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Climate, Hydrology and Vegetation Patterns Hot Weather Creek, Ellesmere Island, Arctic Canada

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Recent studies at Hot Weather Creek, Ellesmere Island document the climate and vegetation of a major part of the intermontane zone of Ellesmere Island. Summer temperatures in this region are much higher than would be expected for its 80° N location. This enables a variety of arctic species with more moderate temperature tolerances to thrive. The dense and diverse tundra and wetland vegetation in parts of the region, however, does not conform to polar desert or semidesert vegetation expected from the meager amount of precipitation (< 70 mm per year) recorded there. Comparisons between differing biological and geomorphological responses to the summer climatic regimes of 1988 and 1989 suggest a two source supply of moisture to the active layer in summer. Supplementary source of water, from the melting of massive ground ice bodies provides water from the base of the active layer, during the hot, dry summer of 1988. During the wet summer of 1989, a more conventional nival regime was in operation. These two potential sources of moisture in summer provide a fail-safe delivery system to vegetation in areas underlain by massive ground ice, and permit a richer vegetation growth than climate alone could.

Introduction

The Queen Elizabeth Islands of Arctic Canada generally fit the climatological definition of polar desert or polar semidesert (Bovis and Barry 1974) and botanical definition of polar desert or semidesert (Alexandrova 1970, Bliss 1977, Bliss and Bliss 1984), but some large areas are botanically richer and do not fit these definitions. West-central Ellesmere Island has a more dense and diverse tundra and sedge meadow vegetation than would be predicted for 80° from the bioclimatic law (Hopkins 1920).

In 1988, the Terrain Sciences Division of the Geological Survey of Canada began investigations of these vegetation anomalies (Edlund *et al.* 1989). Hot Weather Creek in Fosheim Peninsula was selected as the focal point of this study because of its central location in the peninsula, away from large water bodies and mountain ranges, with vegetation representative of the best of the region. The basin is located 30 km east of the Eureka weather station with continuous climatic records beginning in 1947.

This paper gives an account of two years of climatic, hydrological and vegetation studies and offers an explanation for the seemingly atypical vegetation for such polar latitudes. Results of this study have applications to other arctic sites where apparent anomalous vegetation patterns occur.

Study Area

Hot Weather Creek basin (area 50 km^2) is situated at 79°58′ N, 84°28′ W. Its rolling topography is typical of the non-glacierized portion of Fosheim Peninsula. The basin is underlain by poorly consolidated clastic rocks of the Eureka Sound Group which is in some places covered by younger beds of sand and silt.

Summers are more moderate than most areas of the Queen Elizabeth Islands (Edlund 1987; Edlund and Alt 1989). Mean July temperatures of at least 5° C are common (Fig. 1). Similar high summer temperatures have been reported in the vicinity by Barry and Jackson (1969) and King (1981). This regional temperature anomaly is a response to the surrounding mountains that tend to deflect or dissipate low level cloud from the Central Arctic Ocean and bar the way to most cyclonic disturbances (Edlund and Alt 1989). This reduction in cloud cover results in high solar radiation input which combined with high surface albedo due to early snow loss, causes a warming of the surface.

The vegetation of Fosheim Peninsula is unusually diverse for this latitude, with 140 vascular plant species occurring in the Hot Weather Creek area alone. This contrasts with the vegetation in similar materials in the western and central Queen Elizabeth Islands which generally have less than 35 vascular plant species. The diversity and richness of vegetation is more typical of warmer areas of the southern Arctic Islands (Edlund 1987, 1988).

Methods

An automatic weather station was installed in mid-June 1988 at a plateau site in the basin. It monitors solar radiation, air, surface and ground temperatures, wind speed and direction, and relative humidity. Additional thermistors were emplaced

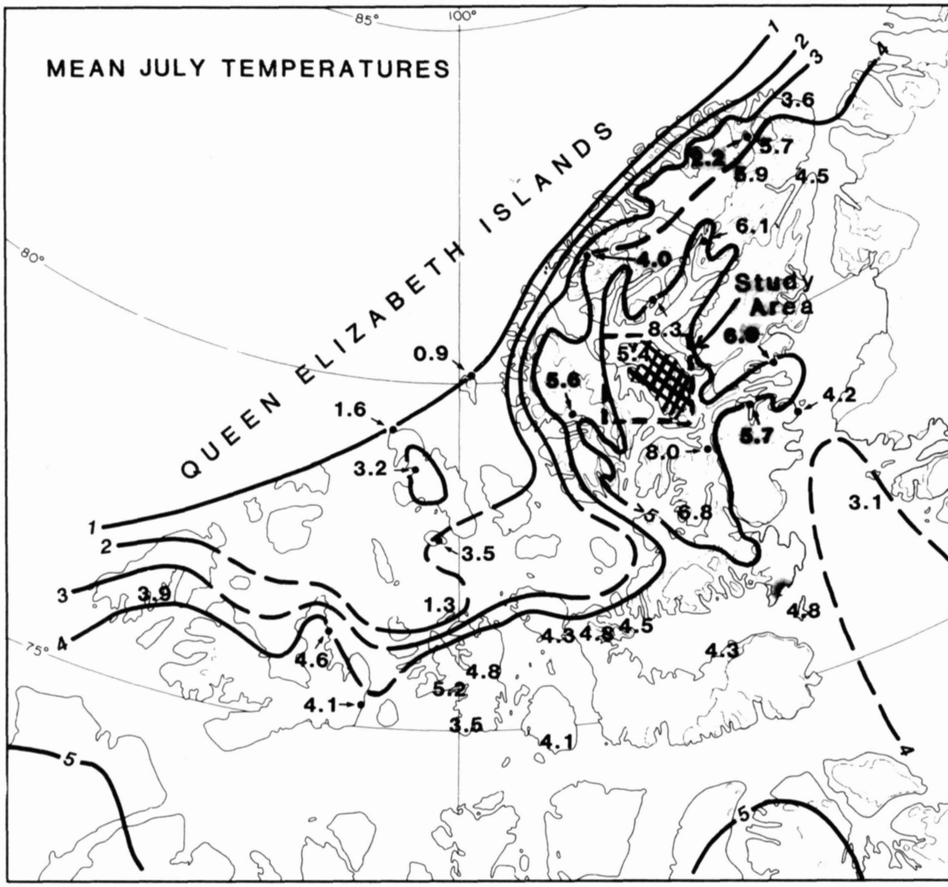

Fig. 1. Location of Fosheim Peninsula in The Queen Elizabeth Islands, showing the distribution of mean July temperatures in the region (from Edlund and Alt 1989).

at an adjacent pond to measure air, soil and water temperatures. In 1989, net radiation and rainfall were also monitored on the plateau and four micrometeorological stations were set up on different slopes (north-, south-, east-, and west-facing) to measure net radiation, air and ground temperatures, wind speed, relative humidity and rainfall. Snow surveys were carried out at all five sites in May 1989 to determine the total accumulation during the winter. The methods are described in Woo *et al.* (1983).

On each study slope, a network of nine groundwater wells was installed in 1989, and water level readings were taken daily whenever possible. Weekly frost table depth measurements were made on the plateau and at midslopes by pounding a steel rod into the active layer until encountering the frozen ground. A large number of active layer depths were measured in 1988 at several sites where ground

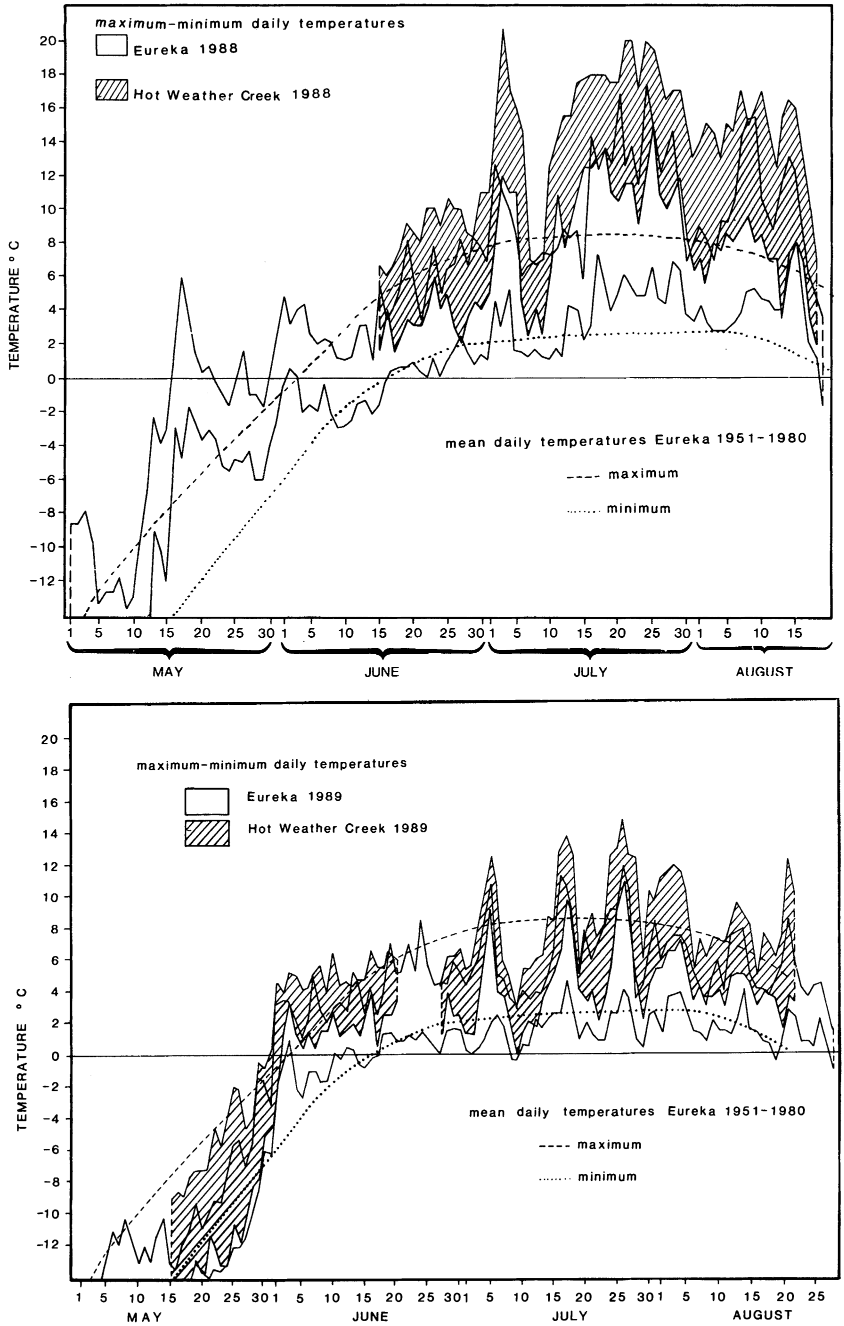

Fig. 2. Daily maximum and minimum temperatures in summers at Eureka and at Hot Weather Creek in 1988 (A) and 1989 (B) as compared to the 30-year normal (1951-1980); (Atmospheric Environment Service 1982).

ice slumps and detachment slides occurred.

Percentage vegetation cover was measured in 1988 using line-transect and quadrat methods (Wein and Rencz 1976). In 1989, per cent cover was determined along 60 m transects at each of the study slopes and at the plateau site. Three replicates of entire transects were performed at each site, involving 1 m^2 quadrat inventories at 5 m intervals along the transects. Additional inventories in other parts of the basin were made in both years, and vegetation phenology was monitored throughout the summers. All nomenclature for vascular plants follows Porsild and Cody (1980).

Temperature and Precipitation

The summers of 1988 and 1989 showed contrasts in temperature and rainfall. In 1988 the mean July temperature at Eureka (7.2° C) exceeded the 30 year mean (5.4° C). At Hot Weather Creek the mean July temperature was 12.7° C (Fig. 2). The total summer thawing degree-days both sites was much greater than the mean thawing degree-days at Eureka (Fig. 3). The largest deviation occurred in August because of a prolonged warm period. In 1989, the mean July temperature at Eureka (5.8° C) was close to the 30-year average, while the July mean at Hot Weather Creek was 6.3° C. The cumulative thawing degree-days showed that temperatures rose later than the 30-year norm, and the seasonal total fell short of the long-term average.

Mean annual precipitation at Eureka is only 64 mm (Atmospheric Environment Service 1982), but this value is unreliable because snowfall is significantly underestimated (Woo *et al.* 1983). Summer precipitation (May through August) at Eureka

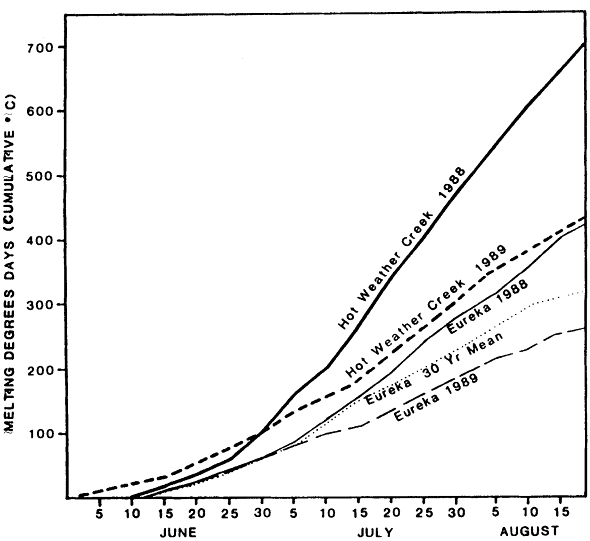

Fig. 3.
Cumulative thawing degree-days at Eureka and Hot Weather Creek in 1988 and 1989, as compared to the 30-year mean.

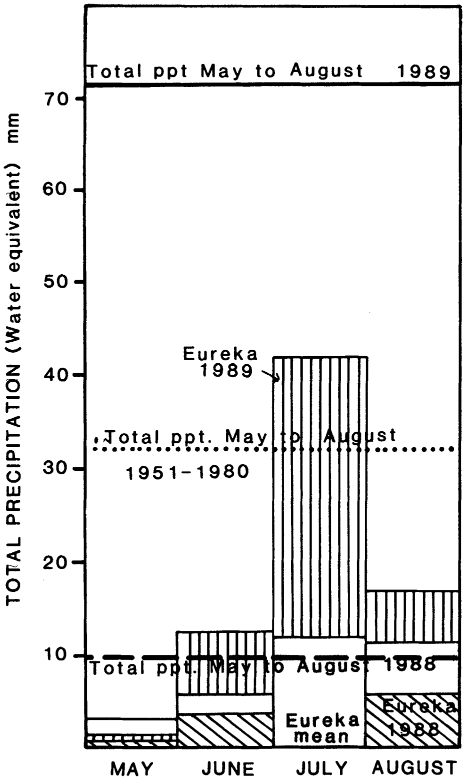

Fig. 4. Summer and total precipitation at Eureka in 1988 and 1989, as compared with the 30-year mean.

averages 32 mm water equivalent (Fig. 4), but in 1988, the total was only 0.6 mm, with none being recorded in July. At Hot Weather Creek, only three days during June through mid-August produced rainfall higher than 0.5 mm. In contrast, 1989 was unusually wet. A snow survey conducted at the end of winter at the plateau station of Hot Weather Creek yielded 89 mm water equivalent. Between June 1 and August 22, this site received 115 mm of rain, compared with 71.6 mm recorded at Eureka for the same period.

There are large variations in precipitation even at a local scale, causing spatial contrasts in hydrological activities at different sites. In terms of snow accumulation, the north, east, south and west slopes had 181, 109, 51 and 26 mm water equivalent, respectively. For rainfall between June 1 and August 22, the corresponding values were 168, 94, 130 and 66 mm. The significantly higher rainfall on the north and south slopes may be related to the prevailing wind. All heavy rain (over 15 mm/day) during this summer occurred when the wind was from the south (between 135° and 225° azimuth). While the south slope received direct impact of rain, the more sheltered northerly aspect was where most rain collected. As the wind funnelled along north south orientated valleys, the east- and west-facing slopes received less rainfall.

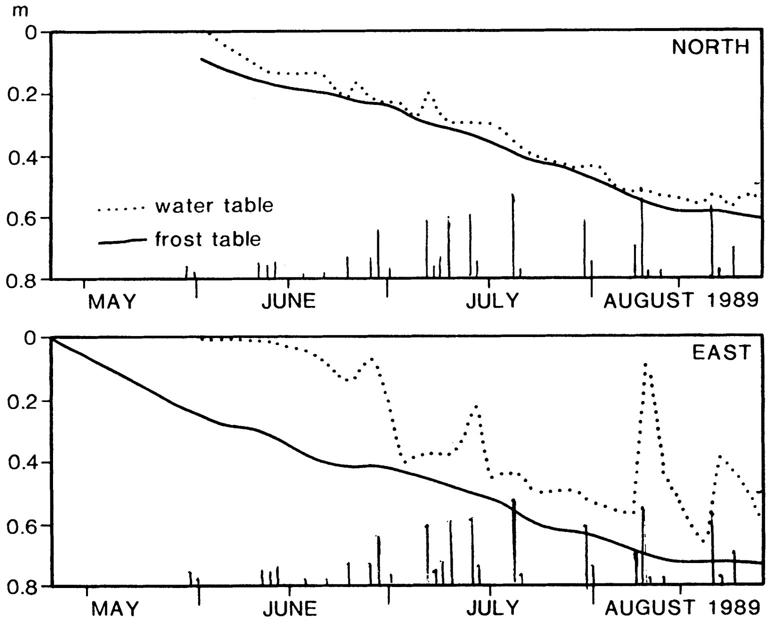

Fig. 5. Water table fluctuations in relation to frost table development on two slopes at Hot Weather Creek in 1989.

Hydrological Responses

Snowmelt and rainfall patterns influence the soil moisture regime and the water table position which, in turn, affect the availability of moisture to plants. The west slope which was snow free in mid-May, never had a saturated zone during or after the melt season. The north and east slopes, both of which had much snow, produced overland flow and high soil moisture content during the snowmelt period. These conditions were facilitated by abundant water supply and a shallow thawed zone in the active layer (Woo and Steer 1986).

Infiltration of rain-water into the silty soils at Hot Weather Creek is strongly influenced by soil cracks. Infiltration experiments using double-ring infiltrometers showed that in the absence of deep cracks, rainfall only moistened the soil surface, as the tiny soil fissures quickly sealed during rain to prevent further water penetration. Areas with deep cracks have the highest infiltration rates, and this limits the occurrence of Hortonian overland flow. Thus, after the ground had thawed, rain events did not produce overland flow except at the base of some slopes where the water table rose above the ground.

Evaporation and progressive thawing of the active layer led to a drop in the water table (Fig. 5), reducing the amount of surface moisture available to the vegetation. In 1989, the west slope was snow-free in mid-May, leading to an initial-

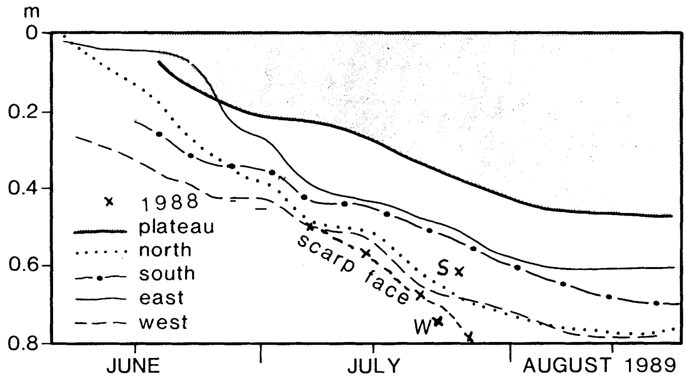

Fig. 6. Frost table development in 1989 on the plateau and on four study slopes at Hot Weather Creek. Sporadic frost table measurements from 1988 are also displayed for comparison.

ly deeper frost table than on the other slopes. Soils on the plateau and the east slope began to thaw later than the other sites because the snow lingered longer. The plateau thawed more slowly because of its lower air temperature, and eventually thaw depth reached 0.46 m (Fig. 6). In contrast, rapid thaw occurred on the north slope because its sandy soil had a higher thermal conductivity than the silty materials on the other slopes. By mid-July, its frost table was as deep as that of the west slope despite the early start at the latter site. The deepest active layer measured in the study area in 1989 was 0.79.

Few active layer depth measurements were made in 1988, but the subsurface thermistors at the plateau site showed that the 0.5 m thermistor was above 0° C after July 20. Extrapolations between the 0.5 and 1.0 m thermistors suggest that the maximum thaw there would have been about 0.75 m. Other active layer depth measurements were made at the headwall of a retreating north-facing ground ice slump. On July 9, it was 0.52 m, approximately the same as the experimental north slope in 1989. However, the prolonged and intense warmth of 1988 caused further deepening of the active layer to 0.8 m on July 28, and reached a maximum of 0.84 m in mid-August (Fig. 7).

The extremely dry, warm summer of 1988 triggered many active layer detachment slides along the slopes of Hot Weather Creek during the third week of July, and continued throughout the first two weeks of August (Edlund *et al.* 1989). Similar events occurred simultaneously in other places on Fosheim Peninsula and the adjacent Axel Heiberg Island. The failure planes corresponded with the base of the active layer (0.5 to 0.75 m depth), sometimes revealing massive ground ice. Immediately after such slides, water commonly pooled behind the slumped material. In some instances, water was so abundant that it breached the dam to maintain an ephemeral stream for several days. Another phenomenon related to this unusu-

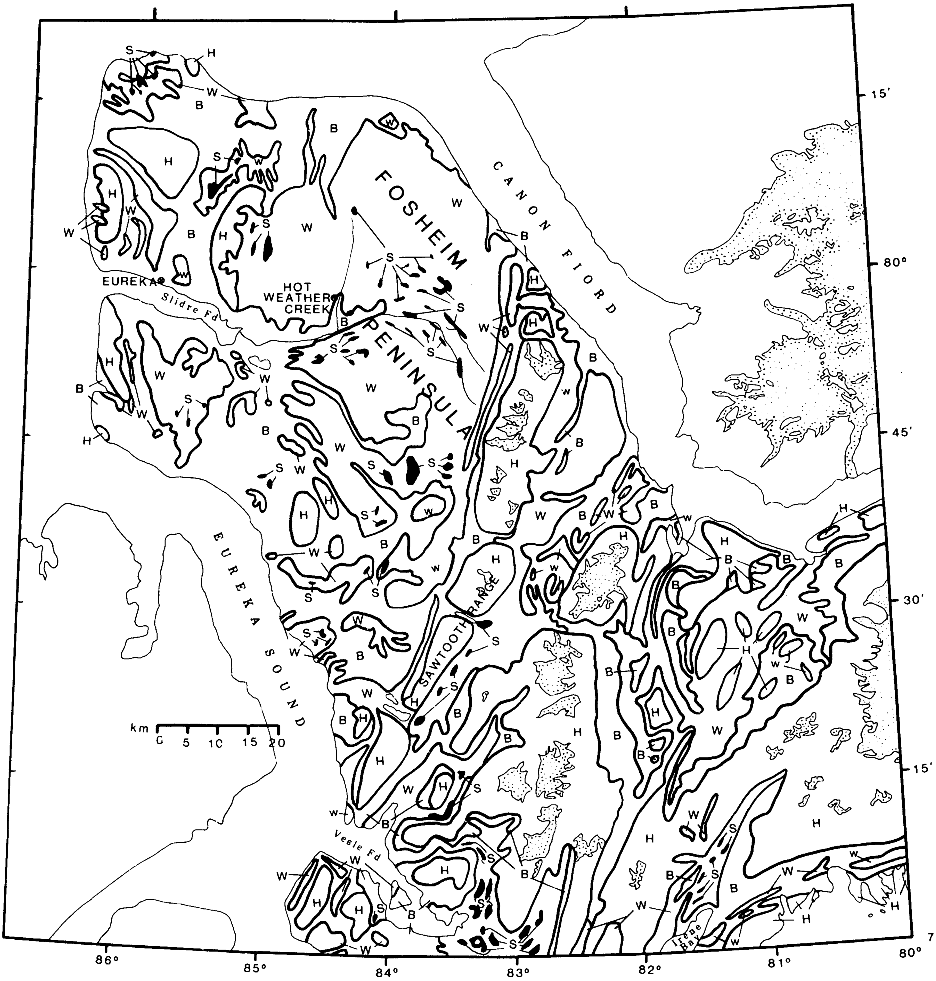

Fig. 7. Vegetation distribution on Fosheim Peninsula. W ≡ Shrub (*Salix* and *Dryas*) tundra (per cent cover > 25 %); S ≡ sedge wet meadows; H ≡ herb dominated tundra and barrens (shrubs and sedges rare to absent). Glaciers a shown as stippled pattern.

ally warm summer was the occurrence of small, artesian-like features near the crests of slopes. Silty water intermittently discharged through a small (1 to 3 mm diameter) hole or cracks, leaving concentric rings of wet silt, less than 1 m in diameter. In some places, the silty water flowed downslope. After July 18, damp spots appeared on formerly dry slopes and upland surfaces. These slowly increase in size. On some dry terraces, some damp areas coalesced into patterns that outlined ice wedges that had minimal surface expression, but in most cases, the damp patterns seemed random.

Vegetation Patterns

The relative uniformity of the weakly alkaline, silty soils in the Hot Weather Creek area has produced rather homogeneous shrub and sedge dominated tundra communities. Woody plants dominate the moderately to well-drained terrain below 300-500 m a.s.l. on Fosheim Peninsula (Fig. 7). *Salix arctica* and *Dryas integrifolia* are the most common woody plants in the region. *Salix* is ubiquitous on all types of materials, whereas *Dryas* is most abundant on sandy and gravelly terrain. *Salix arctica* dominates most slopes, generally rooting in shallow troughs, in major cracks between hummocks and in shallow, depressions. *Dryas integrifolia,* the most common associate, occurs on more exposed micro-habitats, and is more abundant on sandier soils facies.

The Experimental Sites

The irregular upland surfaces are occupied by high-centre polygons, the middle of which are covered by hummocks with a height of 0.1 to 0.3 m. The amount and duration of soil moisture supply during the melt period are the prime controls of the distribution of plant communities in this area. Vegetation on the slope study plots located on moderately to well drained soils includes 29 vascular plant species (Woo *et al.* 1990). Twelve additional species occur on the plateau and on similar slopes in the immediate vicinity, but are often associated with specialized habitats such as enriched sites around animal burrows. The north-facing slope site has the greatest diversity of species because it includes parts of a *Cassiope*-dominated heath community at the foot of the slope, and a disturbed zone on the uppermost part of the slope. Vascular plants generally cover over 50 per cent of the slopes, but at each site, percentage cover decreases from bottom to top, corresponding with the decrease in soil moisture.

Wetlands

Wetlands are common around lakes and ponds at the head of the creeks. Localized wetlands occur in poorly drained troughs and junctions of troughs, with a dense sedge meadow vegetation and a thick bryophytic mat as ground cover. Vascular plant diversity in wetlands totals 49 species, often dominated by the sedge *Carex aquatilis var. stans* and/or *Eriophorum scheuchzeri.* In places, these are accompanied by a variety of *Carex* species not normally found at this latitude and includes other rare herbaceous species such as *Hierochloe pauciflora, Cardamine pratense, Saxifraga hieracifolia,* and *Epilobium arcticum.* Many perennial ponds and shallow lakes have aquatic and emergent species which root in the muddy bottoms.

Some deep, flat-bottomed, narrow valleys, often with a limited catchment, have a rich wetland vegetation in the valley bottom. There are no channels, but only a series of moss dykes which form terraces. In spring, they are covered by standing water or may have overland flow over the frozen or shallowly thawed ground.

Active layer depth is no greater than about 0.3 m because of the insulative properties of the bryophytic mats which remain saturated through the summer.

Small patches of wetland communities also appear at the break of some slopes, and on raised berms, well above the summer level of the modern creeks. The presence of these shallow rooting species indicates that ample moisture is available at or near the surface during most of the growing season.

Phenology

The length of thaw season (approximately three months) provides ample time for most vascular plants to break dormancy, flower, set and disperse seed. In 1988, most plants broke dormancy in early to mid-June, and most had completed their life cycles by early August, starting to senesce even though temperatures were still mild and without any freezing temperature shocks. Several species, including *Braya purpurescens, Lesquerella arctica* and *Dryas* had second and third waves of flowering from the same plant.

Some plants showed the effects of the 1988 drought early in July. The drought was sufficiently severe to delay seed development in the cotton grass *Eriophorum scheuchzeri* around some shallow plateau ponds for at least ten days, as compared to development of the same species around nearby lakes where moisture was available throughout the summer. Sudden availability of abundant water after mid-July, possibly from ground ice sources, was sufficient to permit *Eriophorum* to produce seed, though it was one to two weeks later than those in communities around the lakes.

In 1989, many species did not break dormancy until early July and many early flowering species like *Dryas* and *Saxigraga oppositifolia* sporadically flowered throughout July and August in low numbers. Few mature seed heads were produced on *Dryas* by the end of August. Several species of *Carex* and *Eriophorum* did not produce seed, nor did many grasses and herbs. This may be attributed to periodic freezing and below normal minimum temperature during most of July.

Discussion

As expected, the coastal weather station at Eureka does not represent the continentality of the intermontane zone. During 1988 and 1989, Hot Weather Creek was warmer, and its cumulative thawing degree-days were higher than the totals for Eureka. The July means at both sites in 1989 were more typical of Middle to Low Arctic regimes. Summer temperatures and the length of the thawed season during 1988 at Eureka and Hot Weather Creek were similar to that experienced in the Low Arctic and the Forest-Tundra transition zone, respectively (Edlund *et al.* 1989). These show that the thermal regime of the intermontane zone is closer to the sourtherly regions than its location in the High Arctic suggests.

The diversity of vegetation of the Fosheim Peninsula, while atypical of its geographical location, is not atypical for its thermal regime (Edlund 1988). However, the high percentage cover of vascular plant species cannot be accounted for easily by the meagre summer precipitation reported by the weather stations. One reason is that precipitation is probably inaccurately measured (Koerner 1979, Woo *et al.* 1983). Even if precipitation is doubled, the amount still puts the region within the Polar Desert climate category, but the vegetation is not characteristic of that expected in a true polar desert precipitation regime.

Topographic disposition may enhance water supply on a local scale to overcome precipitation shortage. The presence of well developed wetlands in the bottomland and at the break of slope indicates that plentiful moisture is available in all years. However, the presence of wetland vegetation in trough ponds that dried up in early July 1988 suggests that an alternate moisture is needed to explain the maintenance of the well established vegetation.

During 1988 the abundance of subsurface moisture from mid-July to mid-August was indicated by the geomorphic (detachment slides) and hydrological (damp spots) phenomena noted previously. The water source was most likely the melting of ground ice because: 1) slumping exposed massive ground ice on many head walls; 2) ice wedges are abundant in the troughs of the polygons that criss cross the land and some the damp spots delimited such wedges; 3) soil cores revealed lenses of ice at the base of the active layer after mid-July; 4) water re-appeared in dried up creeks and ponds starting in mid July. The clarity of this water suggests its subterranean origin. The temperature regime of 1989 was close to the norm, and the measured active layer depths should be representative of the average conditions. The depth measured on the plateau in the previous year was almost double that of 1989, and this would have melted a substantial amount of ground ice. Such a moisture source is probably available only during the warmest, cloud-free summers when heat flux to the ground is maximized.

This study demonstrates that precipitation and ground ice are the two sources of soil moisture in this region. The precipitation controlled mechanism operates in years with near normal temperatures, and the ground ice controlled regime prevails in the warmer years. The activation of the latter regime enables the lush vegetation of Fosheim Peninsula to withstand drought conditions that are typical of a polar desert. The availability of two possible sources of moisture, from above and below the ground surface, offers a fail-safe moisture supply to the vegetation. This enables a denser tundra and wet meadow vegetation to grow in areas where sparse polar desert and barrens vegetation would have been expected.

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