, and Winston. New York.

Graham, E. H. 1937. Botanical studies in the Uinta Basin of Utah and Colorado. Annuals of Carnegie Museum, Pittsburgh, Vol. 26:1-432.

Hanson, W. R. 1975. The geologic story of the Uinta Mountains. Geological Survey Bulletin 1291:1-144. U.S. Government Printing Office, Washington, D.C.

Harper, K. T. 1976. Work plan: Ecological impact study of weather modification in the Uinta Mountains, Utah. Submitted to Utah Division of Water Resources, Salt Lake City, and the U.S. Bureau of Reclamation, Office of Atmospheric Resources Management, Denver, Colorado. 46 p.

________. 1978. The Uinta Ecology Study: Biennial Report. Submitted to Utah Division of Water Resources, Salt Lake City, and the U.S. Bureau of Reclamation, Office of Atmospheric Resources Management, Denver, Colorado. 24 p.

Harper, K. T., W. K. Ostler, and D. C. Anderson. 1978. The Utah Ecology Project: Ecological impacts of weather modification studies in the Uinta Mountains, Utah: Resources of the Uinta Mountains. Submitted to the Utah Division of Water Resources, Salt Lake City, and the U.S. Bureau of Reclamation, Office of Atmospheric Resources Management, Denver, Colorado. 148 p.

Harrington, H. D. 1962. Manual of the plants of Colorado. Swallow Press, Inc., Chicago, Illinois. 666 pp.

Hayward, C. L. 1945. Biotic communities of the southern Wasatch and Uinta Mountains, Utah. Great Basin Naturalist 6:1-124.

________. 1952. Alpine biotic communities of the Uinta Mountains, Utah. Ecological Monographs 22:93-120.

Hutchings, S. S. and J. E. Schmautz. 1969. A field test of the relative-weight estimate method for determining herbage production. Journal of Range Manage. 22:408-411.

Knight, D. K., et al. 1975. The Medicine Bow Ecology Project: Final report to U.S. Bureau of Reclamation, Division of Atmospheric Water Resources Management, Denver, Colorado. 397 pp.

Knight, D. H., S. W. Weaver, C. R. Starr and W. H. Romme. 1979. Differential response of subalpine meadow vegetation to snow augmentation. Journal Range Manage. 32:356-359.

Lewis, M. E. 1970. Alpine rangelands of the Uinta Mountains, Ashley and Wasatch National Forests, Region 4 of the U.S. Forest Service. Mimeographed by U.S. Forest Service, Ogden, Utah. 69 pp.

Murdock, J. R. 1950. Alpine plant succession near Mount Emmons, Uintah Mountains, Utah. Master's Thesis, Brigham Young University, Provo, Utah. 58 pp.

Pammel, L. H. 1903. Some ecological notes on the vegetation of the Uinta Mountains. Proceedings of the Iowa Academy of Science 10:57-68.

________. 1913. Some grasses of the Uintah Mountains. Proceedings of the the Iowa Academy of Science 20:133-149.

Pederson, J. C. and K. T. Harper. 1979. Chemical composition of some important plants of southeastern Utah summer ranges related to mule deer reproduction. The Great Basin Naturalist 39:122-128.

Peterson, S. R. 1969. Ecology of waterfowl in the Uinta Mountains. Utah State Division of Fish and Game, Publication No. 69-1:1-57.

Scott, D. and W. D. Billings. 1964. Effects of environmental factors on standing crop and production of alpine tundra. Ecological Monographs 34:243-270.

Stutz, H. C. 1951. An ecological study of a sphagnum lake in the subalpine forest of the Uinta Mountains of Utah. Master's Thesis, Brigham Young University, Provo, Utah. 53 pp.

Weaver, T. 1974. Ecological effects of weather modification: Effects of late snowmelt on Festuca idahoensis Elmer Meadows. American Midland Naturalist 92:346-356.

Weaver, T. and D. Collins. 1977. Possible effects of weather modification (increased snowpack) on Festuca idahoensis meadows. J. Range Manage. 30:451-456.

Webber, P. J., J. C. Emerick, D. C. Ebert May, and V. Komarkova. 1976. The impact of increased snowfall on alpine vegetation, p. 201-264

In H.W. Steinhoff and J. D. Ives (eds.), Ecological impacts of snowpack augmentation on the San Juan Mountains, Colorado. Final Report, San Juan Ecology Project, Colorado State Univ. Publ., Fort Collins. 489 pp.

Welsh, S. L. and G. Moore. 1973. Utah plants: tracheophyta. Brigham Young University Press, Provo, Utah. 474 pp.

Whaley, B. L. and K. C. Jones. 1977. Water supply outlook for Utah as of May 1, 1977. Report prepared by Snow Survey Section, Soil Conservation Service, 4012 Federal Building, Salt Lake City, Utah.

________, B. L. and L. K. Lytton. 1978. Water supply outlook for Utah as of May 1, 1978. Report prepared by Snow Survey Section, Soil Conservation Service, 4012 Federal Building, Salt Lake, City, Utah.

CHAPTER 7

EFFECTS OF LATE-LYING SNOW ON AN ALPINE HERBLAND IN THE UINTA MOUNTAINS

By

K. T. Harper

W. K. Ostler

Karl B. McKnight

and

Deborah L. Hunter

ABSTRACT

Snowpacks on the high, windswept herblands of the alpine zone of the Uintas vary little from year-to-year, since only snow protected by physical objects such as rocks, robust clumps of vegetation and ridge crests remains on a site. Plant cover and plant species diversity are positively and significantly correlated with deeper snowpacks on alpine sites exposed to wind. Deep, persistent drifts accumulate on the leeward side of ridges in the alpine zone: plant cover is dramatically reduced on such sites, but the areas so affected are small. The herblands are dominated by broad leaved herbs; graminoid species generally contribute less than 40% of the total above-ground production. Production averaged about 800 kg/ha/yr in this study. Production can be expected to decline in the summer following an unusually cold winter with minimal snow cover. Vegetation is highly heterogeneous in the alpine herblands with the species complement of exposed sites being almost totally different from that on sites that are usually covered by even moderately heavy snowpacks. Soils supporting this community type are shallow, moderately acidic and heavily leached. Sheep grazing is the primary economic use on these lands: use is locally heavy enough to result in soil instability.

INTRODUCTION

Alpine herblands alternate with barren rock outcrops over extensive areas above timberline in the Uinta Mountains. Lewis (1970) estimated that the alpine zone in the Uintas included about 1,012 km^2 (250,000 acres): He apparently considered the alpine to include only areas above 3,353 m (11,000 ft). We calculated from Ridd's (1978) vegetational map of the Uintas that the area above timberline in the Uintas includes about 1,862 km^2 (roughly 460,000 acres). About one-third of that area is essentially barren of vegetation, consisting of exposed bedrock, talus rubble, and cliff-terraced slopes. The remaining land (1,242 km^2 or 307,000 acres) carries a vegetative cover of variable density: dry meadows, wet meadows, cottongrass bogs, low willow thickets, and cushion plant communities are common in the zone.

STUDY AREA

Our studies were conducted on the north slope of Bald Mountain (Township 2 north, Range 13 east, south half of section 30), Summit County, Utah, at an elevation of 3,373 m (11,066 ft). The last remnants of timberline disappear just a few hundred meters to the south and west of our study plots (Fig. 7-1). The study area is a dry alpine meadow (Lewis 1970) on nearly flat terrain with moderately well developed soils. Elevation declines rapidly to the west of the study area and more gently toward the east. Prevailing westerly wind scours snow from the entire study area, but removal is more complete on the west end of the area. The site is slightly convex: sampling plots that slope to

Figure 7-1. The location of 21 macroplots on the alpine herbland at Bald Mountain. The diagonal strip running from the upper right-hand corner toward the middle of the left margin is a steep slope of coarse quartzite rubble.

the west (Nos. 11-21) are unable to retain more than a shallow layer of snow except under unusual conditions; plots with easterly exposures (Nos. 1-10, see Fig. 7-1) accumulate progressively more snow along the gradient from west-to-east. Since elevational differences are small and gradual across the study area (less than 3 m), all plots are regularly windswept and none retain all the snow that falls. Thus snowpacks are not heavy on any plot in any year.

Soils at the site are derived from residual geological materials. The geological strata have been disturbed by faulting and left standing nearly vertical: the study area lies on the transition zone between Red Pine Shale and Mutual Formation quartzite, both of upper Precambrian age (Stokes and Madsen 1961). Plots on the west end of the study area are more influenced by the shale and less by the quartzite parent material. The reverse is true on the east end of the area. A steep slope of very coarse talus immediately to the north of the study area is derived from the edge of the quartzite stratum which has been exposed as the softer shale has been eroded away.

Although a precipitation storage gauge was not maintained at this study area, nearby storage guages maintained by the Soil Conservation Service suggest that the area must receive in the neighborhood of 75-90 cm (29.5 - 35.4 in) per year with about 20-25% of that total falling during the period July-September (Whaley and Lytton 1979).

METHODS

Twenty-one 0.02 ha circular plots (macroplots) were established along two transects that ran east and west across the alpine herbland studied (Fig. 7-1). On the basis of three years of data, macroplots were assigned to one of three snow depth categories (April 1 data) for evaluation of the effects of size of snowpack on plant parameters. Each macroplot was permanently marked at its center with a steel reinforcing bar. Exact locations of all macroplots are given in Harper et al. (1979).

Twenty-five subsamples (quadrats) were regularly spaced within each macroplot. Each quadrat was circular and had an area of 0.25 m^2. To facilitate relocation of quadrats, each was marked by a red, 9 cm long, wooden dowel and a zinc coated 16 penny nail driven into the soil at the center of the quadrat (Harper 1976 and Harper et al. 1979). The dowels facilitated immediate relocation of quadrats, while the nail was considered to be invaluable in relocation of quadrats in the distant future with a metal detector. Four-meter-tall poles painted red or black in alternate, 1.0 meter bands were secured at the center of each macroplot to permit exact relocation of the plot in winter and to permit estimation of snow depth from photographs taken from a low flying plane.

At each quadrat, the following data were recorded: 1) all species present, 2) total living cover, 3) the foliage cover of each species shading the quadrat, 4) plant litter cover, 5) cover of rocks of diameters in excess of 5 mm, and 6) the proportion of the total living cover contributed by each of the following plant lifeform categories: perennial grasses, perennial forbs, shrubs, annuals and cryptogams. Cover in all cases was estimated using a cover-class method similar to that described by Daubenmire (1959). Total number of species per quadrat and per macroplot was also recorded. A frequency value was obtained for each species by dividing the number of quadrats of occurrence

for that species by the total number of quadrats placed and expressing the result as a percent. Percent frequency and percent cover values (F X C) were multiplied for each species to yield an index of commonness. Ultimately all species were listed according to decreasing size of the F X C index. The prevalent species were selected by counting down from the top of the commonness list until a number equal to the average number of species per macroplot was reached. This method of selecting prevalent species is patterned after that described by Curtis (1959).

Annual, above-ground production of plants was estimated using the method of Hutchings and Schmautz (1969) Four 0.25 m^2 quadrats were equally spaced around and about 1.0 m from a central quadrat of equal size. Production of each of the major lifeform groups was then estimated in each peripheral quadrat as a percentage of production of the corresponding group in the central quadrat. The central quadrat was then clipped by plant lifeform group and the tissue was oven dried and weighed. Two clusters of five quadrats each were sampled per macroplot per year giving a total of ten estimates of production per macroplot per year. The lifeform groups recognized for production estimates were perennial graminoides, perennial forbs, and annuals: shrubs were absent on these study plots and production of mosses, liverworts and lichens (cryptogams) was ignored. Annuals never contributed more than 0.5% of the current year's growth.

Soils were sampled in the fall of 1976. Samples were taken from the 2.5-15.0 cm layer of the profile. Composite samples were assembled from 12-15 subsamples per macroplot. Soil samples were oven dried at 60°C and sieved to remove gravel and rock particles over 2.0 mm in diameter. Samples were analyzed for texture, pH, available phosphorus, and exchangeable potassium, magnesium and calcium. Texture was determined by the hydrometer method; pH was taken with a grass electrode meter on a saturated paste; phosphorus was extracted wtih 0.2 N acetic acid and measured photometrically after complexing with ammonium molybdate; and cations were displaced with 1.0 N ammonium acetate and determined by atomic absorption procedures. Soil depth was measured at the center of alternate vegetational sampling quadrats with a sharpened, slender (diameter 1.0 cm) steel rod that was pushed into the soil until inpenetrable material was encountered. Thirteen depth probes were taken per macroplot.

At each macroplot, slope and aspect were determined using an Abney level and a compass. All plant species at the study site were collected, identified and placed on file in the Brigham Young University Herbarium. Plant nomenclature usually follows Harrington (1962): species not found in Harrington were classified using the flora of Welsh and Moore (1973).

Snowpack data were collected by photographing plots from a low flying, fixed-wing aircraft or from laborious overland trips into the area. Overland trips were made on skis while snowpacks were continuous and by an all-terrain vehicle when large areas became snow-free. The remoteness of the study area and stormy weather often made it impossible to obtain readings at the appropriate time; accordingly our snow depth data for the April 1 date and our 75% snow-free dates for individual macroplots are incomplete. A criterion of 75% snow-free was required since drifts occasionally resulted in small patches of snow that lingered after the bulk of the macroplot was snow-free.

RESULTS

Snowpack

Snowpack apparently varies little from year-to-year at the study area. Although April 1 snowpacks in 1977 were some of the lightest on record in the Uinta Mountains (Whaley and Jones 1977), while 1979 snowpacks were near normal, April 1 water content of snowpacks on our Bald Mountain macroplots was similar in those two years (Table 7-1). The windiness of the site apparently results in removal of snow in excess of a certain minimum amount held in place by physical objects such as rocks, clumps of hardy plant cover and the curvature of the ridge.

Snow-free dates were not obtained for all macroplots in 1977, but in 1978 the plots became snow-free in early June. In 1979, the plots were all free of snow before June 1 (Table 7-1). Snow-free dates were late throughout the Uintas in 1978 (see Chapters 4, 5, and 6).

The macroplots were assigned to three groups that became snow-free at roughly similar times in the two years of record. The early snow-release group consisted of four macroplots (15, 16, 17 and 18 - see Fig. 7-1). The mid-release-date group became snow-free about four days after the first group and included eight macroplots (10-14 and 19-21). The late-release group became free of snow about eight days after the mid-release group on the average and included macroplots 1-9 (Table 7-2).

Soils and Site Characteristics

Many characteristics of the soil and site varied significantly among snow-release-date groups. Since the study area extended across the top of a ridge, both slope and exposure varied significantly among release-date groups (Table 7-1).

Table 7-1. Abiotic characteristics of the Bald Mountain study area. All soil measurements were taken in 1976. Soil samples are all from the 2.5-15.0 cm depth interval. Snowpack water content was measured on about April 1 annually. Each zone average is followed by its standard deviation.

Characteristic	Snow Release Zone Early	 Mid	 Late	Test of Significance of Differences Among Zones (F - Values)
No. Macroplots Sampled	4	8	9	--
1977 Water Content of Snowpack (cm)	9.0 ± 2.0	13.3 ± 4.5	22.2 ± 1.5	30.83**
1978 Water Content of Snowpack (cm)	NA	NA	NA	--
1979 Water Content of Snowpack (cm)	5.1 ± 4.3	4.9 ± 3.1	20.0 ± 6.1	24.62**
1977 Snow-Free Date	NA	NA	Ca. June 1	--
1978 Snow-Free Date	June 6.5±0.0	June 12.0±1.8	June 19.1±0.4	163.70**
1979 Snow-Free Date	May 18.5±1.0	May 20.0±1.5	May 28.7±3.6	32.69**
Exposure (° from N)	285 ± 0.1	286 ± 0.0	42 ± 0.1	--
Exposure (Coded[1])	0.49	0.51	1.04	15.69**
Slope (%)	6.5± 1.0	5.0±1.1	2.3±0.3	40.82**
Soil Parameters				
Depth (cm)	1.5±0.2	2.0±0.2	1.9±0.1	2.02
Texture (%)				
Sand	59.6±3.2	55.7±4.9	43.6±3.4	29.79**
Silt	21.8±2.7	26.1±7.3	34.6±4.3	9.23**
Clay	18.6±2.0	18.2±4.8	21.8±2.7	2.42
Organic Matter (%)	7.8±0.6	8.9±1.4	10.4±1.6	5.39*
pH	6.1±0.1	5.7±0.1	5.4±0.1	10.16**

Table 7-1. Continued.

Exchangeable Cations				
Calcium (ppm)	1,382 ±137	1,277 ±214	934 ± 99	15.11**
Magnesium (ppm)	258 ± 26	270 ± 58	155 ± 32	16.99**
Potassium (ppm)	138 ± 32	102 ± 25	89 ± 20	5.64**
Extractable Phosphorus (ppm)	7.8± 0.4	4.9± 1.2	1.8 ±0.6	68.41**

---

1. Exposure transformed according to the procedure of Beers, Dress and Wensel (1966).

* - Significant at the .05 level.

** - Significant at the .01 level.

Table 7-2. Vegetational and soil characteristics of the study area related to characteristics of the snowpack at the Bald Mountain study area. Vegetational data represent an average of conditions in the third week of July 1977 and 1978. Snowpack water content represents an average for April 1, 1977 and 1979. Snow-free dates are averaged for 1978 and 1979. Means are followed by their standard deviations.

Characteristic	Snow Release Zone Early	 Mid	 Late	Test of Significance of Differences Among Zones (F - Values)
No. Macroplots Ave.	4	8	9	--
Ave. Water Content of Snowpack (cm on April 1)	7.1 ± 3.2	9.1 ± 3.8	21.1 ± 3.8	18.00**
Ave. Snow-Free Date	May 27.8 ± 9.0	June 0.5 ± 11.5	June 8.4 ± 10.3	2.10
Total Living Cover (%)	53.5 ± 4.6	63.5 ± 7.1	67.3 ± 6.8	5.99**
Litter Cover (%)	7.2 ± 1.5	7.6 ± 3.3	10.2 ± 2.9	2.38
Rock Cover (> 5 mm Diam. -%)	28.5 ± 10.8	19.8 ± 11.4	6.3 ± 5.2	9.63**
No Species/0.02 ha				
Vascular	27.8 ± 3.5	27.6 ± 4.8	26.7 ± 5.1	0.12
Nonvascular	6.8 ± 1.7	6.9 ± 1.0	6.9 ± 2.4	0.01
No. Species/0.25 m^2				
Vascular	8.5 ± 2.3	10.8 ± 2.5	12.5 ± 0.9	6.00**
Nonvascular	1.1 ± 0.6	1.2 ± 0.8	0.9 ± 0.4	0.50
Total Above-Ground Production (g/m^2)	70.4 ± 21.2	97.6 ± 19.6	80.8 ± 26.0	2.16
Composition of Above-Ground Production (% by Weight)				
Forbs	87.9 ± 6.9	84.6 ± 7.7	73.8 ± 13.2	3.50
Graminoides	12.1 ± 7.0	15.2 ± 7.7	26.2 ± 13.3	3.52
Annuals	0.1 ± 0.2	0.2 ± 0.4	0.1 ± 0.3	0.19

** - Differences among zones statistically significant at the 0.01 level.

Soil depth was predictably shallow and rather uniform across the entire study area. Other soil parameters, both physical and chemical, varied significantly across the study area (Table 7-1). Soils were sandier and less organically enriched in the early-release-date groups, but usually contained more available mineral ions than soil in the late snow-release-date area (Table 7-1). All soils were unusually impoverished in phosphorus, potassium and magnesium, elements essential for plant growth. The impoverishment of the soil for essential elements is greater than in either lodgepole pine or spruce-fir forests (Chapters 4 and 5). The subalpine meadow soils (Chapter 6) have about the same levels of soil minerals as those considered here (Table 7-1), except for phosphorus which is in greater supply in the subalpine herbland soils.

The decline in base forming cations on the late-release-date macroplots is probable not attributable to leaching induced by heavier snowpacks. Even though snowpacks averaged over three times as large on the subalpine meadows of Elizabeth Ridge as here on Bald Mountain, the late-release-date zone on Elizabeth Ridge showed no significant reduction in base forming cations (Chapter 6). The difference in cations on the Bald Mountain plots in early and late-release-date groups is more likely attributable to the parent material differences described earlier in the description of the study area. The increase in rock cover in the late-release zone (Table 7-2) reflects the greater importance of hard quartzite rock in the parent material of that zone.

Snow and Plant Production

In the assemblage of macroplots considered here, there is a significant increase in living plant cover as snow release-date is retarded

(Table 7-2). In contrast, plant production does not vary significantly across the gradient of progressively later snow release-dates (Table 7-2), but regression analysis shows an increasing, albeit nonsignificant, trend for the regression line for above-ground production on snow-free date (Table 7-3). The disparity in results for cover and production is perhaps attributable to the increase of four grasses which produce considerable low cover but little weight in the late-release zone. Carex pseudoscirpoidea, Danthonia intermedia, Deschampsia caespitosa and Festuca ovina all reached maximum frequency in the late-release zone (Table 7-4), but all are represented by small stature ecotypes at the study site.

The number of vascular plant species per quadrat is significantly greater in the late-release zone than in either of the earlier snow-free zones (Table 7-2). Thus late lying snow at the study site encourages both more plant cover and more plant species diversity. The great cryptogamic species diversity derives largely from rock lichens.

Plant production at the site averaged about 85 g/m^2 for the years 1977 and 1979 (about 84% of the above-ground production for the subalpine meadow at Elizabeth Ridge). Forbs contributed about 81% of the above-ground production at Bald Mountain in contrast to 42% at the Elizabeth Ridge Meadow (Chapter 6).

Regression equations predict that a 10% increase in average annual snowpack should result in a delay of 0.7 day in snow-free date. That amount of increase in snow would also produce an 0.8% increase in cover and an increase of 0.5 g/m^2 in above-ground plant production (Table 7-3). The regression equations for decline in snow-free date and increase in plant cover are highly significant statistically, but that for production is not significant (see footnotes to Table 7-3).

Table 7-3. Predicted impacts of various relative increases in water content of the average April 1 snowpack on the Bald Mountain study area. The regression equations are based on 1977 and 1979 snowpacks and 1977 and 1978 plant data. In this area, heavier snowpacks are predicted to trigger greater plant growth. Average April 1 water content of snowpack was 13.81 cm.

		Absolute Increase in Plant	
Increase in Snowpack (%)	Delay in Snow-Free Date (Days)[1]	Cover[2] (%)	Production[3] (g/m^2)
5	0.4	0.4	0.2
10	0.7	0.8	0.5
15	1.4	1.2	0.7
20	1.8	1.6	0.9
25	2.3	2.0	1.1

1. Regression equation: $Y = 25.24 + 0.653 X$, where X is cm of water in April 1 snowpack. Correlation coefficient is + 0.958; regression is significant at 0.01 level.

2. Regression equation: $Y = 55.33 + 0.573 X$, where X is cm of water in April 1 snowpack. Correlation coefficient is + 0.574; regression is significant at 0.01 level.

3. Regression equation: $Y = 19.37 + 0.078 X$, where X is cm of water in April 1 snowpack. Correlation coefficient is + 0.162; the regression is not statistically significant. The Y-variable is read in $g/0.25\ m^2$.

Table 7-4. Prevalent species on the study areas. Species prevalent in the light, medium, and heavy snowpack macroplots are so designated by the letters L, M or H after the Latin name. Species whose frequency differed significantly among snowpack zones are asterisked in the list. Frequency is the percentage of 0.25 m^2 subsamples that contain each particular species in a snowpack zone. Cover was ocularly estimated for each species in each of the 25 subsamples per macroplot.

	FREQUENCY (%)			COVER (%)		
	Size of Snowpack			Size of Snowpack		
Species	Light	Medium	Heavy	Light	Medium	Heavy
Forbs						
*Achillea millefolium L, M, H	48.0	40.0	12.9	1.5	0.9	0.3
Androsace septentrionalis L,M,H	34.0	23.0	9.8	0.2	0.2	0.0
Antennaria parvifolia L,M,H	23.0	21.5	19.6	0.3	0.3	0.3
Arenaria congesta L, H	9.0	9.5	15.1	0.1	0.2	0.2
**Arenaria rubella M, H	0	22.5	70.2	0.0	0.4	1.6
Artemisia campestris H	0	4.0	8.4	0.0	0.1	0.2
**Artemisia scopulorum M, H	1.0	40.0	73.3	0.0	2.8	2.4
**Draba aurea L, M	16.0	33.0	0.9	0.2	0.3	0
*Draba sp. L, M	34.0	21.5	0	0.4	0.1	0
Draba lanceolata H	2.0	11.5	15.6	0	0.1	0.1
**Draba oligosperma H	0	8.5	74.7	0	0.1	0.4
**Erigeron compositus L	14.0	2.0	0	0.2	0.1	0
*Erigeron simplex L, M, H	4.0	41.0	35.6	0.1	0.8	0.5
*Eretrichum nanum L	3.0	0.5	0	0	0	0
**Ivesia gordonii L, M	70.0	43.5	2.2	7.6	3.4	0.1
**Lewisia pygmea M, H	1.0	28.5	76.4	0	0.3	1.7
*Lychnis drummondii L,	15.0	10.0	0	0.2	0.1	0
**Mertensia viridis L, M	27.0	12.0	0	0.3	0.1	0
**Oxytropis parryi L	6.0	0	0	0.1	0	0
**Penstemon uintahensis	15.0	10.5	0	0.3	0.2	0
**Polygonum bistortoides L, M, H	0	31.5	91.1	0	0.9	2.5
**Potentilla diversifolia M, H	2.0	18.5	80.0	0.1	0.4	1.8
*Potentilla gracilis L	7.0	0.5	0	0.2	0	0
*Potentilla plattensis L, M, H	86.0	91.5	70.7	3.0	2.3	1.4
Saxifraga rhomboidea M, H	0	13.0	26.7	0	0.1	0.1
**Sedum stenopetalum L, M, H	76.0	96.5	65.3	2.0	3.3	1.0
Stellaria longipes L, M, H	18.0	14.5	10.2	0.1	0.1	0.1
Thlaspi alpestre L, M, H	23.0	14.0	8.4	0.1	0.1	0
**Trifolium dasyphyllum L, M	94.0	62.0	0	23.3	21.2	0
**Trifolium parryi L, M, H	10.0	44.5	99.1	0.3	8.9	23.9
Graminoides						
**Agropyron trachycaulum L, M	27.0	13.5	0.9	0.5	0.2	0
Carex microptera M, H	2.0	24.5	29.3	0.1	0.6	0.8
*Carex geyeri L	7.0	1.0	0	0.3	0	0
*Carex pseudoscirpoidea M, H	0	31.0	53.8	0	0	1.2
*Danthonia intermedia H	0	0	27.1	0	0	1.4
**Deschampsia caespitosa H	0	6.5	73.8	0	0.2	11.3
Festuca ovina L, M, H	56.0	84.0	76.4	1.2	1.9	1.6
Luzula spicata M, H	0	24.0	44.0	0	0.3	0.3
**Poa alpina L, M, H	75.0	70.0	15.1	2.3	1.4	0.3
Poa sp. L, M	20.0	12.0	0	0.3	0.2	0
Trisetum spicatum L, M, H	7.0	29.0	36.0	0	0.4	0.6

Table 7-4. Continued.

* - Species average frequency differs significantly among the three snow-free date zones: $.01 < P < .05$.

** - Species average frequency differs significantly among the three snow-free date zones: $P < .01$.

Nineteen of the vascular plant species achieve maximum frequency in the early snow-release zone, five other species perform best in the moderate-release date plots, while an additional 17 species show preference for the late-release-date zone (Table 7-4). Twenty-eight of the 41 species considered show statistically significant preferences for one snow-release zone or another, with slightly more of the species showing a preference for the early snow-release zone.

The two commonest species on the basis of cover on the Bald Mountain study area are legumes, *Trifolium dasyphyllum* and *T. parryi*. Those two congeners prefer different ends of the snow-release gradient with the latter species preferring spots with late lying snow. Other abundant species are *Artemisia scopulorum*, *Draba oligosperma*, *Ivesia gordonii*, *Lewisia pygmea*, *Polygonum bistortoides*, *Potentilla diversifolia*, *Potentilla plattensis*, *Sedum stenopetalum*, *Deschampsia caespitosa*, *Festuca ovina*, and *Poa alpina* (Table 7-4).

The data show that ten prevalent species from the subalpine meadow on Elizabeth Ridge (Chapter 6) are also prevalents on the Bald Mountain herblands considered here. The prevalent species common to both studies are *Achillea millifolium*, *Antennaria parvifolia*, *Artemisia scopulorum*, *Lewisia pygmea*, *Polygonum bistortoides*, *Potentilla diversifolia*, *Trifolium parryi*, *Carex pseudoscirpoidea*, *Danthonia intermedia*, *Deschampsia caespitosa*, and *Luzula spicata*. Interestingly, all but the first named reach maximum development on Bald Mountain on the late snow-release sites (Table 7-4). Snow cover apparently makes the environment more moderate for these lower elevation species.

Table 7-5 demonstrates that apparent above-ground plant production is reduced by late sampling. The 1976 sample for production, taken in

Table 7-5. Above-ground plant production data for the Bald Mountain alpine herblands in 1976, 1977, and 1978. All data are oven dry weights reported in grams per square meter. Data are arranged according to snow-free date zone. Weights for perennial forbs and perennial graminoides are reported separately in an attempt to evaluate influence of harvest date and wet summers on those two plant groups. The plots were harvested in mid-September in 1976 and in mid-July in 1977 and 1978.

Plant Group	Snow-Free Date Zone	Year 1976	1977	1978	Average
Forbs	Early	31.2	82.0	60.8	58.0
	Mid	42.8	83.2	88.4	71.2
	Late	34.0	42.8	82.0	52.8
	Average	36.0	69.2	77.2	60.8
Graminoides					
	Early	17.6	10.8	8.8	12.4
	Mid	23.2	16.0	15.2	18.0
	Late	41.6	24.0	16.8	27.6
	Average	27.6	16.8	13.6	19.2
Total	Early	48.8	92.8	69.6	70.4
	Mid	65.6	99.2	103.6	89.6
	Late	75.6	66.8	98.8	80.4
	Average	63.6	86.0	90.8	80.0

mid-September, is only about 72% of the average for 1977 and 1978 when production was estimated in the last half of July. As predicted by Ostler et al. (Chapter 6), the grasses made their largest relative contribution to production (43% of the total) in the year of latest harvest. In July 1977 and 1978, when the meadows had not yet been grazed and early maturing forbs had not yet evanesced, grasses contributed only 28 and 15% respectively of the total harvests.

Vegetational Similarity

The Ruzicka (1958) index of similarity based on frequency data showed that the vegetation of the early-release-date zone was only 18.5% similar to average composition of the late-release zone (Tables 7-4 and 7-6). The vegetational dissimilarity between early and late-release zones was thus far greater in these alpine herblands than in the same zones in lodgepole pine forest where the identical comparison gave a similarity value of 50% (Chapter 4 and Table 7-6). The moderate-release-date zone in the alpine herblands studied was vegetationally similar to both the early and the late zones: the moderate zone was 51 and 42% similar to the early and the late zones respectively (Table 7-6) when similarity was computed on the average composition data from Table 7-4.

It must be noted that basing similarity between zones on average composition of all macroplots in each zone gives higher similarities than if each macroplot in one zone is compared individually with every macroplot in the other zone being compared (Table 7-6). Basing similarity on individual macroplots also permits one to compute within zone

---

Table 7-6. Vegetational similarity among the three snow-release zones described in the preceding tables. Similarity was evaluated using the Ruzicka (1958) index of similarity and frequency data for the species in each macroplot. In these analyses, the vegetation of each macroplot was individually compared for similarity with every other macroplot. In the matrix below, the values represent averages based upon the similarity of each macroplot in one snow-release group with every macroplot in another snow-release group. The all possible combination average permits one to compute not only between group similarities, but within group similarities too. Similarity of one group with itself represents internal homogeneity or similarity.

		Snow-Release Zone		
		Early	Moderate	Late
		% Similarity		
Snow-Release Zone	Early	53.2	--	--
	Moderate	42.8	38.9	--
	Late	17.3	30.2	56.9

similarity; such an analysis shows that vegetation is highly variable within each of the three snow-release zones at Bald Mountain. Within zone similarity there was 53, 39, and 57% respectively for the early, moderate and late snow-release zones in those alpine herblands (Table 7-6). Even though within zone similarity was low in those analyses, internal similarity was always significantly greater than between zone similarity.

DISCUSSION

The dry meadows considered in this report are some of the more successionally advanced plant communities in the alpine zone of the Uintas (Murdock 1950, Hayward 1952, Lewis 1970). Hayward (1952) described the native animal associates of this type of community. He found such areas to be used for nesting by the pipit and for foraging by the marmot and pika. Dipteran insects were found to dominate the invertebrate community by Hayward (1952). Thilenius (1975) noted that sheep are the principal domestic livestock using alpine communities such as that studied on Bald Mountain. Sheep are better adapted to cold, windy alpine environments than other domesticates.

Wagner (1973) reported soil reaction values for high alpine herblands near Mt. Lovenia and elsewhere to the south of our study area in the Uintas: many of his meadow soils register pH values between 4.0 and 5.0. Our own data (Table 7-1) also show highly leached soils, but they are less acidic than those reported by Wagner (1973).

The Highline Trail, a main access route for sheep grazing the alpine areas of the Uintas, crosses the Bald Mountain herbland considered

here about 0.5 km from our study plots. As a consequence, the study area receives heavy sheep grazing at both the beginning and the closing of the grazing season. Continued heavy use has induced some soil instability near our study area. Our permanent plots will provide useful monitoring points for evaluation of the longterm impact of sheep grazing on community composition and soil stability in future years.

LITERATURE CITED

Beers, T. W., P. E. Dress and L. C. Wensel. 1966. Aspect transformation in site productivity research. J. Forestry 64:691-692.

Curtis, J. T. 1959. The vegetation of Wisconsin. University of Wisconsin Press, Madison. 657 pp.

Daubenmire, R. F. 1959. A canopy-coverage method of vegetational analysis. Northwest Sci. 33:43-64.

Harper, K. T. 1976. Work plan: ecological impact study of weather modification in the Uinta Mountains, Utah. Report to Utah Division of Water Resources, Empire Bldg., Suite 300, 231 E. 400 S., Salt Lake City 84111 and the U.S. Bureau of Reclamation, Office of Atmospheric Resources Management, Engineering and Research Center, Denver, Colorado 80225. 46 pp.

Harper, K. T., W. K. Ostler and K. B. McKnight. 1979. The Uinta ecology study, interim report. Report to Utah Division of Water Resources Empire Bldg., Suite 300, 231 E. 400 S., Salt Lake City 84111 and The U.S. Bureau of Reclamation, Office of Atmospheric Resources Management, Engineering and Research Center, Denver, Colorado 80225. 76 pp.

Harrington, H. D. 1962. Manual of the plants of Colorado. Swallow Press, Inc., Chicago, ILL. 666 pp.

Hayward, C. L. 1952. Alpine biotic communities of the Uinta Mountains, Utah. Ecological Monographs 22:93-120.

Hutchings, S. S. and J. E. Schmautz. 1969. A field test of the relative-weight estimate method for determining herbage production. J. Range Manage. 22:408-411.

Lewis, M. E. 1970. Alpine rangelands of the Uinta Mountains, Ashley and Wasatch National Forests, Region 4 of the U.S. Forest Service. Mimeographed by the U.S. Forest Service, Ogden, Utah 69 pp.

Murdock, J. R. 1950. Alpine plant succession near Mount Emmons, Uintah Mountains, Utah. Master's thesis, Brigham Young University, Provo, Utah. 58 pp.

Ridd, K. 1978. Vegetation of the Uinta Mountains above 7,000 feet (a map). Department of Geography, University of Utah, Salt Lake City.

Ruzicka, M. 1958. Anwendung mathematisch-statisticher methoden in der geobotanik (synthetische bearbeitung von aufnahmen). Biologia, Bratisl. 13:647-661.

Stokes, W. L. and J. H. Madsen, Jr. 1961. Northeast quarter of Geological Map of Utah. Utah State Land Board, Salt Lake City.

Thilenius, J. F. 1975. Alpine range management in the western United States-principles, practices, and problems. USDA Forest Service Research Paper RM-157. 32 pp.

Wagner, W. W. 1973. Cesium-137 accumulation and distribution in plants and soils of an alpine community of Utah. Ph.D. Dissertation, University of Utah, Salt Lake City. 267 pp.

Welsh, S. L. and G. Moore. 1973. Utah plants: tracheophyta. Brigham Young University Press, Provo, Utah. 474 pp.

Whaley, B. L. and K. C. Jones. 1977. Water supply outlook for Utah as of May 1, 1977. Report prepared by Snow Survey Section, Soil Conservation Service, 4012 Federal Bldg., Salt Lake City, Utah.

Whaley, B. L. and L. K. Lytton. 1979. Summary of mountain precipitation measurements for Utah, 1930-1978. Report distributed by Snow Survey Section, Soil Conservation Service, U.S. Dept. of Agriculture, Salt Lake City, Utah. 168 pp.

CHAPTER 8

SILVER CONTENT OF SOILS AND PLANTS
ON THE NORTH SLOPE OF THE
UINTA MOUNTAINS, 1978

by

K. T. Harper

ABSTRACT

Silver content of 41 soil samples from four ecosystems on the North Slope of the Uinta Mountains is reported. Silver content averaged about 9.9 ppm in the samples: no significant difference existed in soil silver concentrations among lodgepole pine forest, subalpine meadow, spruce-fir forest, and alpine herbland ecosystems. No difference was found in silver content of soils overlain by snowpacks that varied greatly in water content and time of disappearance.

Silver content of 49 plant samples from the same area averaged .178 ppm on a dry weight of tissue basis. There was a tendency for dicotyledonous herbs to accumulate more silver than monocotyledonous herbs, but the difference was not statistically significant. There is a weak but statistically significant trend for silver content of dicot herbs to be positively correlated with silver content of associated soils. Silver content of monocot and dicot herbs from the same soil was not significantly correlated.

Silver iodide is currently the preferred ice nucleating agent in weather modification operations (Klein and Mulvey 1978). Approximately 3.1×10^6 g of silver are released annually into the atmosphere as silver iodide in connection with weather modification programs. Although this is a formidable amount of silver, it accounts for only about 0.15% of the total silver released into the environment annually (Klein and Mulvey 1978). During the winter of 1979-80, over 1.55×10^4 g of silver were released during cloud seeding operation in the state of Utah (Summers 1980).

Authorities agree that silver iodide is so insoluble that it releases little ionized silver into the environment, and thus it is not likely to pose an environmental problem (Cooper and Jolley 1970). Nevertheless, the silver ion is among the most toxic of heavy metal ions, particularly to microorganisms and fish. Since the possibility exists that silver iodide may be ionized at accelerated rates in unusual microenvironments, Cooper and Jolley (1970) considered it prudent for the nation to regularly monitor all sources of new silver entering the environment, but decision makers have considered the issue to be of insufficient importance to merit such complete monitoring. Nevertheless, background levels of silver are often established for areas where weather modifications programs are being conducted or anticipated.

This report presents the results of 90 analyses of surface soils and vegetation for silver on the North Slope of the Uinta Mountains, Utah.

METHODS

In order to improve the likelihood that silver additions to the environment from cloud seeding might be detected and separated from background concentrations, soil and plant samples were taken from the zones that regularly accumulate the heaviest snow drifts in each of the four major study areas considered in this report (Fig. 1-1). Zones where snow drifts did not accumulate were also sampled in each area. These study areas are situated in 1) lodgepole pine forest (site 1 average elevation 2,760 m, SE 1/4 of Section 3, T. 2 N., R. 12 E. and site 2 average elevation 2,846 m, NW 1/4 Section 25, T. 2 N., R. 12 E.), 2) subalpine meadow (elevation 3,203 m, SW 1/4 of section 15, T. 2 N., R. 11 E.), 3) spruce-fir forest (elevation 3,203 m, SW 1/4 of section 15, T. 2 N., 11 E.), and 4) alpine herbland (elevation 3,373 m, S 1/2 of Section 30, T. 2 N., R. 13 E.). All areas are in Summit County, Utah.

Since projected weather modification plans for the North Slope of the Uinta Mountains emphasize winter orographic cloud seeding for snow augmentation, I have assumed that silver, the artificial ice nucleating agent likely to be used, will accumulate faster in drifted than undrifted sites. In each of the four study areas, a composite sample of the surface centimeter of mineral soil (the litter layer was removed prior to sampling) was taken at 5 permanently marked vegetation monitoring plots known to accumulate heavy drifts and at 5 other vegetation monitoring sites that are known to have consistently light snowpacks. Each composite sample was taken from at least 12 different spots within a given vegetation plot (plots were 0.02 ha in area). Samples were taken with a stainless steel soil sampling tube inserted parallel to the soil surface so as to remove a sample 1.0 cm deep. Soil samples were taken in late July 1978 and mid-July 1979.

Samples were stored in plastic bags and transported to the laboratory within 72 h of collection. In the laboratory, samples were spread on paper towels to air dry. Dried samples were passed through a 2 mm brass sieve to separate gravel and large fragments of plant tissue. Material passing through the sieve was rebagged in plastic and delivered to the chemist for analysis.

Plant samples were taken during the last week of July 1978. Individual species were collected for analysis from the subalpine meadow and spruce-fir forest study areas on Elizabeth Ridge. Only current year's twig growth (including both stem and foliage) was collected for trees and shrubs (only one shrub, Vaccinium scoparium, was sampled). All above ground, current year's growth was taken for herbaceous species samples. Samples of both woody and herbaceous species were composited from a minimum of 10 different individuals scattered over a 0.5 ha area. Composite samples consisting of all above-ground tissue of herbaceous monocotyledonous or dicotyledonous species within 2 objectively placed 0.25 m^2 quadrats were taken from all of the vegetation plots that were sampled for soil content of silver. Since herbaceous growth in the two quadrats clipped in a single plot was often too meager to produced a sample of adequate size for analysis, samples were sometimes pooled with other samples of the same plant group, vegetation type and snowpack zone (i.e., light or drifted snowpack).

Plant samples were collected and stored in paper bags. When air dry, samples were ground in a Wiley Mill using a stainless steel sieve with 0.1 mm openings. Ground samples were stored in plastic containers.

Both soil and plant samples were analyzed by chemists at Billings Energy Corp. The same analytical procedures were used for both soil and plant samples. Samples were digested in a mixture of HNO_3, $HClO_4$ and H_2SO_4 acids. Silver was determined in the digestate using atomic absorption procedures. A reagent blank was included with each batch of 20 samples. A duplicate sample was run for every 10th sample. All plant samples were run by the same analyst in an interval of one week. Twenty-five soil samples were run in early 1979 by one technician; 16 additional samples were run in late 1979 by another technician.

RESULTS

Soils show a range of from .04 to 36.2 ppm of silver and an average of 9.89 ppm silver for 41 samples (Table 8-1). Plant tissue silver content varied from .01 to 1.43 ppm with an average of .18 ppm for 49 samples (Table 8-2). Based upon the data reported in Table 8-3, silver content of soils can be shown to not differ significantly among study areas or between drifted and undrifted sites within any one study area.

The various plant lifeform categories recognized in our sampling program (i.e., trees, shrubs, graminoides and forbs) display average silver contents that differ widely from one group to another, but due to high within group variance, only shrub tissue silver content can be shown to differ significantly from other groups (Table 8-4). Since only one species (Vaccinium scoparium) is included in the shrub category, the conclusion that shrubs as a group take up less silver than other plant groups is unjustified. A more realistic comparison would seem to be a comparison of the silver content of all woody plants versus silver

Table 8-1. Silver content of the surface mineral soils (top 1.0 cm) of selected study plots within the four ecosystems considered in this report. Asterisked samples were run by the same laboratory but a different technician than unasterisked samples.

Sample No	Ecosystem and Plot No.	Relative Weight of April 1 Snowpack	Silver Content (ppm)
1	Lodgepole Pine #1	Light	0.40
2	" " #3	"	0.25
3	" " #4	"	29.90
4*	" " #6	"	0.55
5*	" " #7	"	0.04
6	" " #22S	Heavy	23.90
7	" " #23S	"	21.30
8	" " #24S	"	0.08
9*	" " #2	"	0.08
10*	" " #25S	"	1.51
11	Spruce-Fir #1M	Light	10.10
12	" " #5T	"	35.50
13	" " #6B	"	1.50
14*	" " #8B	"	1.65
15*	" " #10B	"	1.76
16	" " #15	Heavy	0.16
17	" " #4S		4.80
18	" " #5S	"	36.20
19	" " #6S	"	26.10
20*	" " #3S	"	4.05
21*	" " #2S	"	1.14
22	Subalpine Meadow #1B	Light	25.10
23	" " #2B	"	8.70
24	" " #3B	"	32.00
25*	" " #9B	"	2.18
26*	" " #10B	"	1.89
27	" " #4T	Heavy	22.10
28	" " #5T	"	10.40
29	" " #6T	"	7.90
30*	" " #9T	"	0.89
31*	" " #10T	"	1.89
32	Alpine Tundra #15	Light	23.90
33	" " #16	"	16.20
34	" " #17	"	11.10
35*	" " #18	"	0.28
36*	" " #14	"	2.65
37	" " #1	Heavy	13.00
38	" " #2	"	7.40
39	" " #3	"	9.70
40*	" " #4	"	2.48
41*	" " #5	"	4.56
Overall Average			9.89

Table 8-2. Silver content of selected plant species and groups of species in the Uinta Mountains. Collection sites for plant tissue are given for all samples. Current year twigs only are included in samples for woody plants. Where multiple plots are listed for a sample, tissue from any one site was inadequate to make a sample large enough for analysis. Letters in parentheses often composite samples indicate whether sample came from an area of light (L) or heavily drifted (H) snowpack.

Sample No.	Species or Group	Collection Site	Silver (ppm)
TREES			
1	Abies lasiocarpa	Elizabeth Ridge Forest	.21
2	Picea engelmannii	" " "	.01
3	Pinus contorta	" " "	.04
MONOCOTYLEDONOUS HERBS			
4	Danthonia intermedia	" " Meadow	.03
5	Deschampsia caespitosa	" " "	.01
6	Luzula spicata	" " "	.01
7	Phleum alpinum	" " "	.01
8	Poa nervosa	" " "	.01
DICOTYLEDONOUS HERBS			
9	Antennaria parvifolia	" " "	.55
10	Artemisia scopulorum	" " "	.01
11	Lewisia pygmea	" " "	.25
12	Polygonum bistortoides	" " "	1.43
13	Saxifraga rhomboidea	" " "	.01
14	Senecio integerrimus	" " "	.01
COMPOSITE SAMPLES OF SHRUBS			
15	Shrubs (L)	Spruce-fir Plot 4M	.01
16	Shrubs (L)	" " " 6B	.01
17	Shrubs (L)	" " " 1B	.01
COMPOSITE SAMPLES OF MONOCOTYLEDONOUS HERBS			
18	Monocot Herbs (L)	Spruce-fir Plots 1M, 5T, 6B	.01
19	" " (H)	" " " S1, S2, S3	.03
20	" " (L)	Lodgepole Pine Plots 1, 2, 3	.20
21	" " (H)	" " " S1	.21
22	" " (H)	" " " S3, S4	.28
23	" " (L)	Elizabeth Ridge Meadow 3B	.47
24	" " (L)	" " " 1B	.09
25	" " (L)	" " " 2B	.08
26	" " (H)	" " " 4T	.05
27	" " (H)	" " " 5T	.01
28	" " (H)	" " " 6T	.02
29	Monocot Herbs (L)	Bald Mt. Tundra #15	.09
30	" " (L)	" " #16, 17	.33
31	" " (H)	" " #1	.01
32	" " (H)	" " #2	.01
33	" " (H)	" " #3	.88

Table 8-2. Continued.

COMPOSITE SAMPLES OF DICOTYLEDONOUS HERBS						
34	Dicot	Herbs	(L)	Elizabeth Ridge Forest	6B, 5T, 1M	.01
35	"	"	(H)	" " "	S1, S2, S3	.89
36	"	"	(H)	Lodgepole Pine	S1	.22
37	"	"	(H)	" "	S3, S4	.66
38	"	"	(L)	Elizabeth Ridge Meadow	3B	.14
39	"	"	(L)	" " "	1B	.10
40	"	"	(L)	" " "	2B	.27
41	"	"	(H)	" " "	4T	.01
42	"	"	(H)	" " "	5T	.16
43	"	"	(H)	" " "	6T	.44
44	"	"	(L)	Bald Mt. Tundra #15		.16
45	"	"	(L)	" " " #16		.23
46	"	"	(L)	" " " #17		.01
47	"	"	(H)	" " " #1		.01
48	"	"	(H)	" " " #2		.01
49	"	"	(H)	" " " #3		.01
Overall Average						.178

Table 8-3. Silver content of the surface centimeter of soils at the four general study areas utilized in this study. Results are reported separately for spots that accumulate large drifts of snow and nearby, undrifted sites.

Study Area	Vegetative Cover	Snow Conditions	Sample Size	Mean Ag Content (ppm) and standard error
East Fork Blacks Fork	Lodgepole Pine	Undrifted	5	6.2 ± 5.9
		Drifted	5	9.4 ± 5.4
Elizabeth Ridge	Spruce-fir	Undrifted	5	10.1 ± 6.6
		Drifted	5	12.1 ± 6.8
Elizabeth Ridge	Meadow	Undrifted	5	14.0 ± 6.2
		Drifted	5	8.6 ± 3.8
Bald Mt.	Alpine Tundra	Undrifted	5	10.8 ± 4.3
		Drifted	5	7.4 ± 1.9

Table 8-4. Silver content of tissue of plants from various lifeform groups. Plants from all study areas are pooled in this analysis.

Plant Lifeform	Sample Size	Average Ag Content (ppm) Followed by Standard Error
Trees	3	.09 ± .11
Shrubs	3	.01 ± .00
Graminoides	21	.14 ± .05
Forbs	22	.25 ± .08

content of each herbaceous plant group. That comparison has been made: results show that silver content of woody plants is not significantly smaller than that in either graminoid or forb herbs, although the results approach significance for the woody plant - forb comparison.

In Table 8-5, the average silver content of all plant samples (irrespective of lifeform) from each major study area is reported. The highest average silver content of plant tissue thus pooled (.31 ppm) was found in plants of the lodgepole pine forest on the East Fork of Blacks Fork. The lowest average silver content of plant tissue (.12 ppm) was for plants from the spruce-fir forest on Elizabeth Ridge. Again however, large within group variances rendered all differences nonsignificant in a statistical sense.

The possibility exists that plants in zones of heavy snowpack take up silver in different amounts than do plants in areas having light snowpacks. We have combined forb and graminoid samples across all study areas to test the foregoing possibility. The results (Table 8-6) show no significant differences in silver content of plants from zones of light and heavy snowpacks.

DISCUSSION

The silver content of soils varies widely. Singleton and White (1975a and b) report values ranging from .032 to .061 ppm silver in soils of the Medicine Bow Mountains, Wyoming. Teller, Cameron and Klein (1976) give natural silver concentrations in soils of the San Juan Mountains ranging from .06 to 3.38 ppm. Chaffee (1972) found from less than .5 to 70 ppm silver in soils of the Empire mining district of Clear

Table 8-5. Silver content of plant tissue from our four general study areas. All samples from each area are averaged in this summary.

Study Area	Sample Size	Average Ag Content (ppm) and Standard Error
East Fork Blacks Fork	5	.31 ± .09
Elizabeth Ridge Forest	10	.12 ± .09
Elizabeth Ridge Meadow	23	.18 ± .07
Bald Mt.	11	.16 ± .08

Table 8-6. Silver content of plant samples grouped according to lifeform and snow melt date at the site of collection. Samples from all study areas were pooled for this analysis.

	Lifeform			
	Forbs		Graminoides	
	Snow Melt Date			
	Early	Late	Early	Late
Average Ag Content (ppm)	.13	.27	.18	.17
Standard Error	.038	.110	.060	.097
Sample Size	7	9	7	9
Significance of Difference	NS		NS	

Creek County, Colorado. Chaffee considered that values over 0.7 ppm silver were elevated above normal background levels.

Based on the foregoing values, the average silver content of over 9.0 ppm found in soils of our study areas on the North Slope of the Uinta Mountains are unusually high but still within normal ranges for the region. The levels are far below those shown to be required to depress metabolism of biological systems when insoluble forms of silver such as silver iodide are applied to soils (Klein and Sokol 1976 and Weaver and Super 1973).

Silver concentrations in plants like those in soils vary widely also. Cannon (1960) summarized the results of analyses for silver in the ash of over 1000 plant species: she found less than 1.0 ppm silver on the average in plant ash. Only 1.5% of the species analyzed contained detectable quantities of silver (Curtin et al. 1971). Singleton and White (1950a and b) report an average of .052 ppm silver in dry plant tissue in Wyoming and Teller, Cameron and Klein (1976) and Klein and Sokol (1976) show an overall average of .688 ppm silver in dry plant tissue in Colorado. Curtin et al. (1971) found from .5 - 3.0 ppm silver in the ash of pine needles in Clear Creek County, Colorado, and from < .5 - 2.0 ppm silver in the ash of quaking aspen leaves. Shacklette (1965) reports an average of 5.0 ppm silver in ash of vascular plant based on a summary of analyses on over 1,500 species.

Silver concentrations in dry plant tissue in this study averaged .178 ppm with a range of .01 to 1.43 ppm. Silver concentration in vascular plants of the North Slope of the Unita Mountains is thus well within the limits reported in the literature.

Both Singleton and White (1975b) and Klein and Sokol (1976) show that plant tissue content of silver increases as silver is artifically added to the soil that supports the plants. The increase is especially strong and reliable when silver is added to soils in a soluble form such as $AgNO_3$. In the Uintas, our data show a weak but statistically significant (.05 probability level) correlation between content of silver in soils and herbaceous dicots or forbs (r = .506, N = 16) but not for graminoid (monocot) plants. When silver content of monocot and dicot tissue form the same sampling plots is correlated in our study, there is a positive but statistically nonsignificant correlation. We thus find only a weak correlation between the silver content of soils and that in associated plants. We also find that one cannot predict silver content in dicotyledonous plants from a knowledge of silver content of monocotyledonous plants in our area.

The data on silver content of either soils or plants analyzed in this study show skewed distributions (Tables 8-1 and 8-2). Any effects of cloud seeding on environmental levels of silver are likely to be detected first in plants or soils that had the lowest pretreatment silver contents. Accordingly, the best sites to monitor for increases in soil content of silver would be the lodgepole pine stands on East Fork of Blacks Fork. Current year's twig growth of woody plants had low silver contents in this study, but the deep rooting habits of woody plant may isolate them from silver additions resulting from cloud seeding. Although they contain more silver than woody plants, the shallow, dense root systems of monocotyledonous herbs may make them more susceptible to silver accumulating on the soil surface. Accordingly, monocot herbs on snow accumulation sites on Blacks Fork are recommended for future monitoring programs.

LITERATURE CITED

Cannon, H. L. 1960. Botanical prospecting for ore deposits. Science 132:591-598.

Chaffee, M. A. 1972. Distribution and abundance of gold and other selected elements in altered bedrock, empire mining district, Clear Creek County, Colorado. U.S. Geological Survey Bulletin 1278-C. 23 pp.

Cooper, C. F. and W. C. Jolley. 1970. Ecological effects of silver iodide and other weather modification agents: a review. Water Resources Research 6(1):88-98.

Curtin, G. C., H. W. Lakin, A. E. Hubert, E. L. Mosier and K. C. Watts. 1971. Utilization of mull (forest humus layer) in geochemical exploration in the Empire District, Clear Creek County, Colorado. U.S. Geological Survey Bulletin 1278-B. 39 pp.

Klein, D. A. and G. Mulvey. 1978. Amounts of silver-derived agents used in weather modification in relation to contributions from other sources, pp. 5-8 <u>In</u> D. A. Klein (ed.), Environmental Impacts of Artificial Ice Nucleating Agents, Dowden, Hutchinson and Ross, Inc., Stroudsburg, Pennsylvania. 256 pp.

Klein, D. A. and R. A. Sokol. 1976. Evaluation of ecological effects of silver iodide seeding agent, pp. 125-138 <u>In</u> H. W. Steinhoff and J. D. Ives (eds.). Ecological Impacts of snowpack augmentation in the San Juan Mountains, Colorado. Final Report, Colorado State University, Fort Collins.

Shacklette, H. T. 1965. Element content of bryophytes. U. S. Geological Survey Bulletin 1198-D. 21 pp.

Singleton, P. and R. White. 1975a. Silver iodide: Natural concentrations in the Medicine Bow Mountains, pp. 10-15 In D. H. Knight (ed.) Final Report, Medicine Bow Ecology Project. University of Wyoming. Laramie.

Singleton, P. and R. White. 1975b. Silver iodide: its movement in an alpine ecosystem and its effects on two plant species, pp. 329-351 In D. H. Knight (ed.) Final Report, Medicine Bow Ecology Project. University of Wyoming, Laramie.

Summers, P. 1980. 1979-80 winter cloud seeding project. Weather Modification in Utah Newsletter 6(1):1-2.

Teller, H. L., D. R. Cameron, and D. A. Klein. 1976. Disposition of silver iodide used as a seeding agent, pp. 105-123 In H. W. Steinhoff and J. D. Ives (eds.) Ecological impacts of snowpack augmentation in the San Juan Mountains, Colorado. Final Report, San Juan Ecology Project, Colorado State University, Fort Collins.

Weaver, T. W. and A. B. Super. 1973. Ecological consequences of winter cloud seeding. Journal of the Irrigation and Drainage Division IR3: 387-399.

CHAPTER 9

EVALUATING PLANT COMMUNITY MONITORING DESIGNS USED IN THE UINTA ECOLOGY PROJECT

By

W. Kent Ostler

K. T. Harper

M. W. Carter

and

K. B. McKnight

ABSTRACT

Four major plant communities (lodgepole pine and Engelmann spruce forests, subalpine meadow and alpine herbland) have been sampled for three or more years. Problems associated with selection of sample unit size, number of samples required for adequacy, observer effects, and the statistical advantages imparted by permanent versus annually relocated sample sites are considered. Our results show that the sample size required to detect community changes of a given magnitude with a specified level of confidence is affected by community structure, absolute abundance of the species (or magnitude of the characteristic) being sampled, morphological characteristics of the species of concern, and whether or not the sampling units are relocated annually. Heavily vegetated areas are more easily sampled to a given level of adequacy than sparsely vegetated areas within the same community. Herbaceous layers of forests require larger samples than herblands of equal absolute cover. Common species are more easily sampled than uncommon species; broadleaved herbs are easier to sample to a given level of adequacy than grasses or grasslike species even when both have equal cover and frequency. Ways of increasing the efficiency of long-term monitoring programs in plant communities are suggested.

INTRODUCTION

The exactness of our knowledge of the natural world is dependent upon the accuracy of the sampling procedures employed to gain information. In order to accurately describe a natural community, the sample must be drawn from the full range of variation within the community and must be of sufficient size to estimate the true parameters of the community within narrow limits. Numerous investigators have suggested techniques for determining the size of sample required to adequately describe a population (Cain 1934, Pechanec and Stewart 1941, Rice 1967, Snedecor and Cochran 1967, Mueggler 1976, and Cook and Bonham 1977). Other workers have considered the most efficient method for drawing samples from the universe of concern (Pechanec and Stewart 1940, Bourdeau 1953 and Eddleman et al. 1964). Still others have devoted attention to the question of proper sampling unit size (area) in vegetational studies (Day 1920, Clapham 1932, Bormann 1953, Eddleman et al. 1964 and West and Baasher 1968). In all of the preceding references, the authors emphasize that if one wishes to describe a community with a known degree of confidence, good sampling design is imperative.

Innumerable vegetation management programs demand a knowledge of plant community structure, composition and/or production. Managers frequently desire to know how some community characteristic varies in time at a given point or in space along gradients of known environmental change. It is also often necessary to predict carrying capacity of a given segment of a plant community for some animal or group of animals. Since a complete inventory of the vegetation of any sizeable area would be prohibitively expensive in terms of both time and money, the population parameters of interest must be estimated from samples. If samples are drawn in compliance with proven statistical methods, inferences of acceptable accuracy can be made for large areas.

The Water and Power Resources Service of the U.S. Department of Interior and the Utah Division of Water Resources are currently investigating the possibility of cloud seeding winter storms to augment winter snowpack and subsequent streamflow in the Uinta Mountains of Utah. The sampling program reported here was initiated to estimate long term effects of deeper snowpacks on plant communities of the Uintas. In this report, we describe various aspects of our investigative methods and give our recommendations for sampling designs for detection of long-range trends.

STUDY AREA

The primary study area for this analysis is located on the northern slope of the Uinta Mountains in Summit County, Utah. The area that will receive primary emphasis lies at about 3,200 m elevation on Elizabeth Ridge, a north-south trending prominence which forms the divide between the Great Basin and the Colorado River Basin drainage systems. The area appears to have escaped glaciation during the Pleistocene, because of its isolation from large areas where ice might accumulate (Hansen 1975). Two major plant communities are represented within the study area. The first is a subalpine meadow dominated by perennial grasses and forbs. The second is an open spruce-fir forest with trees forming the dominant plant cover. Results for these two communities will be compared with results from lodgepole pine and alpine herbland communities in an attempt to test the generality of conclusions.

The sample size (number of .02 ha macroplots) for spruce-fir and lodgepole pine forests was 36 and 25 respectively. Twenty-nine .02 ha macroplots were monitored in the subalpine meadow and 21 macroplots were sampled in alpine herbland.

The study area on Elizabeth Ridge is situated on the nearly flat top of the ridge. Drainage water moves slowly from east and west across the area. Soil depth increases down the drainage gradient; thus soils are shallow along the eastern side of the ridge and gradually increase in depth across the .5 km wide study area. Spruce (*Picea engelmannii*) and fir (*Abies lasiocarpa*) trees have established on the shallower soils to the east but appear unable to invade the subalpine meadow where soils are deeper and more uniformly moist throughout the year. The soils are derived from late Tertiary alluvium: parent material is uniform across the study area, but organic matter content of the soil increases down the drainage gradient.

Although total elevational change across the study area is less than two meters, the open forest to the east causes the prevailing westerly winds of winter to begin to deposit their burden of snow more than 100 m in front of the forest edge. As a consequence, a large snowdrift parallels the forest-meadow border. The drift extends over 100 m into the meadow and the forest. At the point of maximum depth (which usually lies immediately behind the forest edge), the drift may be over twice as deep as along its leading edge. Within the forest, the drift varies greatly in depth over short distances because of variation in wind patterns caused by trees. Water storage in the drift varied from 18 to 68 cm of precipitation equivalent from place-to-place in the forest in April, 1977: in 1978, water storage in the drift varied from

41 to 117 cm on our forest study plots.

Annual precipitation at the study area during the 1976-77 water year (Oct. 1 - Sept. 30) was about 56 cm. Precipitation between Oct. 1, 1977 and Sept. 30, 1978 totalled about 73 cm.

METHODS

Twenty-nine .02 ha circular study plots (macroplots) were established in a stratified block design across the meadow study area in June, 1976 (Fig. 5-1). The design allocated about equal numbers of macroplots to areas covered by shallow, moderately deep, and deep snowdrifts. Each macroplot was permanently marked with a steel reinforcing bar at its center. Thirty-six macroplots of identical size and shape were established in the spruce-fir forest community: macroplots were again placed across the gradient of snowdrift depth in a stratified block design. The .02 ha macroplots are small enough to minimize within-plot environmental and vegetational heterogeneity but large enough to give a fair sample of the entire plant community at given locations.

Within each macroplot, 25 subsamples (quadrats) were regularly spaced. Each quadrat was circular in shape and had an area of 0.25 m^2. To facilitate relocation of quadrats, each was marked by a red, 8 cm long, wooden dowel driven 7 cm into the soil at the center of the quadrat (see Harper, 1976, for a more detailed description of quadrat placement procedures). In the final year of study, a 16 penny, zinc coated nail was driven into the soil at the center of each 0.25 m^2 quadrat to permit relocation of quadrats in the future with the aid of a metal detector. The quadrats and macroplots serve as the basic experimental units (BEUs) in all subsequent analyses.

The quadrat size employed here was selected on the basis of data reported by Eddleman et al. (1964) for alpine vegetation in Colorado. Eddleman et al. (1964) as well as Pechanec and Stewart (1940), Bormann (1953) and Rice (1967) recommend using quadrats as large as possible in order to reduce edge effects, increase data for uncommon species, and minimize time lost in locating sample sites. We have found that the 0.25 m^2 quadrat yields frequency values of 80-90% for our more common species. That quadrat is also small enough to permit the worker to look directly down on the plot while estimating cover, thus eliminating parallax problems. We relied on foliage cover and frequency of occurrence (% of quadrats in which a species occurs) to describe response of individual species. We did not count individuals in the quadrats, since establishing the extend of an individual plant that reproduces vegetatively is impossible without excavating underground parts. Where plant numbers are required for plants that do not reproduce vegetatively, a smaller quadrat than we have used would probably be desirable, since plant numbers would be large for many species in 0.25 m^2 quadrats.

Eddleman et al. (1964) reported that rectangular quadrats were slightly more efficient than other shapes for estimating vegetation parameters. We selected circular quadrats primarily for ease of marking locations for later visits (i.e., exact location of circular quadrats can be recorded with a single peg while four-sided quadrats require at least two pegs). For analysis of long-range trends in vegetation, exact relocation of quadrats is essential: this point will be enlarged upon later.

At each quadrat, the following data were recorded: 1) an estimate of the foliage cover of each species that shaded the quadrat, 2) total living cover of all species combined, 3) cover of plant litter, 4) cover of rock of > 5 mm diameter, and 5) composition of the total living cover with the relative contribution of the major lifeform groups being estimated as percentages of the total. Cover for all categories was estimated using a cover-class method (Daubenmire 1968) with the classes delimited as follows: trace) < 1.0%, 1) 1.1-5.0%, 2) 5.1-10.0%, 3) 10.1 25.0%, 4) 25.1-50.0%, 5) 50.1-75.0%, 6) 75.1-95.0%, and 7) > 95.0%. Lifeform groups recognized in the relative cover estimates were: trees, shrubs, perennial graminoides, perennial forbs, annuals, and cryptogams (mosses, liverworts, and lichens). Total number of species per quadrat and per macroplot was recorded. Frequency values for all species were obtained by dividing quadrats of occurrence for each species by total quadrats in the sample. All samples were taken in July and early August of each sampling year.

Our hypothesis that the 25 permanently marked subsamples per macroplot adequately described the vegetation of the macroplot was tested by placing an additional 25 quadrats at new, objectively chosen locations in two randomly selected macroplots in both meadow and forest communities. The new quadrats were located exactly midway between each pair of original quadrats. New quadrats were sampled in the same manner as the original BEUs. Average values for the various vegetational characteristics in the original BEUs were then compared with comparable values derived from the new suite of quadrats. Significance of differences between values from the original and new BEUs for the various vegetational characteristics was evaluated with an unpaired t-test (Snedecor and Cochran 1967).

In order to evaluate the ability of different workers to provide closely similar estimates of vegetational composition, all quadrats on two macroplots in meadow and two in forest vegetation were sampled independently by two workers on August 12, 1977. This sample provided 50 BEUs per community per worker for analysis. Since each worker sampled the same quadrats, data were analyzed with a paired t-test.

RESULTS

Adequacy of Sample

We have evaluated the adequacy of our sample for the subalpine meadow and the spruce-fir forest in the following ways: 1) determination of the sample size (number of macroplots/community and number of quadrats/macroplot) required to adequately describe a site or to detect a change in total living cover with a known level of confidence, 2) evaluation of the degree to which different observers give similar results for community composition on the same macroplots and in the same season, and 3) analysis of the influence of permanent placement versus annual relocation of quadrats by random means on the sample size required to detect long-term trends for selected community characteristics (e.g., total living cover).

Adequacy of sample size was considered in several contexts as follows: 1) how many quadrats are required to describe the herbaceous cover of individual macroplots at a specified level of accuracy, 2) how many macroplots are required to describe the local manifestation of a vegetational type (or snow-release zone within the type) at a specified level of accuracy, 3) how many macroplots are required when one desires to detect differences of a given magnitude between two means (e.g., changes in plant cover on a given site in different years or differences in cover between two snow-release zones in the same year) with a specified degree of confidence, and 4) how does the method of quadrat placement (i.e., fixed point or annual relocation by objective procedures) influence the sample size needed to detect cover changes of a given size at a specified level of accuracy?

Sample Size for Describing Single Populations. Several formulae have been published for determination of adequacy of sample. We will first use Snedecor and Cochran's (1967, p. 58) equation for establishing the minimum sample size for adequate description of a given site or characteristic. In that equation, minimum sample size, N, is computed as follows: $N = \frac{4S^2}{L^2}$. In the equation, the value 4 in the numerator represents the square of the tabular value for the two-tailed-t at infinite degress of freedom and the .05 probability level (the tabular value is actually 1.96 but the value 2.0 is used instead for simplicity). The value S^2 is the parameter for population variance, but the sample value is used in place of the parameter. L represents a value specifed by the investigator. This equation estimates the number of samples required to estimate a mean within specified limits of accuracy with 95% confidence.

When adequacy of sample for living plant cover was to be evaluated in this study, the L-value was set at 8.0% absolute plant cover which is equal to 10% of the mean for living cover on the subalpine meadow (Table 9-1). We have also set L equal to 8.0% for evaluation of adequacy of sample sizes for cover estimates in the spruce-fir forest, the lodgepole pine forest, and the alpine herblands even though all of those communities supported less cover in the herb layer than the subalpine meadow (See chapters 4-7). Others (Cook and Bonham 1977) have suggested that

---

Table 9-1. Sample size required to estimate total living plant cover within eight absolute units (percentage units) with 95% confidence in various vegetational contexts within the four plant communities sampled on the North Slope of the Uinta Mountains. All values are based on an assumption of annual relocation of BEUs. Only understory cover (foliage less than 2.0 m high) is considered for the forest communities. The sampling units were 0.25 m^2 quadrats within macroplots and 0.02 ha macroplots within communities or snow-release-date zones. Average cover and the standard deviation of cover is shown for each community or snow-release date zone.

Quadrats Required per Macroplot

Community	No. Quadrats Needed	No. Quadrats Actually Sampled
Subalpine Meadow	19	25
Alpine Herbland	16	25
Lodgepole Pine Forest	25	25
Spruce-fir Forest	20	25

Macroplots Required to Obtain Specified Accuracy for Entire Stand

Community	Average Cover (%)	No. Macroplots Needed	No. Macroplots Sampled
Subalpine Meadow	78.4 ± 8.7	5	29
Alpine Herbland	60.8 ± 7.4	4	21
Lodgepole Pine Forest	33.9 ±15.3	15	25
Spruce-fir Forest	54.2 ±12.7	10	36

Macroplots Required to Obtain specified Accuracy for Estimates of Living Cover in Snow-release Zones of Each Community

Community	Average Cover (%)	No. Macroplots Needed	No. Macroplots Sampled
Subalpine Meadow			
Early-Melt Date	77.7 ± 8.2	5	11
Moderate-Melt Date	83.9 ± 6.1	3	10
Late-Melt Date	72.5 ± 8.8	3	8
Alpine Herbland			
Early-Melt Date	50.6 ± 3.7	1	4
Moderate-Melt Date	61.0 ± 5.3	2	8
Late-Melt Date	65.1 ± 7.6	4	9
Lodgepole Pine Forest			
Early-Melt Date	27.2 ±13.9	12	8
Moderate-Melt Date	32.4 ±15.9	16	13
Late-Melt Date	51.9 ±16.1	16	4
Spruce-fir Forest			
Early-Melt Date	56.7 ±11.4	9	14
Moderate-Melt Date	51.8 ±10.2	7	16
Late-Melt Date	35.8 ± 4.2	2	6

when adequacy of cover estimates are to be made, L should be set equal to 10% of the mean for living cover in the community of concern. Such an approach has the disadvantage of forcing the investigator to detect very small differences when average cover in a community is small. As a consequence, samples must be very large in communities with sparse cover, if the standard of adequacy is to be met. The investigator is thus forced into the illogical position of expending the greatest amount of effort in sampling communities that produce the smallest amount of plant resources. To circumvent that problem, we have set L equal to an absolute rather than a relative value for cover. In our case, setting L at 8.0% should permit us to detect a 10% change in cover in the subalpine meadow, but only 13.3, 14.8, and 28.4% relative changes in cover in the herb layers of alpine herbland, spruce-fir forest, and lodgepole pine forest respectively (see Table 9-1).

In Table 9-1, we have computed variance for different BEUs in the three subdivisions of the table. In the top section of the table, variance is based on cover estimates in 50 quadrats (25 per macroplot) in two randomly chosen macroplots per community. In the middle section of the table, variance is based on average cover per macroplot sampled in each community. The final section of the table is based on variance values for mean cover in each macroplot in a given snow-release date group.

Using the foregoing adequacy of sample equation, the number of quadrats required to adequately describe macroplots in the meadow was found to be 19; the comparable value for alpine tundra was 16 (Table 9-1). For macroplots in the spruce-fir forest, the number of quadrats required to describe absolute plant cover within 8% with 95% confidence

---

was 20, but the comparable value for lodgepole pine forest was 25. Since 25 quadrats were taken per macroplot in all communities, sample size within macroplots (assuming annual relocation of quadrats) was adequate for all communites.

The number of macroplots needed to adequately describe each community and each snow-release zone within each community is also reported in Table 9-1. In all communities and most snow-release zones, the number of macroplots available was adequate to describe the living plant cover within ± 8% absolute cover units of the true mean with 95% confidence. The number of macroplots sampled was adequate to describe the entire lodgepole pine community considered with the desired level of confidence, but variance within each of the three snow-release-date zones for that community was large. As a consequence, our sample size is insufficient to give 95% confidence that our means for lodgepole snow-release zones are representative. The sample size in the early and moderate snow-release zones was large enough to give 90% confidence that the means are representative, but there is only 60% confidence that the sample mean for the late-release zone is representative.

Sample Sizes for Testing Hypotheses. If one wishes to use sample means to test hypotheses (e.g., living cover on a given macroplot does not change significantly between years or the living cover of early and late snow-release zones does not differ significantly) the adequacy-of-sample equation previously discussed must be changed significantly. Snedecor and Cochran (1967) give the following equation for computing sample size for specified levels of accuracy when 2-tailed tests of hypotheses are to be made: $N = \frac{(Z_{\alpha/2} + Z_{\beta})^2 \; 2S^2}{L^2}$ where $Z_{\alpha/2}$ is equal to the two-tailed t-value (at infinite degress of freedom) for the specified level of confidence for avoiding type I errors (stating there is a difference when none actually exists), Z_β is equal to the two-tailed t-value (degrees of freedom also at infinity) for the desired confidence level for not making a type II error (stating that no difference exists when one actually does), S^2 is the pooled sample variance and L designates a value specified by the investigator and represents the magnitude of difference that one wishes to detect between the two populations. The above equation is used when the BEUs are relocated annually, and comparisons are to be made between years. In this equation, the $Z_{\alpha/2}$ value has a subtle meaning: one might conclude that the t-value should be divided by two. The intent instead is that the probability value for entry to the t-table to give the desired confidence level must be divided by two.

Should the BEUs be permanently fixed (not relocated each year), the adequacy-of-sample equation can take the following form: $N = \frac{(Z_{\alpha/2} + Z_\beta)^2 S_d^{\,2}}{L^2}$. In this equation, all symbols are defined as above, but $S_d^{\,2}$ is the variance of the difference between two readings of each of a series of permanently located BEUs in a common population in the same season. Experience shows that sample sizes can usually be smaller (while maintaining a given level of confidence that type I and type II errors will not be made) when BEUs are permanently fixed in space (see Table 9-7).

It is difficult to imagine cases where the investigator would not be interested in avoiding both type I and II errors. Accordingly, the worker must decide on a practical probability level for avoiding type I and type II errors. Snedecor and Cochran (1967, p. 113) give multipliers that are commonly used for $(Z_\alpha + Z_\beta)^2$ in the equations for avoiding type I and type II errors shown in the preceding paragraphs.

If one selects the two-tailed t-value at the 0.01 level for type I errors and desires 95% assurance that type II errors will be avoided, $(Z_\alpha + Z_\beta)^2$ must be set at 17.8, but if the two-tailed t-value is taken at the 0.10 level for type I errors and the investigator is content with 80% assurance that he will not make type II errors, the $(Z_\alpha + Z_\beta)^2$ value can be reduced to 6.2. If one-tailed t-values can be justified, and the t-value for type I errors is set at the 0.10 level and an 80% level of assurance that type II errors will not be made is acceptable, the value for $(Z_\alpha + Z_\beta)^2$ could be lowered to 4.5. In studies that test the hypothesis that winter orographic snow augmentation will not reduce plant cover in the mountains where cloud seeding is to be practiced, the one-tailed t-value seems justified. If one-tailed tests can be justified, sample size can be reduced considerably without loss in confidence. The adequacy of sample equation for one-tailed tests when sample units are relocated annually is as follows: $N = \frac{(Z_\alpha + Z_\beta)^2\, 2S^2}{L^2}$. It will be noted that only the Z_α entry differs in this and the two-tailed adequacy-of-sample equation for situations where BEUs are annually relocated. In this latter case, the probability value for entry to the t-table need not be divided by two.

The results of our analyses of adequacy of sample size for testing hypotheses show that sample sizes would have to be very large to give 95% confidence that both Types I and II errors would be avoided (Table 9-2). Even though the one-tailed adequacy of sample equation was used to construct Table 9-2, none of the snow-release date sample pairs had adequate macroplots in the smaller of the samples to give 95% confidence that differences of 8% cover between snow-release zones could be detected.

Table 9-2. Sample size required to detect an absolute change of 8% in total living plant cover between two snow-release zones in the four vegetation types considered in this study. Sample size varies with degree of confidence required for both type I and II errors. In this table, two confidence levels are considered for the one-tailed adequacy of sample equation: 1) a 95% probability of avoiding both type I and II errors, and 2) 90% probability of avoiding type I errors and 80% probability of avoiding type II errors. The tests assume annual relocation of BEUs.

Community, Snow Zone Comparisons	Macroplots Required To Detect 8% Change With 95% Confidence of Avoiding Type I & II Errors.	Macroplots Required To Detect 8% Change With 90 and 80% Probability of Avoiding Types I & II Errors.	No. of Macroplots Sampled (Smallest of Either Zone)
Subalpine Meadow			
Early-Melt Date vs. Moderate-Melt Date	17	7	10
Moderate-Melt Date vs. Late-Melt Date	24	10	8
Late-Melt Date vs. Early-Melt Date	19	8	8
Alpine Herbland			
Early-Melt Date vs. Moderate-Melt Date	7	3	4
Moderate-Melt Date vs. Late-Melt Date	14	6	8
Late-Melt Date vs. Early-Melt Date	11	4	4
Lodgepole Pine Forest			
Early-Melt Date vs. Late-Melt Date	77	32	8
Moderate-Melt Date vs. Late-Melt Date	87	36	4
Early-Melt Date vs. Moderate-Melt Date	75	31	8

Table 9-2. Continued.

Community, Snow Zone Comparisons	Macroplots Required To Detect 8% Change With 95% Confidence of Avoiding Type I & II Errors.	Macroplots Required To Detect 8% Change With 90 and 80% Probability of Avoiding Types I & II Errors.	No. of Macroplots Sampled (Smallest of Either Zone)
Spruce-Fir Forest			
Early-Melt Date vs. Moderate-Melt Date	40	16	14
Moderate-Melt Date vs. Late-Melt Date	24	10	6
Late-Melt Date vs. Early-Melt Date	26	11	6

This result was expected, for as Snedecor and Cochran (1967) reported, sample sizes adequate to give high probabilities that small differences between groups will be detected are so expensive that high probabilities (> 90%) of avoiding type I and type II errors are rarely required.

Even when probability values of 90 and 80% for avoiding Types I and II errors respectively were set, sample sizes in both forest communities were inadequate for tests between snow-release zones (Table 9-2). Given the variance encountered and the small sample size in the late-release zone, the actual probability of avoiding type I and type II errors, while trying to detect a difference of 8% absolute cover between release zones in the lodgepole pine forest understory is not much better than 60% given the assumption of annually relocated sampling plots. Fortunately, the BEUs are permanently fixed: that fact greatly enhances the likelihood that differences can be detected with samples of the size available (Table 9-7).

Observer Effects

Reproducibility. The degree to which different observers agree among themselves is a vital factor in any sampling program that must depend upon several observers to gather the sample. In order to accurately estimate the true mean for a suite of sites in any one year or to detect real differences among those sites in different years, observers must agree among themselves and be able to accurately estimate the parameter for any variable in question. In our study, each of four observers have sampled a portion of the macroplots for plant parameters in both 1976 and 1977. No attempt was made to have one observer sample all macroplots in any one community or snow-release zone within that

community. Neither was an attempt made to have each macroplot sampled by the same observer in successive years. Accordingly, observer effects must be evaluated before the reliability of our results can be judged.

As a first test of the ability of observers to provide similar results for comparable vegetation plots, we analyzed their results for living plant cover for an array of 29 macroplots in meadow and 30 in spruce-fir forest (all on Elizabeth Ridge) sampled in 1976 and 1977. We used Spearman's rank correlation statistic (Snedecor and Cochran 1967) to compare living herbaceous cover estimates for all macroplots in each community in the two years (Table 9-3). Living cover in the meadow averaged 73.6% in 1976 and 78.2% in 1977. Cover values for meadow macroplots had a total range that ran from 91.6 to 57.1% in the two years. Understory cover in the forest averaged 53.0% in 1976 and 54.2% in 1977. Absolute range of understory cover in the forest sample ran from 86.3 to 23.0%. The 1976 growing season was preceded by average snowpack conditions followed by a dry summer; in 1977 the snowpack was unusually light, snow-free dates were early and growing season precipitation was unusually heavy. The combination of weather conditions of the 1976 growing season were apparently less favorable for herbaceous plant growth than conditions of 1977, since cover was greatest in 1977 in both meadow and forest. The Spearman rank correlation coefficients were significant at the 1% level when 1976 cover was compared to 1977 cover for all macroplots in each communities (meadow and forest). The results indicate that all observers tended to place the array of plots in about the same relative order in respect to cover in the two years.

Table 9-3. Total living cover (understory cover only for the forest) in 1976 and 1977 in the subalpine meadow and spruce-fir forest macroplots of Elizabeth Ridge.

Forest			Meadow		
Macroplot No.	1976	1977	Macroplot No.	1976	1977
	% Cover			% Cover	
1A	37.3	49.3	1A	76.8	83.0
1B	44.3	47.3	1B	79.0	85.4
1C	48.9	48.2	1C	63.8	59.1
2A	44.5	50.9	2A	80.6	80.1
2B	65.5	63.0	2B	85.3	85.8
2C	51.3	50.0	2C	74.5	76.6
3A	55.8	51.0	3A	75.7	73.5
3B	69.6	79.9			
3C	41.7	60.7	3C	66.5	67.0
4A	49.1	43.3	4A	72.4	69.3
4B	57.6	56.3	4B	76.4	84.0
4C	51.2	52.3	4C	61.1	60.6
5A	70.5	70.4	5A	72.1	72.5
5B	48.5	42.5	5B	77.1	85.8
5C	52.4	48.1	5C	74.0	75.5
6A	31.4	23.0	6A	69.6	81.1
6B	35.3	29.8	6B	77.3	84.4
6C	63.6	58.2	6C	63.9	68.0
7A	48.4	42.7	7A	65.8	68.8
7B	60.0	55.8	7B	77.9	82.1
7C	52.2	52.8	7C	78.7	88.2
8A	86.3	83.0	8A	57.1	65.9
8B	59.1	67.6	8B	82.0	82.1
8C	63.8	62.0	8C	62.9	73.7
9A	29.4	35.3	9A	74.8	86.3
9B	53.8	52.4	9B	83.8	91.1
9C	36.2	38.0	9C	67.8	74.8
10A	65.3	74.2	10A	82.3	91.6
10B	60.0	64.0	10B	80.7	88.0
10C	56.9	73.1	10C	75.5	84.3
Average	53.0	54.1		73.6	78.2
Standard Deviation	12.6	14.1		7.4	9.0

In a second evaluation of the ability of different observers to provide similar descriptions of the plant cover on a given plot, two observers sampled the same 100 fixed (permanently marked) quadrats (0.25 m^2) in four macroplots (two in the meadow and two in the forest at Elizabeth Ridge). The results obtained by the two observers were compared for similarity of 1) species composition based upon quadrat frequency, 2) species composition based upon species cover estimates, 3) total living cover of herbaceous species, and 4) number of vascular species per quadrat.

The results (Table 9-4) demonstrate that the two observers were in close agreement on composition of all macroplots considered, but they were usually in closer agreement when the similarity was based on frequency data than when cover data were used. Since frequency data are based on qualitative observation (i.e., presence or absence) while cover values are quantitative, it is reasonably clear why the observers agreed more closely on frequency than on cover. Others have reported (Curtis 1959) that repeated sampling of the same vegetational sample by the same individual will rarely yield similarity values in excess of 80%. Our observers thus appear to be estimating composition about as similarly as observers can be expected to.

When the two observers' estimates of various compartments of ground cover (i.e., % living cover, % litter, and % rock) are compared for the 100 quadrats distributed among the four macroplots noted in Table 9-4, it is seen that all estimates are in close agreement (Table 9-5) and most do not differ significantly in a statistical sense. The observers differ significantly in respect to their estimate of number of plant species per quadrat in the meadow (but not in the forest). One observer

Table 9-4. Similarity of community composition as measured by samples taken from the same quadrats and macroplots on the same day but by different observers. One-hundred quadrats in four macroplots were sampled by each observer. Half the macroplots were in subalpine meadow and half in spruce-fir forest. Similarity of community composition values obtained at each macroplot by the two observers was assessed with the similarity index of Ruzicka (1958). Similarity of composition estimates was evaluted on the basis of both frequency and cover of all vascular species in the sample.

Community	Macroplot	% Similarity Based on Frequency	% Similarity Based on Cover
Subalpine Meadow	A	80	77
	B	90	75
Spruce-fir Forest	A	77	74
	B	83	89

Table 9-5. Comparison of two observer's estimates for various compartments of ground cover, number of vascular species per quadrat, and composition of the vegetation on the four macroplots noted in Table 4. The sample for each community consists of 50 quadrats uniformly spaced over the surfaces of two macroplots. Each observer read the same set of quadrats at each macroplot. Test criterion for detection of differences between means obtained by the two observers for each variable was the paried t-test.

Community		Variable							
						Composition of Living Cover			
Subalpine Meadow	Observer	Living Cover	Litter	Rock	No. of Vascular Species/Quadrat	Forbs	Grasses	Annuals	Cryptogams
		%	%	%		%	%	%	%
	1	72.2	6.9	8.7	12.7	52.5	43.9	1.0	2.5
	2	75.1	5.2	12.0	11.9	47.7	49.5	0.5	2.1
Absolute Difference		2.9	1.7	3.3	0.8	4.8	5.6	0.5	0.4
Significance of Diff.		NS	NS	NS	*	*	*	NS	NS
Spruce-fir Forest									
	1	49.7	28.0	9.5	9.5	63.8	23.8	1.1	1.6
	2	47.0	25.8	12.8	9.3	62.3	26.9	0.7	1.0
Absolute Difference		2.7	2.2	3.3	0.2	1.5	3.1	0.4	0.6
Significance of Diff.		NS	NS	NS	NS	NS	NS	NS	NS

NS - not statistically significant
* - difference significant at the .05 probability level

consistently failed to detect the presence of one species of small stature, but even though the difference between observers was significant, it was small (less than one species in about 12). The observers also differed to a statistically significant degree in respect to their estimate of the relative contribution of perennial forbs and grasses to total living cover in the meadow (Table 9-5). Their estimates of relative contributions of grasses and forbs were closer in the forest where there was less cover and forbs and grasses did not grow intertwined as in the meadow. Again although the observers' estimates of the relative contribution of forbs and grasses in the meadow differed significantly, the absolute differences were small and do not seriously alter the usefulness of the results for many purposes.

<u>Influence of Plant Form and Abundance</u>. It was of interest to us to know whether observers agreed more closely on some characteristics of vegetation than on others. In particular, we desired to know whether grasses and forbs of equal abundance (frequency or cover) could be sampled with an equal degree of agreement between observers. The degree to which two observers agreed on the occurrence (frequency) and cover of common and uncommon forb and graminoid species was tested in 100 quadrats distributed equally between two subalpine meadow and two spruce-fir forest macroplots. All quadrats were independently sampled by two observers on the same day in August 1977. Average frequency and cover values were obtained for each species at each macroplot by each of the two observers. A total of 7 forb and 6 graminoid species were considered to be common (> 50% frequency and > 2.5% living cover). Thirteen forb and 7 graminoid species occurred in the sample with lower frequency and cover and are included in Table 9-6 as uncommon species.

Table 9-6. Results of the attempt of two observers to estimate frequency and cover of 33 plant species in four macroplots. The agreement indices (the ratio formed by dividing the difference between the two estimates by the average of those estimates) are averaged for species of similar lifeform (forb or graminoid) and abundance (common = > 50% frequency or > 2.5% living cover). When group variances differed significantly between groups being tested, an unequal variance group-comparison model was used to test for significance of differences between means.

	FREQUENCY		
	<u>Common</u>	<u>Uncommon</u>	<u>Significance of Difference</u>
FORBS			
Average $\frac{\text{Difference}}{\text{Mean}}$	.62 ± .050	.277 ± .228	t = 5.168***
Sample Size	(22)	(32)	
GRAMINOIDES			
Average $\frac{\text{Difference}}{\text{Mean}}$	.126 ± .105	.273 ± .215	t = 2.634*
Sample Size	(10)	(23)	
Significance of difference	t = 1.844*	t = .066 N.S.	
FORBS			
Average $\frac{\text{Difference}}{\text{Mean}}$	.194 ± .159	.366 ± .300	t = 2.186*
Sample Size	(18)	(36)	
GRAMINOIDES			
Average $\frac{\text{Difference}}{\text{Mean}}$	.273 ± .266	.366 ± .300	t = .675 N.S.
Sample Size	(11)	(22)	
Significance of Difference	t = 1.017 N.S.	t = .388 N.S.	

* significant at the .05 level
*** significant at the .001 level
N.S. not statistically significant

Average frequency values for the common forbs and graminoides were 71 and 79% respectively. Average cover values for the common forbs and graminoides was 7.1 and 6.8% respectively. Uncommon forb and graminoid species had the following average values for frequency and cover respectively: 27 and 25% for frequency and 0.9 and 0.9% for living cover.

The degree to which the two observers agreed on frequency or cover of a specific species in a given macroplot was quantified by subtracting the smaller from the larger estimate and dividing that difference by the average of the two estimates. Finally, results were summarized by pooling the "agreement indices" for all common (or uncommon) species of a given lifeform (forb or graminoid) in the sample and computing an average "agreement index" for the group. Should a particular species occur in all four macroplots, four agreement indices were entered into the analysis for that species.

The results demonstrate that the observers agreed more closely on forbs than on graminoides (Table 9-6). They were also in closer agreement on common species of either lifeform group than on uncommon species. Estimates were thus least reliable for uncommon graminoides. As expected, estimates for frequency were always in closer agreement than those for cover.

Permanent Placement Versus Annual Relocation of Quadrats

Values given in Tables 9-1 and 9-2 for sample sizes required for the desired level of precision are based on the assumption that BEUs would be randomly relocated each year. Since our sampling stations (both quadrats and macroplots) are permanently marked, we desire to know

whether permanent placement of BEUs affects the sample size needed to detect a 10% change in living cover (or any other parameter) at given points across a sequence of years. We assume that if individual permanent quadrats vary less from year-to-year than randomly relocated quadrats would differ from each other in different years, a smaller sample will yield the desired level of precision if quadrats are permanently marked and resampled year-after-year rather than relocated at random annually.

Sample size required to detect a 10% change in the mean with 90 and 80% confidence that type I and II errors respectively will not be made is reported in Table 9-7 for three characteristics of the vegetation of two meadow and two forest macroplots on Elizabeth Ridge. The number of quadrats required per macroplot assuming annual relocation of quadrats is computed using the two-tailed adequacy-of-sample equation presented earlier; variance for this analysis is that derived from the 25 quadrats sampled annually in each macroplot. Minimum sample size required for the designated level of precision assuming annual resampling of the same marked quadrats was computed by taking the differences between the quantitative estimates of two independent observers for a given vegetational characteristic at each quadrat in the same year. The variance of the suite of 25 differences thus obtained per macroplot and characteristic was then used in the adequacy-of-sample equation to predict the minimum sample size needed to detect a change equal to 10% of the mean (not 10% of the average difference between observers) for the variable in question.

The results indicate that the minimum sample size required for the specified level of adequacy is always smaller when quadrats are permanently

Table 9-7. The influence of annual relocation versus permanent placement of quadrats on the number of quadrats required to detect a 10% change in each of three parameters in different years with 90 and 80% confidence that type I and type II errors respectively will not occur. The four macroplots considered are the same as those of Table 9-4. See the text for methods of estimating the two kinds of variance.

Macroplot	Parameter	Average Value For Each Parameter	Standard Deviation With Relocation (S)	Standard Deviation With Permanent (S_d)	Sample Size Required With Quadrats Relocated	Sample Size Required With Quadrats Permanent
Meadow A						
	Total Living Cover (%)	63.3	12.2	10.3	46	17
	No. Vascular Species/0.25 m^2	12.7	1.8	1.4	26	7
	% Cover Contributed by Forbs	56.0	12.5	6.9	61	9
Meadow B						
	Total Living Cover (%)	82.9	7.8	7.2	11	5
	No. Vascular Species/0.25 m^2	12.0	1.2	1.1	13	6
	% Cover Contributed by Forbs	48.1	7.2	4.5	28	6
Forest A						
	Total Living Cover (%)	44.9	13.4	10.0	110	31
	No. Vascular Species/0.25 m^2	10.6	2.1	1.2	47	8
	% Cover Contributed by Forbs	65.5	11.9	6.2	41	6
Forest B						
	Total Living Cover (%)	46.3	19.4	10.6	219	32
	No. Vascular Species/0.25 m^2	8.5	2.3	1.1	90	10
	% Cover Contributed by Forbs	62.5	21.8	9.2	150	13

[illegible] (Table 9-7). Since 25 permanent quadrats were sampled per macroplot, it is apparent that our sample size is adequate for all characteristics considered. The results also suggest that the number of vascular species per quadrat and the relative contribution of forbs to the total living cover are more easily estimated than total living cover itself. The advantage of permanent quadrats is such that a sample of equal reliability would require from 2 to 6 times as many quadrats if the quadrats were to be relocated at random each year.

DISCUSSION

The results demonstrate that the herbaceous communities considered in this study are easier to sample at specified levels of adequacy than are associated forest communities. Several factors may contribute to the observed sampling differences between tree and herb dominated communities. Some of the factors are related to an inherently greater environmental heterogeneity in forests, but the problem is also complicated by a simple numerical difference in the amount and complexity of herbaceous cover in herblands and forests, if a percentage of the mean criterion is employed for the difference that is to be detected as in Table 9-7.

Forest environments develop more heterogenity than herblands because of the irregular placement of trees. Areas under the influence of trees experience different conditions for light, moisture, temperature, snow drifting patterns, and chemistry than do adjacent spots beyond the influence of trees. The effects of trees are intensified by the litter layer that commonly accumulates under coniferous trees in our area.

Large trees are also prone to windthrow, thus forested areas are usually pock-marked with "tip-up" mounds and depressions. Depressions are formed as root systems are wrenched from the earth when trees are blown over by wind. The "tip-up" mounds form as soil adherent to the root system gradually falls to the ground at the base of the fallen tree. Such mounds and depressions may alter both chemical and moisture relations of the affected soil for centuries, and thus impart long-term heterogeneity to the forest floor. These patterns are all magnified in open forests such as those that characterize high elevation sites in the Uinta Mountains. The heterogeneity of forest environments is still further intensified as trees die or are removed for lumber. Such actions transform a former tree influenced site into an open site thus introducing heterogeneity in time as well as space.

It should be noted that not only variance but also the absolute value for a parameter influences the ease with which one can detect a given degree of change in that parameter at a specified level of confidence, if a percentage of the mean criterion is employed for the difference to be detected. Examination of the "adequacy-of-sample" equation (see third paragraph of RESULTS) used to predict minimum samples shows that differences in cover in the understory of two forest types could result in requirement of a much larger sample in the forest with less understory cover even though variance for cover was equal in the two forests. It is obviously harder to detect a 3.4% change in cover (10% of the average cover under lodgepole) than it is to detect a change of 5.4% (10% of the understory cover in spruce-fir forests).

The sampling advantage imparted by permanently marked BEUs is large. As shown in Table 9-7, our sample size for quadrats within macroplots was grossly inadequate in the forest stands when annual relocation of BEUs was assumed, but given permanent BEUs, the number of quadrats was shown to be adequate (are nearly so) for the specified confidence levels. Environmental heterogeneity resulted in large variance for most biotic variables, and the sparse cover made our chosen criterion of adequacy (the ability to detect a 10% change in any given variable with 95% confidence) difficult to achieve. Using permanently marked BEUs, however, we have demonstrated that independent observers can closely approximate each others results for a given suite of sampling units.

RECOMMENDATIONS

We recommend that the following points be stressed in long-term monitoring programs aimed at detecting the impact of manmade influences on plant communities.

1. Sampling units should be stratified within impacted vegetative types and within different disturbance intensity zones within individual plant communities.
2. All macroplots and quadrats within macroplots should be permanently marked. Marking should be as inconspicuous as possible in order to minimize visits from curious animals and vandals.
3. Following the initial year of sampling, means and variances should be computed for important parameters. Sample values should then be used in adequacy of sample equations to determine the minimum sample size required for the desired levels of accuracy.

4. Workers responsible for the monitoring should train as a group so as to standardize estimating procedures among observers. Training sessions should precede each day's work.
5. Wherever possible, the same workers should be utilized throughout the course of the monitoring program. If personnel must be changed, every attempt should be made to retain a majority of experienced workers on the crew in any season or sequence of seasons. Such a program will minimize the possibility that sampling procedures and standards will change through time.
6. Readers should rotate sampling duties at individual macroplots in successive years in order to minimize observer effects. This could be done by assigning observers to plots by random procedures.
7. Absolute rather than relative criteria for adequacy of sample should be applied.
8. Wherever possible, well proven ocular sampling procedures should be employed in preference to laborious mechanical methods in order to minimize monitoring costs.

LITERATURE CITED

Bourdeau, P. F. 1953. A test of random versus systematic ecological sampling. Ecology 34:499-512.

Bormann, F. H. 1953. The statistical efficiency of sample plot size and shape in forest ecology. Ecology 34:474-487.

Cain, S. A. 1938. The species-area curve. American Midland Naturalist 19:573-581.

Clapham, A. R. 1932. The form of the observational unit in quantitative ecology. Journal of Ecology 20:192-197.

Cook, C. W. and C. D. Bonham. 1977. Techniques for vegetation measurements and analysis for a pre- and post-mining inventory. Range Science Series No. 28:1-82. Department of Range Science, Colorado State University, Fort Collins.

Curtis, J. C. 1959. The vegetation of Wisconsin. The University of Wisconsin Press, Madison. 657 pp.

Daubenmire, R. F. 1968. Plant communities: a textbook of plant synecology. Harper and Row Publishers, New York. 300 pp.

Day, J. M. 1920. The relation of size, shape and number of replications of plots to probable error in field experimentation. Journal of American Society of Agronomy 12:100-105.

Eddleman, L. E., E. E. Remmenga and R. T. Ward. 1964. An evaluation of plot methods for alpine vegetation. Bulletin of the Torrey Botanical Club 91:439-450.

Hansen, W. R. 1975. The geologic story of the Uinta Mountains. Geological Survey Bulletin 1291:1-144. U. S. Government Printing Office, Washington, D. C.

Harper, K. T. 1976. Work plan: Ecological impact study of weather modification in the Uinta Mountains, Utah. Report to Utah Division of Water Resources, Salt Lake City, and the U.S. Bureau of Reclamation, Office of Atmospheric Resources Managements, Denver. 46 pp.

Mueggler, W. F. 1976. Number of plots required for measuring productivity on Grasslands in Montana. USDA, Forest Service Research Note INT-207. 6 pp.

Pechanec, J. F. and G. Stewart. 1941. Sagebrush-grass range sampling studies: variability of native vegetation and sampling error. Journal of American Society of Agronomy 33:1057-1071.

Rice, Elroy L. 1967. A statistical method for determining quadrat size and adequacy of sampling. Ecology 48:1047-1049.

Ruzicka, M. 1958. Anwendung mathematisch-statistischer methoden in der geobotanik (Synthetische bearbeitung von aufnahmen). Biologia, Bratisl. 13:647-661.

Snedecor, G. W. and W. G. Cochran. 1967. Statistical Methods, Sixth Ed. Iowa State University Press, Ames, Iowa. 593 pp.

West, N. E. and M. M. Baasher. 1968. Determination of adequate plot size by use of mean distance between salt desert shrubs. The Southwestern Naturalist 13:61-74.

CHAPTER 10

THE POTENTIAL FOR USING REMOTE SENSING TECHNIQUES IN SNOW RETREAT STUDIES

By

K. T. Harper

and

M. K. Ridd

ABSTRACT

Landsat imagery has been used to evaluate the areal extent of late lying snow in the Uinta Mountains and to monitor snow retreat on nine major watersheds. Snow cover during the melt season has also been correlated with portion of the annual streamflow released at any given time.

In 1974, about 7.0% of the study area was snow covered on July 1st. In 1976, 6.3% of the area was snow covered on that date. Since neither of those years had above average snowpack in our area, late lying snow may cover as much as 10% of the area in years of cool temperatures and heavy snowpacks.

During the melt season, snow cover increases with elevation. In 1974 and 1976, all snow cover below 2,630 m, had disappeared by July 1st. At 3,353 m elevation, there was an average of about 20% snow cover on July 1 in 1974.

The relationship between percent snow cover and the percentage of the total yearly streamflow released is unique for each individual watershed, but a relatively precise predictive equation can be developed for each watershed. In our area, the best regression model relating snow cover to streamflow is based on the logarithm of percent snow cover and the untransformed percent of annual runoff released.

INTRODUCTION

Mapping snow cover on critical watersheds and wildlife habitats from aerial photography and satellite imagery has been investigated repeatedly during the past two decades (Nicholson 1975, Rango 1975, Abelson 1976, Schneider et al. 1976, Steinhoff and Barnes 1976, McGinnis and Schneider 1978, McGinnis et al. 1979, and Wyckoff 1980). Leaf (1967, 1971) has used aerial photographs and streamflow records to correlate runoff with snow cover on Colorado watersheds. He concludes that there is a strong correlation between snow ablation and runoff during the peak of the annual snow melt season, but that correlation is unique for each watershed. Wyckoff (1980) demonstrates that the area of mule deer winter range covered by snow is significantly and positively correlated with water content of snowpack on higher elevation snow courses. Ward et al. (1975) conclude that increased snow accumulations on elk winter ranges below 2,743 m could have detrimental effects on the animals, especially if the winter range is topographically uniform. In rougher terrain, south and west-facing slopes usually had enough snow melt in all periods of even hard winters to expose forage for elk, but in areas of gentle slopes, few sites received enough radiation to melt snowpacks sufficiently to insure that the elk could reach adequate forage to meet their needs. Strickland and Diem (1975) drew similar conclusions for mule deer. Sweeney and Steinhoff (1976) conclude that a 15 percent increase in snowpack on elk winter range in Colorado may reduce the amount of usable range by an average of about 5 percent.

OBJECTIVES AND STUDY AREA

In this study, we have sought to determine 1) how much area could be expected to be affected by late lying snow in the Uinta Mountains, 2) how elevation affected the amount of late lying snow, and 3) how retreat in snow cover was related to the amount of water released from selected watersheds.

Our studies are centered on the west end of the Uinta Mountains. Snow cover and streamflow are evaluated for nine watersheds in two or more years.

METHODS

The boundaries of nine major watersheds were delimited on a false color Landsat image dated 18 August 1975 (Figure 10-1). Scale of the photograph was 1:250,000. Subsequently, black-and-white satellite images of comparable scale were assembled for all dates in 1973-1976 that were sufficiently cloud-free to permit mapping of snow cover on all (or most) of the nine watersheds of concern (Table 10-1). Total area of each watershed was determined by planimeter. Snow cover on each watershed and date was also determined by planimetry.

Water yield from each watershed and time interval of concern was taken from U.S. Geological Survey (1973-76) water resource reports for Utah. Those reports give total water yield by month for individual watersheds. When snow cover surveys fell midway through a month, water yield to that date from any specific watershed was approximated using an assumption of uniform daily flow throughout the entire month.

Figure 10-1. Map showing the limits of all watersheds and the locations of their gaging stations. Vegetative cover of each watershed is also shown.

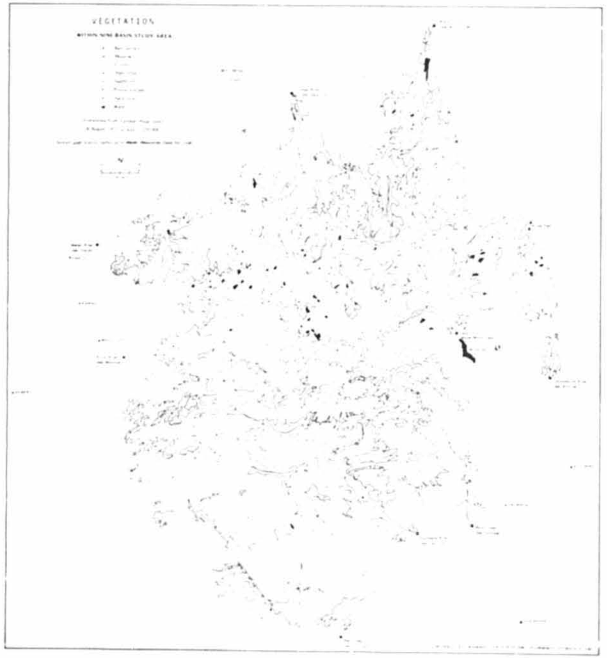


Table 10-1. Watersheds used in the study and selected characteristics of each. Runoff is given for the water year Oct. 1 - Sept. 30.

Watershed	Area (Hectares/100)	Weighted Ave. Elevation (m)	Annual Runoff (Hectare meters) 1973	1974	1975	1976
Bear River	464.1	2,979	171.4	194.6	211.4	128.1
Blacks Fork River	397.8	3,126	146.9	168.4	192.9	130.5
Duchesne River	895.1	2,635	179.1	182.4	217.7	13.51
Lake Fork River	207.2	3,295	107.8	81.6	121.0	76.8
Provo River	422.7	2,751	195.0	212.1	231.0	162.6
Red Creek	812.2	2,403	54.7	39.9	48.5	36.4
Rock Creek	646.5	2,829	164.7	136.2	189.7	114.4
Weber River	431.0	2,843	189.9	217.3	241.5	167.9
Yellowstone River	317.0	3,243	150.4	95.7	146.9	103.6
Total	4,593.6	----	1,359.9	1,328.2	1,600.6	1,055.4

RESULTS

The nine watersheds used in our study are listed in Table 10-1. The watersheds range in size from 20,720 to 89,510 ha; average elevation varies from 2,403 to 3,295 meters above sea level. In aggregate, the nine watersheds account for 459,360 ha or about 33.7% of the total land area above 2,135 m (7,000 ft) in the Uinta Mountains. On the average, the nine watersheds yielded 29.1 cm of runoff per unit surface area for the period 1973-76.

The availability of cloud-free satellite photographs of the nine watershed study areas posed a major problem for the study. Usable photographs were few during the melt seasons of 1973-75 (Table 10-2). The coverage was excellent for 1976. Since the three photo scenes of the study area in 1974 were well spaced across the entire melt season, we have used those photos for comparison with snow melt-stream runoff analyses based upon the 1976 photos. The 1973 and 1975 photo coverage of the study area was not complete enough to justify analyses.

The data in Tables 10-1 and 10-3 demonstrate that water-year 1976 was a year of near normal temperatures but was considerably below normal in respect to precipitation and streamflow. Thus although satellite photo coverage of the study area was excellent in 1976, it is possible that snowpack and streamflow characteristics for that year are not representative of usual conditions. In order to check that possibility, we have plotted 1973 (a cool, wet year) data along with results for 1976 in Fig. 10-4 which will be discussed later. As will be shown, although those two years differ markedly in respect to temperature and precipitation, the relationship of relative snow cover to percent of the annual

---

Table 10-2. Dates during the snowmelt seasons of 1973-1976 for which cloud-free satellite images are available for all or most of the nine watersheds listed in Table 10-1.

1973	1974	1975	1976
April 15	March 23	April 5	March 12
May 3	June 21	May 11	21
June 8	July 9		30
			May 14
			June 1
			19
			28
			July 7

Table 10-3. Comparison of temperature and precipitation data from the Northern Mountains Climatic Region of Utah (U.S. Department of Commerce 1973-1976) with annual values expressed as a percentage of normal expectations for two intervals in each of the years 1973-76.

Temperature	1973	1974	1975	1976
	% of Normal Expectations			
Oct. 1 - Mar. 31	88.8	100.2	98.5	96.9
Oct. 1 - July 31	93.8	104.3	95.6	100.8
Precipitation				
Oct. 1 - Mar. 31	113.3	82.5	103.1	84.2
Oct. 1 - July 31	111.4	83.4	115.8	81.6

streamflow already released appears to be very similar. Therefore, for our purposes, the snow cover-runoff results for 1976 seem representative of a broad suite of conditions and generalizable to other watersheds and years.

AREA OF LATE LYING SNOW

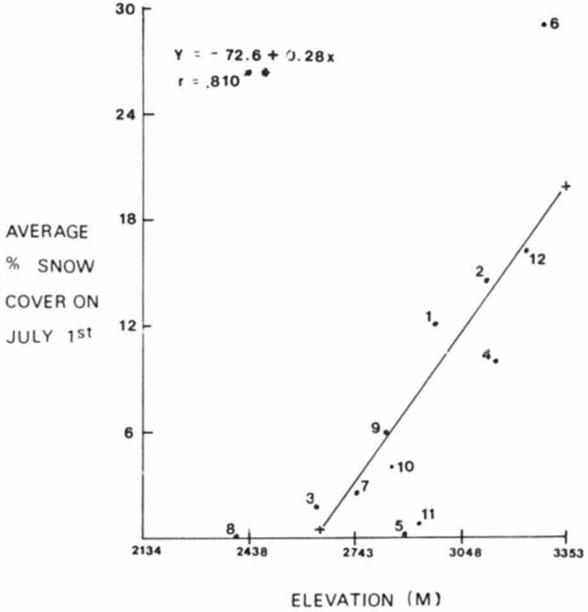
The satellite photos show that about 6.3% of the combined area of the nine watersheds was covered by snow on about July 1, 1976. On about that date in 1974 (a more normal year), 7.0% of the combined area was snow covered. Precipitation (Oct. 1 - July 31) in the Northern Mountains Climatic Region (of which the Uinta Mountains are a part) averaged about 2.2% greater in 1974 than in 1976. Unfortunately, the entire study area was cloud covered when the satellite passed over our area in early July, 1973, the year with the heaviest snowpacks considered in this report.

ELEVATION AND SNOW COVER

As expected, snow cover tends to increase with elevation once the melt season begins. On July 1, snow cover by elevational zones averaged from zero to slightly over 29% in 1974 and 1976. About 2/3 of the variation in snow cover was accounted for by elevation (Fig. 10-2). The data (Fig. 10-2) suggest that one can expect all snow below 2,630 meters to be melted by July 1 in the average year in the Uinta Mountains. At 3,353 m (11,000 ft), one can expect about 20% of the landscape to be snow covered on July 1 of an average year.

Figure 10-2. The relationships of snow cover to elevation on about July 1 on 12 major watersheds on the west end of the Uinta Mountains Percentage snow cover is averaged for 1974 and 1976. Numbers represent different watersheds - the numbers are keyed to watersheds below. Elevation is the weighted average elevation for each watershed.

1. Bear River
2. Blacks Fork River
3. Duchesne River
4. East Fork Smiths Fork
5. Gilbert Creek
6. Lake Fork River
7. Provo River
8. Red Creek
9. Rock Creek
10. Weber River
11. West Fork Smiths Fork
12. Yellowstone River



SNOW COVER AND RUNOFF

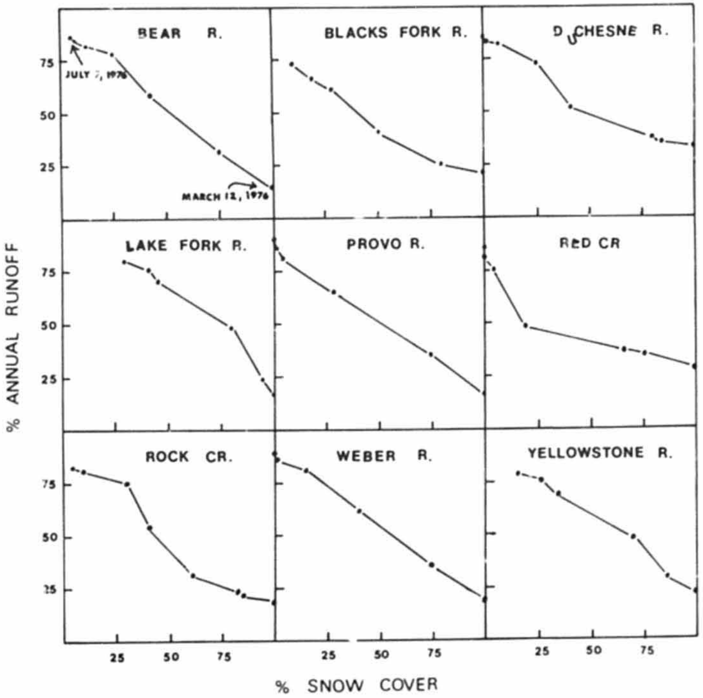
A predictable relationship exists between snow cover and percentage of the annual streamflow released during the melt season (Fig. 10-3). As Leaf (1971) has noted, the tend line relating snow cover to accumulated runoff is unique for each watershed. The percentage of annual flow released by the time bare ground first appears on the watershed varies from 17 (Bear River) to 36% (Duchesne River). When the last vestiges of snow disappear, the accumulated portion of the annual flow appears always to be in excess of 80% in the watersheds considered here.

On July 7, 1976, four of the nine watersheds had lost all of their snow cover (Fig. 10-3). These watersheds (Duchesne, Provo, Red, and Weber) lie on the west end of the range and are without treeless alpine area or have such habitat only at their headwaters and downwind of the rest of the watershed. Consequently these watersheds do not accumulate deep drifts from high elevation herblands on their windward sides. It should be noted that the Duchesne and Provo River drainages consistently accumulate the heaviest snowpacks in the Uinta Mountains (Fig. 2-3 and 2-4, Chapter 2). Thus, their early loss of snow cover is not due to light snowpacks.

Three other watersheds (Bear, Blacks Fork, and Rock) had between about 5 and 10 percent snow cover on July 7th (Fig. 10-3). These watersheds all have some alpine herblands on their headwaters that shed snow into the watersheds. Snow stored in the large drifts formed in such situations persist for long periods.

Two watersheds (Lake Fork and Yellowstone) retained over 15 percent snow cover (29.6 and 15.7% respectively) on July 7th, 1976 (Fig. 10-3).

Fig. 10-3. The relationship of snow cover to the percentage of annual streamflow released from nine watersheds. All data are for 1976. Initial readings for snow cover were taken from Landsat imagery dated Mar. 12: final readings were taken from photos taken on July 7th.

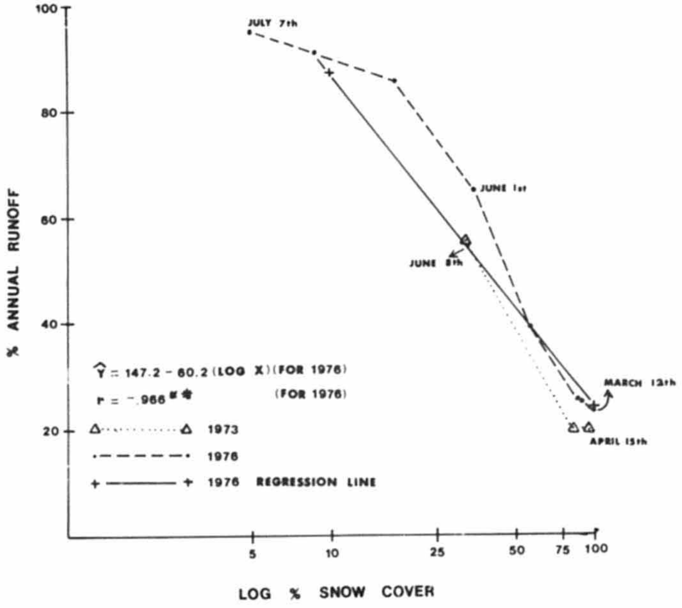


Both watersheds have large areas of barren land and herbland at their headwaters (see Table 2-8, Chapter 2) with much of the herbland area lying windward of the watersheds. These watersheds appear to "capture" snow that falls in other, downwind watersheds and is later blown into the Lake Fork and Yellowstone drainages by prevailing winds. Both watershed also have a great deal of area at very high elevations (Table 10-1). On the average, these watersheds yield about [illegible]9 cm of runoff water per unit area per year (Table 2-5, Chapter 2). Only the Provo and Weber River drainages yield more water than that - the high runoff of these latter watersheds is almost wholly attributable to unusually heavy precipitation rather the snow "capture" by wind.

In Fig. 10-4, the results for snowcover and streamflow in the 1976 water year have been pooled for all nine watersheds. The figure demonstrates that the logarithm of snow cover is rather closely related to the percent of the annual streamflow produced at any given time during the melt season. The regression equation shows that for the period March 12 through July 7, 1976, about 93% of the variation in stream flow is accounted for by changes in snow cover. Less complete data for 1973 (a heavy snowpack and cool year) parallel the 1976 data rather closely (Fig. 10-4).

The trend line of percent annual streamflow produced at a given percent snow cover was sigmoidal in both 1973 and 1976 (Fig. 4), but for the snow melt period, a linear regression line fits the data well. Thus one can predict how much runoff water remains to be released from Uinta watersheds from an analysis of snow cover taken from satellite photos. The relationship will, of course, break down if one includes data for periods prior to the time bare ground begins to appear on the watersheds

Figure 10-4. The relationship between snow cover and portion of the annual water yield released on the west end of the Uinta Mountains. The results are based on the combined area and streamflow of the nine watersheds noted in Table 10-1. The regression line is highly significantly correlated with the real data points for 1976. Data for 1973 are incomplete due to cloud cover, but seem to parallel 1976 results closely.



or for periods after the time when the first of the watersheds have lost all their snow cover. Nevertheless, the relationship between snow cover and water released from watersheds can have value for agricultural interests interested in the amount of runoff water that can be expected during the remainder of a growing season. If photographs can be acquired for analysis within hours of the time they are taken, the regression procedure modelled in Fig. 10-4 could also be used to forecast flood hazards under some conditions.

DISCUSSION

Our data show that late lying (after July 1) snow is concentrated on about 7% of the land area of the Uinta Mountains. Most of the late lying snow occurs at high elevations and to the leeward side of treeless areas.

During the period of accelerated retreat of snow cover (roughly April 15 through July 15 in our area), there is a predictable relationship between snow cover and accumulated water yield from watersheds. That relationship differs in detail from watershed-to-watershed (Fig. 10-3 and Leaf 1971), thus necessitating a unique predictive model for each watershed. In general, however, a regression model based on the logarithm of percent snow cover and the untransformed percent of annual runoff released fits the data better than any other model for the watersheds of the western Uintas.

LITERATURE CITED

Abelson, P. H. 1976. A new window on our planet. Science 194:15.

Leaf, C. F. 1967. Areal extent of snow cover in relation to streamflow in central Colorado. International Association for Science of Hydrology Bulletin 12:42-50.

Leaf, C. F. 1971. Areal snow cover and disposition of snowmelt runoff in central Colorado. U.S. Dept. Agric., Forest Service Res. Paper RM-66. 19 pp.

McGinnis, D. F. Jr., R. A. Scofield, S. R. Schneider, and C. P. Berg. 1979. Satellites as an aid to water resource managers. American Society of Civil Engineers Preprint 348b:1-21.

McGinnis, D. F. and S. R. Schneider. 1978. Satellite detection of an extremely light snowfall in Arizona. Monthly Weather Review 106: 1380-1383.

Nicholson, F. H. 1975. Snow depth mapping from aerial photographs for use in permafrost prediction. Proceedings of the 1975 Annual Meeting of the Eastern Snow Conference, pp. 124-136.

Rango, A. (Ed.). 1975. Operational applications of satellite snowcover observations. Scientific and Technical Information Office, National Aeronautics and Space Administration, Washington, D.C. 430 pp.

Schneider, S. R., D. R. Wiesnet and M. C. McMillan. 1976. River basin snow mapping at the national environmental satellite service. National Oceanic and Atmospheric Administration Technical Memorandum. NESS 83. 19 pp.

Steinhoff, H. W. and A. H. Barnes. 1976. Determination of snow depth and water equivalent by remote sensing. Completion Report, Series No. 76. Submitted to Office of Water Research and Technology, U.S. Dept. of Interior, Washington, D.C. 13 pp.

Strickland, M. D. and K. Diem. 1975. The impact of snow on mule deer, pp. 135-174 In D. H. Knight (ed.), The Medicine Bow Ecology Project. Final Report to U.S. Bureau of Reclamation, Office of Atmospheric Water Resources, Denver, Colorado 80225.

Sweeney, J. M. and H. W. Steinhoff. 1976. Elk movements and calving as related to snow cover, pp. 415-436 In H. W. Steinhoff and J. D. Ives (eds.), Ecological Impacts of Snowpack Augmentation in the San Juan Mountains, Colorado. Final Report, San Juan Ecology Project, Colorado State Univ., Fort Collins. 489 pp.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. 1973-1976. Climatological data - Utah. Volumes 75-78.

U.S. Geological Survey. 1973-1976. Water resources data for Utah. U.S. Geological Survey Water-Data Reports UT-73-1 through UT-76-1. Distributed from Rm 8002, Federal Bldg., Salt Lake City.

Ward, A. L., K. Diem and R. Weeks. 1975. The impact of snow on elk, pp. 105-133 In D. H. Knight (ed.), The Medicine Bow Ecology Project. Final Report to U.S. Bureau of Reclamation, Office of Atmospheric Water Resources, Denver, Colorado 80115.

Wyckoff, J. W. 1980. Evaluating mule deer winter range relationships through Landsat Satellite imagery. Ph.D. Dissertation, University of Utah, Salt Lake City. 107 pp.

CHAPTER 11

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

By

K. T. Harper

This study has not attempted to evaluate all possible impacts of cloud seeding aimed at augmentation of winter snowpacks in mountains. Prior studies have demonstrated that several potential impacts are not likely to be deleterious or can be circumvented by judicious management of seeding operations. Potential impacts that have been considered by others in sufficient detail that we have considered it unnecessary to investigate them further in the Uinta Mountains are discussed in the paragraphs which follow.

PRIOR WORK

Effectiveness of Cloud Seeding. The first aspect of winter, orographic cloud seeding that demands attentions is whether or not the technology is capable of producing additional precipitation. Several independent evaluations have been made of winter orographic weather modification programs in western United States. Foehner (177) summarized the results of snow augmentation programs in the Sierra Nevada Mountains of California: workers there have consistently concluded that precipitation was enhanced by cloud seeding. In 1977, Grant concluded that "a practical technology now exists for augmenting precipitation from some wintertime orographic clouds. Increases in overall precipitation on the order of 5-20%, depending primarily upon the location, can be expected with some confidence." The Utah Division of Water Resources (1981) has recently completed an evaluation of the central and southern Utah weather modification program for the period 1974-78 (five years of treatment). The Utah report showed an overall increase of about 13% in January-March precipitation in the treated area for the five year period.

the probability that the effect was real was computed to be .862. The observed increase was larger (15%) at high elevations than at low (8.8%).

Snowpack and Streamflow. Research by Jeppson et al. (1968) and Hill et al. (1975) demonstrate that larger snowpacks on watersheds consistently result in greater runoff from those watersheds.

Big Game Winter Range. Ward et al. (1975) have concluded that "increased snow accumulations on elk range below 2,743 m (9,000 ft) would have some detrimental effects, particularly if they came early in the season ... or during the calving season." Ward et al. (1975) worked in the Medicine Bow Mountains of Wyoming. Sweeney and Steinhoff (1976) concluded that winter range useable by elk would decrease about 5% given an increase of 15% in the average snowpack of the San Juan Mountains of Colorado. Wyckoff (1980) similarly concluded that snow cover on big game winter ranges is positively correlated with larger snowpacks on higher elevation snowcourses in central Utah. Strickland and Diem (1975) evaluated the impact of snow on mule deer in the Medicine Bow Mountains of Wyoming: they considered that increased snowpack below 2,743 m reduced available winter range.

Since it seems likely that seeding of winter clouds will produce additional precipitation below 2,743 M (9,000 ft) on treated mountains, careful monitoring of snowpacks on big game winter ranges must be coordinated with cloud seeding operations. Even though expected increases in precipitation due to seeding can be expected to be less below 2,743 m than above (Utah Division of Water Resources 1981), there is still a need to minimize the effects of additional snow on winter ranges. Suitable start-stop criteria for seeding are commonly (perhaps universally) used to avoid undesirable effects of seeding. In the case of winter ranges, criteria could be chosen that would prohibit seeding before natural storms had pushed big game from higher elevation ranges and onto the winter range. Once on the winter range, other criteria could be used to terminate seeding should snowpack on the area exceed seasonal norms by a given amount. Carefully chosen criteria would nearly eliminate the possibility that cloud seeding would adversely affect wildlife.

Silver as a Potential Toxicant. Although some environmentalists have considered silver iodide, the preferred ice nucleating agent in most cloud seeding operations, to be potentially dangerous, research has not supported that fear. As early as 1970, Cooper and Jolly reviewed the literature on silver iodide and concluded that silver was not likely to concentrate to harmful levels through either terrestrial or aquatic food chains. More recently, Klein (1978) summarized the results of numerous experiments designed to evaluate the impacts of silver iodide on soil microbiological processes, higher plants, aquatic invertebrates, fish, sewage treatment processes, rumen and caecum microorganisms in vertebrate animals, and human physiology. His conclusion was that silver iodide (and all other ice nucleating agents commonly considered for routine use) represented negligible environmental hazards. Klein (1978) considered that adverse environmental effects from ice nucleating agents would not involve unacceptable risks.

Effects of additional Snow on Nutrient Leaching. Knight and Kyte (1975) felt that an increased loss of essential elements for life could be expected from watersheds where snowpacks had been enhanced by cloud seeding. In contrast, Lewis and Grant (1980) reported that biologically active elements such as nitrogen, phosphorus and potassium were lost significantly faster from a high elevation (> 2,900 m) watershed in the Colorado Rockies in a year of light snowpack than in a year of heavy snowpack. They considered that soil frost was greater when snow cover was incomplete and frost stimulated the loss of essential elements by interfering with biological processes that would otherwise have resulted in the uptake of greater amounts of those elements and reduced losses from the terrestrial environment. More research is needed in this area, but such work was beyond the budgetary capabilities of this study.

THE UINTA ECOLOGY PROJECT

In this project, we have directed our attention to the following tasks:

1. an inventory of the resources of the Uinta Mountains,
2. an analysis of precipitation in the Uintas and its effect on streamflow,
3. evaluating the effects of late lying snow on composition and productivity of four major plant communities (lodgepole pine, subalpine meadow, spruce-fir forest, and alpine herbland) of the Uintas,
4. establishing baseline concentrations of silver in plants and soils of the four plant communities noted above,
5. an evaluation of the monitoring design used in the vegetational analyses, and
6. a consideration of the value of remote sensing tools (such as Landsat) for snow retreat studies.

SUMMARY

The resources of the Uinta Mountains were documented in detail in a 1978 report by Harper et al. The general conclusions of that report are summarized in Chapter 1 of this report. The Uintas produce an average of about 1.8 km^3 (1.6 x 10^6 acre ft) of runoff water per year. Water is the most valuable renewable resource on the range (Fig. 11-1). In addition, the range provides 119,709 animal unit months of grazing for domestic animals and almost three million visitor days of recreation per year. Roughly 1.41 x 10^5 m^3 (5 x 10^6 ft^3) of timber products are also harvested on the range each year. There are currently numerous wells producing oil around the edges of the range, but producing wells in the interior are largely confined to the northeast quarter of the range. Mining is a minor item represented by a coal withdrawal on Currant Creek on the South Slope. The Uintas support herds of moose, elk, mule deer, and antelope: about 10% of the visitor days for recreation are devoted to hunting big game.

Maximum precipitation in the Uintas averages about 102 cm (40.0 in) per year. Approximately three-quarters of the total falls between October 1 and July 1 (Chapter 2). Streamflow is strongly correlated with snowpack water content on April 1. Our snowpack-runoff regression model predicts a 13% increase in runoff given a 10% increase in snowpack. Analyses show that vegetative cover exerts a significant impact on streamflow. Natural successional processes that convert deciduous forests (aspen or oak) to evergreen, coniferous trees can be expected to reduce surface runoff. Should all deciduous forests be converted to coniferous forest, surface runoff can be expected to decline by between

Figure 11-1. The Bear River near the Bear River Guard Station on Utah Highway 150. Streamflow provides water for agriculture and industry, habitat for fish and an important aesthetic resource. Runoff water is the most valuable renewable resource produced by the Uinta Mountains.

4 and 5% (Chapter 2).

Snow melt models that require only water content of the April 1 snowpack (no on-site climatic data required) are reported. The models predict snow-free dates within a few days on a broad spectrum of exposures at any given elevation (Chapter 3).

Our results suggest that a 10% increase in average snowpack can be expected to retard the 75% snow-free date from 0.7-1.5 days (Chapters 4-7). That much additional snow could not be demonstrated to have any significant effect on tree growth or tree reproduction in either lodgepole pine or spruce-fir forest (Chapters 4 and 5). Production in the herb layer differed among plant communities: in the two communities with the lightest snowpacks (lodgepole pine and alpine herblands), a 10% increase in average snowpack can be expected to increase above-ground herbaceous growth (Table 11-1). Where snowpacks were heavy (i.e., in spruce-fir forest and subalpine meadow), a 10% increase in average snowpack produced a small (1.7-2.4%) decrease in herb production (Table 11-1). Manipulation of the data in Table 11-1 demonstrates that weighted average production in the herb layer was 401 kg/ha across the entire area spanned (558,113 ha) by this study. Given a 10% increase in average snowpack, weighted above-ground, herbaceous production is predicted to be 417 kg/ha: thus a 10% increase in snowpack would increase herb production about 4% over the composite area even though reduced production can be expected locally where average snowpacks are already heavy.

Results show Uinta soils to have somewhat more silver than the average soil of the Mountain West. Silver content of plants from our study areas was comparable to values reported for plants from other locations in the West (Chapter 8).

Table 11-1. Areal extent, average above-ground production in the herb layer, and predicted change in production given a 10% increase in average snowpack in each community.

Community	Area (ha)	Average Production kg/ha	Predicted Change (%) in Production with 10% More Snow	Absolute Change (kg/ha)
Lodgepole Pine	294,000	205	+ 15.8	+ 32.4
Spruce-Fir	122,940	335	- 1.7	- 5.7
Subalpine Meadow	16,832	989	- 2.4	- 23.7
Alpine Herblands	124,241	852	+ 0.6	5.0
	558,113			

Our sampling designs for vegetational studies were generally adequate for the herbeceous and spruce-fir communities, but too few macroplots were taken in the lodgepole pine community for reliable tests of hypotheses relative to the effects of late-lying snow. Nevertheless, sample sizes in lodgepole are large enough to describe the community's current composition with good confidence. Both forest communities were inherently more variable than the herbaceous communities, but the lodgepole pine forests had particularly large variances for many important parameters. Reasons for the variability in forests were discussed (Chapter 9).

Landsat imagery proved to be an excellent and economical tool for following snow retreat and predicting additional streamflow that could be expected from a given watershed at any point in the annual snow melt season. In the average year, 6-7% of the area above 2,134 m (7,000 ft) in the Uintas is now covered on July 1 (Chapter 10).

RECOMMENDATIONS

It is recommended that the four plant communities considered in this report be reinventoried periodically even prior to initiation of cloud seeding in the area in order to establish natural "noise" levels in community composition and production. Suitable sites for evaluations such as those initiated here are not common, thus there is reason to preserve these study sites from major disturbances such as logging, fire, and off road vehicles.

The Elizabeth Ridge study area is privately owned. Off-road vehicles regularly drive across the subalpine meadow used in this study,

Figure 11-2. Off-road vehicle damage on the subalpine meadow at Elizabeth Ridge. Three "roads" are visible in this photo: one at the far left, another in the foreground, and a third, less rutted "road", to the right of and paralleling the second "road". All are more-or-less at right angles to surface runoff from snow-melt on the meadow.

while the soils are still wet. Deep ruts result and runoff waters accumulate in the ruts and remove the finer soil particles (Fig. 11-2). The boulder strewn ruts are difficult to drive over, so the next season's visitors "blaze" new trails across the meadow. National Forest officers have no power to control such abuses on private land, thus in the absence of owner control over recreation vehicle movement, Elizabeth Ridge meadow is rapidly being cut up by roads. Drainage patterns are so altered by the roads that even areas not crossed by them are ecologically altered through changed patterns of overland water flow.

It is recommended that the Federal Government acquire the private land where the Elizabeth Ridge subalpine meadow and spruce-fir macroplots are situated. Unless vehicular traffic across the meadow is controlled, this valuable and unique study area will be destroyed.

LITERATURE CITED

Cooper, C. F. and W. C. Jolly. 1970. Ecological effects of silver iodide and other weather modification agents: a review. Water Resources Research 6:88-98.

Foehner, O. H. 1977. Weather modification: a major resource tool. Proceedings of the 45th Annual Western Snow Conference, 13 pp.

Grant, L. O. 1977. Scientific and other uncertainties of weather modification, pp. 7-20 In W. A. Thomas (ed.), Legal and scientific uncertainties of weather modification. Duke University Press, Durham, N.C. 155 pp.

Harper, K. T., W. K. Ostler and D. C. Anderson. 1978. Resources of the Uinta Mountains. Report submitted to the Utah Division of Water Resources, Salt Lake City, and the Water and Power Resources Service, Office of Atmospheric Resources Research, Denver, Colorado. 148 pp.

Hill, G. E., N. E. Stauffer Jr. and H. K. Woodward. 1975. Assessment of cloud seeding programs and evaluation techniques in the State of Utah. Utah Division of Water Resources Publication, Salt Lake City. 61 pp.

Jeppson, R. W., G. L. Ashcroft, A. L. Huber, G. V. Skogerboe, and J. M. Bagley. 1968. Hydrologic atlas of Utah. Publication No. PRWG35-1 from the Utah Water Research Laboratory, Utah State University, Logan. 306 pp.

Klein, D. A. (ed.). 1978. Environmental impacts of artifical ice nucleating agents. Dowden, Hutchinson, and Ross, Inc., Stroudsburg, PA. 256 pp.

Knight, D. H. and C. R. Kyte. 1975. The effect of snow accumulation on litter decomposition and nutrient leaching, pp. 215-223 In D. H. Knight (ed.), The Medicine Bow Ecology Project. Final Report to the Bureau of Reclamation, Division of Atmospheric Water Resources Management, Denver, Colorado. 397 pp.

Lewis, W. M. Jr., and M. C. Grant. 1980. Relationship between snow cover and winter loss of dissolved substances from a mountain watershed. Arctic and Alpine Research 12:11-17.

Strickland, M. D. and K. Diem. 1975. The impact of snow on mule deer, pp. 135-174 In D. H. Knight (ed.), The Medicine Bow Ecology Project. Final Report to the Bureau of Reclamation, Division of Atmospheric Water Resources Management, Denver, Colorado. 397 pp.

Sweeney, J. M. and H. W. Steinhoff. 1976. Elk movements and calving as related to snow cover, pp. 415-436 In H. W. Steinoff and J. D. Ives (eds.), Ecological impacts of snowpack augmentation in the San Juan Mountains, Colorado. Final Report, San Juan Ecology Project, Colorado State University Publication, Fort Collins. 489 pp.

Utah Division of Water Resources. 1981. Evaluation of five years of operation of a central and southern Utah weather modification program, 1974-1979. Utah Division of Water Resources, Salt Lake City. 66 pp.

Ward, A. L., K. Diem, and R. Weeks. 1975. The impact of snow on elk, pp. 105-133 In D. H. Knight (ed.), The Medicine Bow Ecology Project. Final report to the Bureau of Reclamation, Division of Atmospheric Water Resources Management, Denver, Colorado. 397 pp.

Wyckoff, J. W. 1980. Evaluating mule deer winter range relationships through Landsat satellite imagery. Ph.D. Dissertation, University of Utah, Salt Lake City. 106 pp.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1981—576-331 / 006