AN *ARCTIC FOREST* IN THE TUNDRA OF NORTHERN UNGAVA, QUEBEC

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ABSTRACT. An extensive willow thicket community containing *Salix* of tree size was discovered in a river valley thirty-two miles southeast of Deception Bay (61°31′N., 74°5′W.) in northern Ungava. This disjunct community seemed unusual enough to merit investigation. Ecological studies were conducted to determine compositional and environmental features. The development and persistence of the community is discussed in relation to the existing climate and glacial history of the region as it is understood at present.

RÉSUMÉ. *Une "Forêt arctique" dans la toundra du nord de l'Ungava, Province de Québec.* On a découvert, dans une vallée fluviale, à 32 milles au sud-est de la baie Déception (61°31′N. 74°5′O.) dans le nord de l'Ungava, un vaste peuplement de saules en taillis comprenant du *Salix* de taille arborescente. Ce peuplement semblait suffisamment rare pour justifier une étude. Des recherches écologiques déterminèrent les facteurs de composition et de milieu. Les auteurs examinent le développement et la persistance de ce peuplement par rapport au climat actuel et à l'état présent des connaissances sur l'histoire glaciaire de la région.

REZI͡UME. *"Arkticheskiĭ les" v Tundre Severnoĭ Ungavy, Kvėbek.* Bol'shoĭ ivni͡ak, sostoi͡ashchiĭ iz derevoobraznogo *Salix*, byl otkryt v doline reki, 50 km na i͡ugo-vostok ot zaliva Disepshen (61°31′N. 74°05′.W), v severnoĭ Ungave. Ėto izolirovannoe i zamechatel'noe soobshchestvo bylo nami issledovano. My izuchili ego ėkologii͡u, opredeli͡ai͡a ego sostav i uslovii͡a sredy. Evoli͡ut͡sii͡a i postoi͡anstvo ėtogo soobshchestva rassmatrivai͡utsi͡a v svi͡azi s sovremennym klimatom i gli͡at͡sial'noĭ istorieĭ raĭona.

Introduction

THE VEGETATION of arctic regions is frequently described as treeless, or as occurring beyond the limit of trees or tree growth. This emphasis on treelessness is an anomaly since it attempts to describe a phenomenon in terms of what it is not, rather than in terms of what it is. The fact that trees do not grow in the tundra should be no more surprising than that they are absent from lakes.

The lack of trees in the tundra, and the consequent lack of shade, is nevertheless one of the striking aspects of the landscape and, combined with the absence of tall shrubs, is an extremely important ecological feature. Although there are situations at the foot of cliffs or adjacent to ledges, bluffs, and large boulders that are protected from direct sunlight for short periods, there are virtually no habitats that are permanently shaded throughout the growing season. Thus the majority of tundra plants are heliophytes and develop and grow in full sunlight.

It is interesting to speculate on the effects that continuous shading of various degrees might have on tundra species that have evolved in unshaded habitats and have become adapted to abundant light, particularly the effects of the shade cast by a natural forest canopy.

An unusual opportunity to investigate the influence of shading on arctic plant species occurred during the summer of 1961 when Matthews was conduct-

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ing geomorphological studies in the extreme northwestern section of the Ungava Peninsula in northern Quebec and discovered an extensive wooded community. This find was rather unusual because the site was some 300 miles beyond the extreme limit of trees and the community was growing under arctic tundra conditions.

The community can be considered a forest in the strict ecological meaning of the term because members of the dominant stratum are frequently of tree form with boles exceeding 12 sq. in. basal area at breast height, and sometimes attaining heights of 16 ft. A more or less continuous tree layer is formed at 12 ft. and thus the criterion of forming a solid shade-casting canopy is also satisfied. This community type occurs sporadically in several situations in this region and covers several hundred acres in at least one locality.

It was immediately realized that the occurrence of a *willow forest* so far north of the tree-line was so unusual as to merit careful study. Matthews was primarily interested in the initial development and postglacial history of the community but after consultation with Maycock it was agreed that a study of the composition and environmental features, and possibly of the historical patterns, would also assist in understanding the factors responsible for the development and persistence of the community in a region where climatic conditions would seem to prohibit it. An opportunity to investigate shading effects as well as possible floristic peculiarities was also provided.

A study of the composition and structure of the community and the surrounding vegetation was undertaken in early July 1962. Attempts were made to relate these features to environmental conditions. Matthews and assistants obtained the compositional data according to instructions from Maycock and gathered environmental information on topography, geology, climate, and geomorphology. Maycock compiled the floristic material and carried out the growth ring analysis of the trees.

Previous Reports of Arctic Thicket Communities

The first reports of unusual shrub communities in the Canadian Arctic are those of Soper (1930, 1933). These were discovered north of Lake Harbour in south Baffin Island and the most spectacular, along the Willow River, contained *Salix* that attained heights up to 12 ft.

> One of the interesting discoveries . . . a stand of willows over twelve feet in height. This came as a surprise in latitude 63°10'N, over 400 miles north of the timberline in northern Quebec. (Soper 1933)

Polunin (1948, p. 134) says the tallest specimens reported by Soper are probably all *Salix planifolia*.

Polunin also describes many occurrences in the Canadian Eastern Arctic of shrub or thicket communities that are dominated by a variety of woody species and restricted to various favourable environmental situations. A thicket of up to half a metre in height, dominated by *Salix richardsonii* is described near Pond Inlet, and a *Betula-Salix* community near Lake Harbour, Baffin Island, is related to exceptionally favourable conditions of shelter, snow cover, moisture, drainage, and southerly exposure. The same author (1948, pp. 215-16) reports a willow thicket that approaches the type and size treated in this paper in the vicinity of Wakeham Bay in northern Ungava. *Salix cordifolia* the dominant shrub there, grew to almost a metre. Unfortunately no presence list is provided for such an unusual community, but of four underherbs mentioned, three are found in the "Willow Valley" thicket.

Porsild (1955) refers frequently to localized thicket types, usually of low stature and dominated by *Salix alaxensis* and *Salix richardsonii* in the western Arctic Islands. An extensive tall thicket is also described at Orpiksoit, near Holman Post on Victoria Island, in a sheltered valley along a stream.

In the isolated reports of similar thicket communities, the site characteristics that have permitted their development — favourable exposure, deep snow cover, plentiful moisture, good drainage and shelter — are emphasized. Unfortunately the internal environments of the thickets and their influence on microclimate and on the herbs and shrubs growing within, have not been discussed. A series of presence lists from a large number of communities of this kind, with careful environmental observations, would provide very useful information on tundra species that can tolerate varying degrees of shade and provide an indication of their performance under exceptionally favourable microclimatic conditions.

Description of the Area

Topography

The "Willow Valley" forest is located in a 1500-ft.-deep glaciated valley at the southeastern end of Watts Lake which is 170 ft. above sea-level and 32 miles south of Deception Bay (61°31′N., 74°5′W.). The exact location of the community and the region is shown in Fig. 1.

Surrounding the valley is a gently undulating plateau, 1,500 to 2,300 ft. above sea-level, which is dissected by deep glaciated valleys, especially the south-north trending Murray Lake-Watts Lake Trough. The local topographic features are presented in Fig. 2 and Fig. 3.

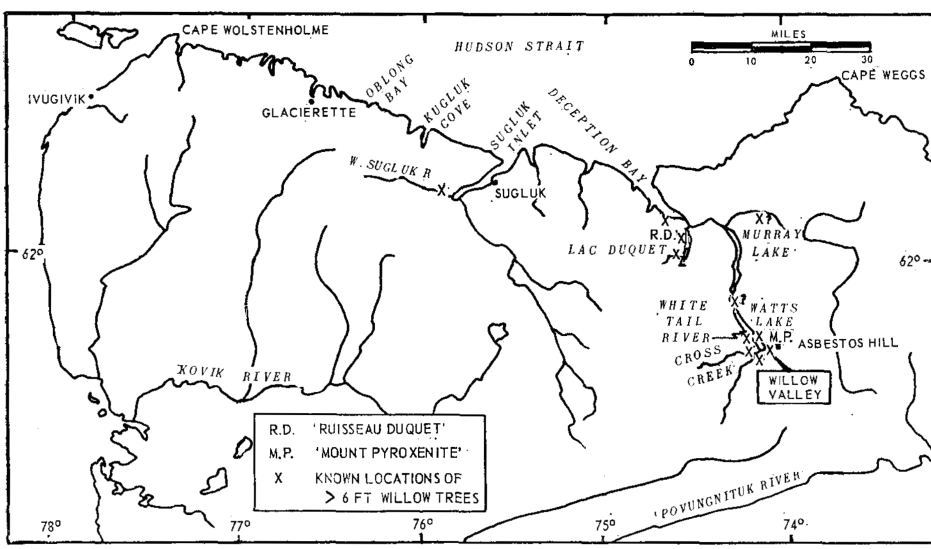

Fig. 1. Location map of the area surrounding "Willow Valley", Arctic Quebec.

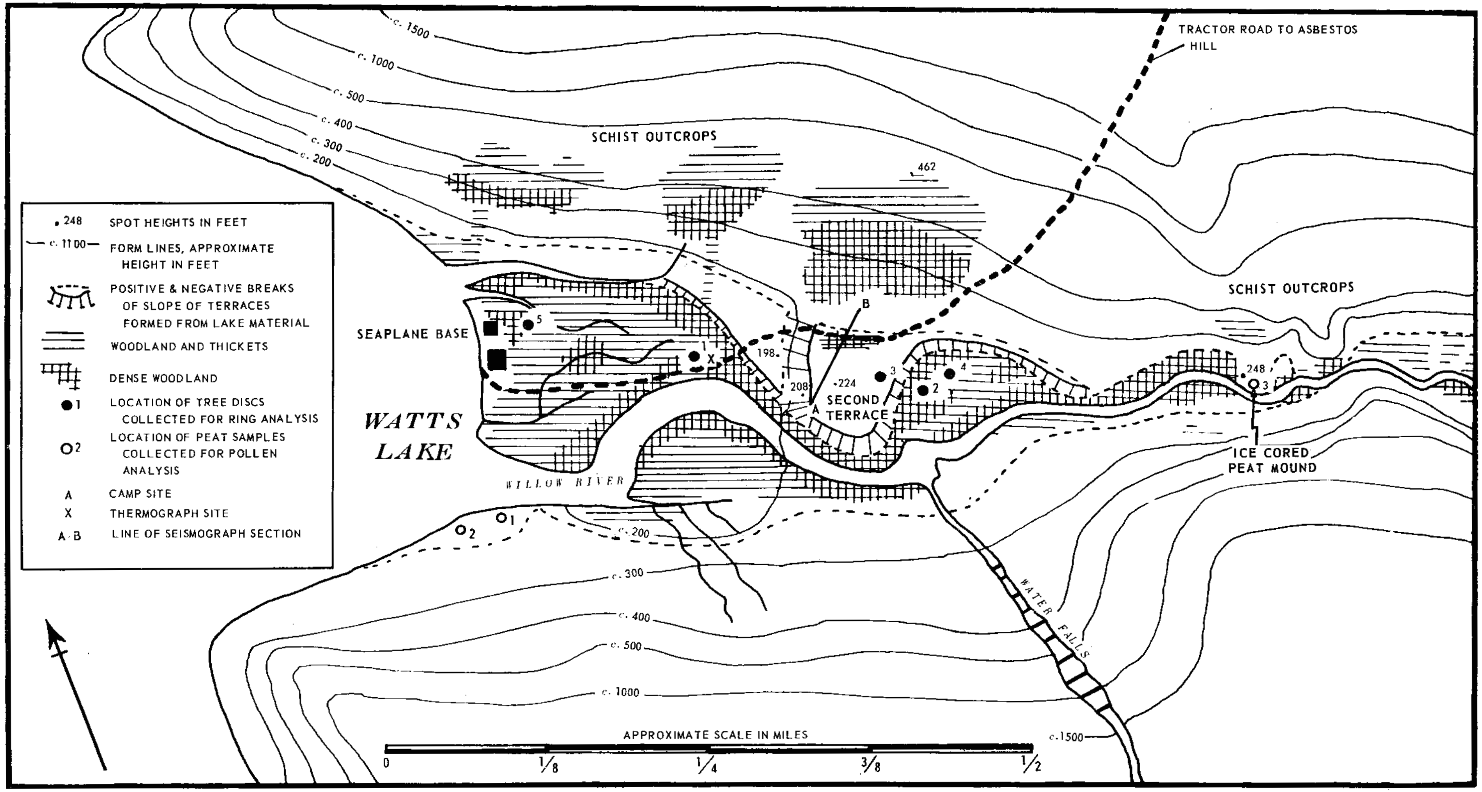

Fig. 2. General environmental features of "Willow Valley."

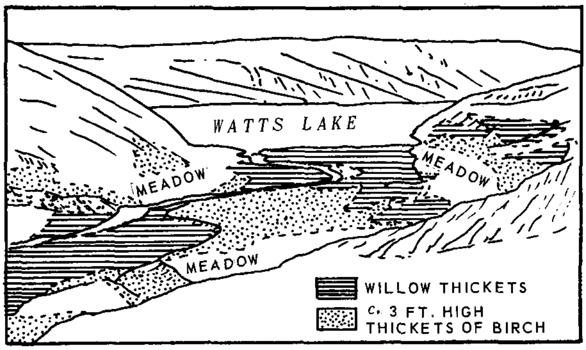

Fig. 3. General topography and vegetation of "Willow Valley", looking northwest down the valley.

Geology and Geomorphology

The "Willow Valley" — Asbestos Hill area lies in the Povungnituk group of metamorphosed sediments and lavas and presents a marked contrast to the area of resistant rocks of the Proterozoic granite-gneiss complex to the north. Here occur relatively easily eroded schists, lavas, and quartzites penetrated by more resistant ultrabasic dykes and isolated plugs of intrusive rocks that form the isolated monadnocks on the plateau surface, such as "Mount Pyroxenite." (Recently named features not yet accepted by the Canadian Board of Geographical Names, will be enclosed in quotation marks.) Bedrock in the immediate vicinity of "Willow Valley" is mainly chlorite and sericite schists covered with morainic material, boulder clay, lake silt, deltaic gravels and sand, and scree and solifluction materials.

The area was extensively glaciated during the Pleistocene. Evidence collected by Matthews points to a late glacial movement of ice from a minor centre in the Asbestos Hill area and its concentration as an outlet glacier in the Murray Lake-Watts Lake Trough. In postglacial times the valley was invaded by a 24-mile-long lake or possibly an arm of the sea. This event took place at least 7,000 years ago because the highest fossil marine shells (148 ft. a.s.l.) 8 miles inland from Deception Bay have been dated as 6,760 ± 140 years B.P. (the shells were collected by the junior author in 1961 and dated by the National Physical Laboratory, England). Thus the ice must have vacated the Deception Bay area by that time at the latest to allow the sea to invade. After an unknown period the land began to rise and the long lake drained gradually northwards until it eventually separated into the present Watts Lake and Murray Lake. The old raised beaches and deltas can still be traced along the sides of the trough valley and especially in the tributary valleys. On these beaches an early "Willow Valley" forest became established, probably during the hypsithermal period, as evidenced by a layer of wood in the thick peat deposits.

Soil and peat deposits

The existence of a *forest* in arctic Quebec is an unusual feature and it is therefore not surprising that the soil that has developed is quite different from normal tundra soils. It possesses some of the characteristics of a brown forest soil and is possibly an arctic equivalent. The local soil might be termed an *arctic thicket* type.

Soil profiles are shown in Fig. 4, and an outstanding feature is the great depth of soil that has developed in contrast to arctic findings. It is doubtful if it could be classed as an arctic brown soil, for apart from colour differences, Tedrow and Cantlon (1958) claim this type is the arctic equivalent of the temperate podsols, and no signs of leaching were observed below the willows. In addition, these well-drained soils are only slightly acid whereas arctic brown soils are usually strongly acid. This was especially true near tree disc locality 2, Fig. 2, where a 3-ft. pit was excavated in the mature willow forest.

This pit was located on the first terrace of the valley and the parent material was composed of poorly sorted sand, gravel pebbles and cobbles, mainly of schist. In Fig. 4 the soil profile has been divided into three horizons: an A_0 (0-3 in.), an A_1 (3-6.5 in.), and a third (6.5-12 in.), termed a B horizon, as there was no evidence of illuviation. The A_1 horizon consisted of a grey gravelly loam with a medium crumb structure and a moderate amount of humus. The greyish colour appears to be the result of melanization of the soil by humus rather than the effect of gleying as there were no signs of drainage impedence. Samples of the 3 horizons were taken for laboratory analysis.

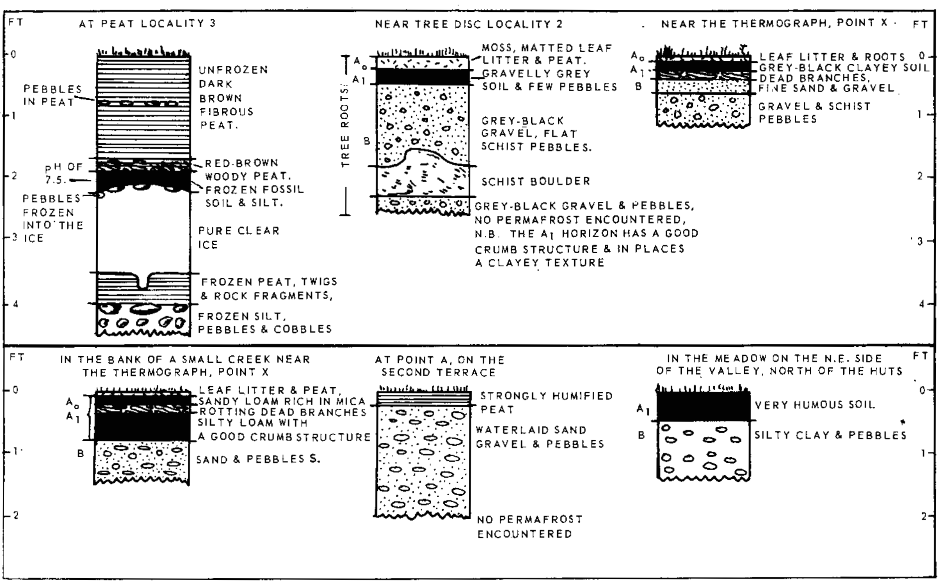

Fig. 4. Peat and soil profiles of "Willow Valley." Localities and points refer to Fig. 2.

The results of the analysis of structural components are presented in Table I. The major feature of the different horizons was the high proportion of stony material which increased greatly with the depth. When the stony material was removed from the B horizon material, there was insufficient left for nutrient analysis emphasizing the almost complete lack of fine materials. The textural analysis emphasizes the extreme skeletal nature of these soils and the importance of the role of the A_0 layer and the upper A_1 layer in supporting the luxuriant growth of the willows.

Table I. Textural classes calculated on basis of percentage weight of total sample. "Willow Valley" forest soils

Portion	*Horizon*		
	A_0	A_1	B
2 mm. +	19.1	51.4	70.1
1 mm.—< 2 mm.	not separated	20.6	14.2
< 1 mm.	80.9	28.0	15.7

The chemical analyses presented in Table II re-emphasize the importance of the organic horizons. The A_1 layer contained significantly less organic matter than the A_0 but was richer in calcium, potassium, magnesium, and phosphate.

Table II. Analysis of nutrient content and reaction, "Willow Valley" forest soils.

	A_0	A_1
Organic matter	22.9%	3.1%
pH	6.0	5.8
Exchangeable bases		
P_2O_5	5.4 mg./100 g.	6.0 mg./100 g.
Ca	62 mg./100 g.	450 mg./100 g.
K	7 mg./100 g.	44 mg./100 g.
Mg	8 mg./100 g.	27 mg./100 g.

Climate

The nearest station for which reliable climatic data are available is Cape Hopes Advance, but it lies almost 180 miles southeast of "Willow Valley" and on an exposed coast. These records are of little value for the inland thicket site where conditions are undoubtedly less severe.

At Cape Hopes Advance the mean annual temperature, based on a 22-year record, is 19.0°F and this is 3.1° colder than Fort Chimo, 200 miles to the south. The total annual precipitation, based on the same period, is 13.74 in., and 8.14 of this falls as rain. The mean annual snowfall of 56.0 in. is high for a tundra climate. Most of the snow falls between October and May although traces have been recorded in all months. Prevailing winds are from the northwest. The average frost-free period of 27 days (13-year record) is very short for the growth of the vigorous shrubs that led to the development of this community.

Vegetation of the "Willow Valley" area

From the air the vegetation in the deep U-shaped valley is seen in sharp contrast to that on the plateau. The plateau is sparsely covered with dry open rocky tundra. Most of the surface is bare glacial rubble, felsenmeer or exposed bedrock. Lichens, mosses, grasses, and a few dwarf shrubs form the depauperate communities.

The shrub stands in the valley present a luxuriant plant cover in comparison with the bleak plateau. The willow forest forms a solid green canopy at 12 ft.

and contains specimens that attain a height of almost 16 ft. Two species of willow dominate the thickets: *Salix planifolia* Pursh and *S. alaxensis* (Anderss.) Cov. The thickets can be divided into two groups, a dense valley bottom forest, growing on gravels and sands, and an equally dense forest on the southwest facing slope. The latter was growing on stabilized scree material and glacial deposits up to a height of 460 ft. above sea-level or 290 ft. above the lake.

Both situations are well drained, although this fact was obscured in early July 1962, in the valley bottom, because of flooding in the lower half of the valley when the lake suddenly rose 8 ft. due to an ice jam in the outlet river during breakup.

The tallest trees (16 ft.) in the slope thickets grow immediately below sheer schist cliffs and may benefit from the rapidly disintegrating bedrock which may produce a constant supply of nutrients. These willows are predominantly *Salix alaxensis* and have diameters at the base of 4 in. Both *S. alaxensis* and *S. planifolia* grow in the valley bottom forest and there attain trunk diameters of up to 8 in. at base. Specimens of *S. alaxensis* tended to be taller than those of *S. planifolia*.

The site requirements of the two dominant *Salix* differ somewhat. *S. planifolia* occurs in wetter areas and tends to border the many interlacing streams to the northeast of the main river channel, a feature noted also by Polunin (1940) in various parts of the eastern Arctic. On the other hand *S. alaxensis* occupies most of the less moist interfluve areas and hence covers the largest section of the valley bottom. In adjacent "Rivière à la Croix" valley, however, the better drained areas are those immediately adjacent to the fast-flowing streams and so *S. alaxensis* tends to border the water courses whereas *S. planifolia* occupies the more waterlogged areas (see Fig. 5).

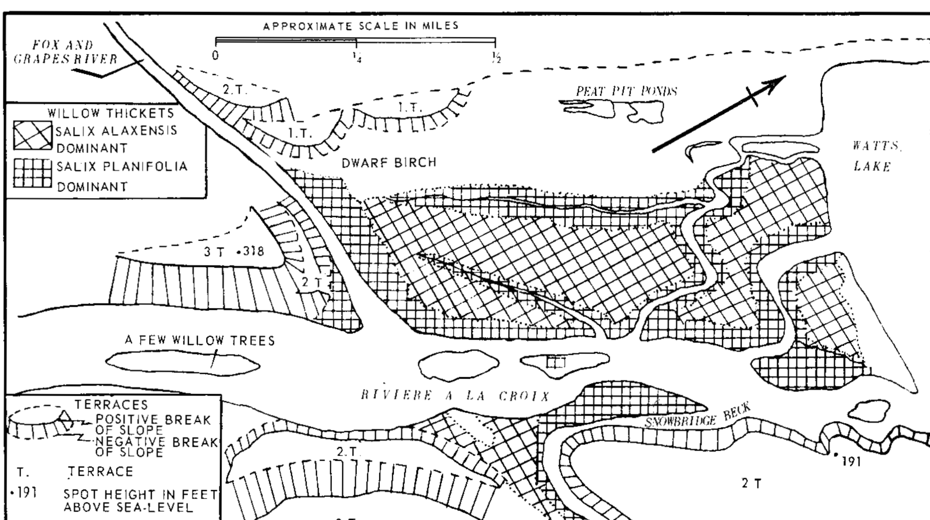

Fig. 5. Map showing vegetation and topography of "Rivière à la Croix" valley forest; based on air photographs and mapping in the field.

All trees in both the slope and valley bottom thickets showed evidence of vigorous growth of terminal shoots during 1962. By July 6, 1.5 in. of new growth had been added on both species in the valley bottom and by July 13 this had increased to 3 to 4 in. This rapid growth was probably due to the exceptionally high temperatures of early July. Temperatures of 70°F and higher prevailed at a time when there were only a few hours of darkness and very little cloud and hence up to 20 hours of sunshine per day.

The oldest part of the valley bottom thicket is near tree disc localities 2 and 4 (Figs. 2, 6 and 7). There the understory is relatively sparse and the trees are larger and much farther apart and attain an average height of 16 ft. Many trees have numerous stems that have developed vegetatively from the base. One tree had over 40 full-sized stems growing from a single main root stock and over half of these were growing prostrate. In general, however, the number of fallen branches was less than would be expected in an area of high winds.

The prolific production of offshoots and the presence of numerous tall branches produces a dense canopy cover. Canopy covers as high as 85 per cent and as low as 25 per cent were recorded, although sporadic openings occurred throughout. These shading effects are important in determining the composition of the shrub and herb cover of the understory.

On the drier areas, especially on the steep edge of the second terrace, the willows give way to a heath community composed of ericaceous species, dwarf birch and willows, grasses, and other herbs. The wetter area between the slope and valley bottom thickets is occupied by a type of meadow vegetation com-

Fig. 6. A general view of the community looking southeast up "Willow Valley."

Fig. 7. General view of willows in one of the small openings of the willow thicket community.

posed of lush grasses, sedges, and herbs. This meadow is crossed by two narrow belts of trees 7 ft. high, which connect the two wooded areas. Vigorously growing willow saplings are occasionally present in the meadow, suggesting that, should present conditions continue, the meadow will eventually become a thicket. A possible reason for the gap is the extreme waterlogging that takes place in July, as noted in 1962. This condition, acting as a factor to inhibit tree growth, was also observed in Alaska by Benninghoff (1952).

The drainage in the open meadow is impeded because the 5 in. layer of peaty soil is underlain by silty clay, pebbles and stabilized solifluction material, which are more susceptible to freezing than are gravels and sands. Thus the active layer is shallow compared with the gravel and sand areas and peaty soils also have a low thermal conductivity. Moreover, before stabilization of the solifluction material by the grasses and herbs, this part of the valley would probably not offer a firm enough surface on which willows could become established.

The fauna of the thickets was rich and varied. A number of species of birds were present including the arctic sparrow which, in two unusual instances had nested in the willows instead of on the ground. One of the nests was discovered 2 ft. up in the crook of a 12 ft. high tree. This height was possibly related to the depth of late spring snow. The excreta of fox and lemming were abundant and an old prospector reported that high populations had occurred previously. In some situations lemming droppings covered more than 20 per cent of the ground. This organic debris must supply necessary nutrients to the herb layer. Spiders, beetles, and slugs were also very numerous.

Thicket Communities of Extreme Northern Ungava

The "Willow Valley" forest is the most extensive known in the northern sections of the Ungava peninsula. It covers an area of several hundred acres. An extensive survey of much of the region by helicopter, coupled with reports of pilots who had passed frequently over the territory, permits the writers to present with some assurance, the distributional pattern of the thicket communities in the extreme northern section of the peninsula.

Other thickets containing 17-ft. trees exist in the "Rivière à la Croix" valley and on various deltas along Watts Lake and Murray Lake (Fig. 1). Asbestos Corporation personnel have also reported the existence of one or two small thickets along the Rivière Déception valley, and Matthews noted large thickets at the south end of Lac Duquet and especially in the west tributary valley. No other trees of this size have been found elsewhere between Cape Wolstenholme and Deception Bay. A few 7-ft. willows were noticed on the southwest side of Deception Bay in the "Renard Noir" valley, on the northwest side of Lac Duquet by Ruisseau Duquet and along the "Rivière Tourbe" valley.

It is a notable fact that the tall willow forests of arctic Quebec are established only on the deep marine, lake or river gravels and sands, except in parts of "Willow Valley" where slope types also occur.

Field and Laboratory Procedures

Environmental features of the thickets were carefully studied as it was recognized that these characteristics are critical for the development and persistence of these willow communities. Topographic, geological, pedological, and geomorphologic phenomena were carefully noted. Measurements of permafrost depth were taken both in the valley and on the surrounding plateaux. Climatic data were accumulated for a site in the valley near the fringes of the thickets (Fig. 2). A thermograph and modified Stevenson screen, placed just 1 ft. above the ground were used (Fig. 8). These modifications may have resulted in the greater diurnal range of these records compared with those from Asbestos Hill, which were taken in a standard screen, but the thermograph is correct only to $\pm$ 2°F and thus the data are considered to be sufficiently accurate to permit a comparison with those for the same period at Asbestos Hill. The weather records for Asbestos Hill mining camp (approx. 2,000 ft. a.s.l.) had been collected only for the previous three years, since 1960, and records are missing for some of the winter months. The growth patterns and ages of the *Salix* were also investigated, using discs that had been cut from a few of the larger trees at the site.

Floristic and compositional data were collected as follows. All vascular plants in the thicket and adjacent areas and on the nearby plateaux were collected and identified. Metre-square quadrats, placed at random, were used to record the density of ground cover plants. Nine quadrats were read, 3 in the dense willow thicket, 3 in the shrubby edges and small openings within the community and 1 in the open tundra. Within the herb and shrub quadrats

Fig. 8. The interior of the thicket at the site where climatic measurements were recorded. The density and size of *Salix* stems are evident as well as the heavy ground cover.

estimates of the coverages of lichens, mosses and bare ground were taken. Finally a 10 x 10 m. quadrat was laid out in one of the more dense sections to record the actual density of *Salix* stems. Time prevented the expansion of this latter project and unfortunately no quadrat was recorded in that part of the thicket where the largest willows were growing.

In the laboratory the quadrat data were sorted and actual densities were calculated. The information was tabulated in the order of the occurrence of species in the thicket community proper, in the thicket openings and fringes, and finally in the surrounding tundra habitats.

Results

Floristics

A flora of 67 species of vascular plants, including 69 different taxonomic entities was determined for the valley and environs. Of these plants 2 were completely new to the flora of Quebec. It is surprising that one of these, *Salix alaxensis*, was one of the major dominants of the community and is now known to be widespread in the interior of the extreme northern section of the Ungava Peninsula. The other addition to the flora of the Province was *Stellaria edwardsii*. Several other vascular plants presented notable range extensions that have already been reported (Maycock 1963). A few species of plants, particularly grasses and sedges, may have been overlooked during the survey, owing to the short period of investigation and the inexperience of the collectors. The complete floral list with authorities as presented in Porsild (1957) is included in Table III.

Table III. Data for presence and density as recorded in metre square quadrats, for plants in willow thicket, shrubby edges and thicket openings, and tundra communities, "Willow Valley", Northern Ungava.

Species	*Presence Willow Thicket*	*Presence Shrubby Edges and Thicket Openings*	*Presence Open Tundra*	*Willow Thicket Quadrats* 1-A	2-B	3-C	4-D	*Shrubby Edges and Thicket Opening Quadrats* 5-G	6-H	7-E	8-I	*Tundra Quadrat* 9-F
Salix cordifolia Pursh var. *callicarpaea* (Trautv.)Fern.	x											
Draba glabella Pursh	x											
Draba nivalis Liljebl.	x											
Anemone richardsonii Hook.	x											
Ledum groenlandicum Oeder	x											
Cerastium beeringianum Cham. & Schlecht.	x				5							
Primula stricta Hornem.	x											
Erigeron eriocephalus J. Vahl	x			26								
Festuca brachyphylla Schultes.	x			33								
Taraxacum lacerum Greene	x					4						
Epilobium angustifolium L.	x	x					40				27	
Petasites sagittatus (Banks) A. Gray	x	x										
Salix alaxensis (Anderss.) Cov.	x	x		1								
Salix planifolia Pursh	x	x		4					2		5	
Pyrola grandiflora Rad.	x	x		3					6			
Arabis alpina L.	x	x										
Calamagrostis canadensis (Michx.) Beauv.	x	x									65	
Equisetum arvense L.	x	x			9	2	41			20		
Polygonum viviparum L.	x	x		6				17	20			
Stellaria edwardsii R. Br.	x	x		5		13						
Carex scirpoidea Michx.	x	x		3					175	40		
Campanula rotundifolia L.	x	x		2					1			
Pedicularis flammea L.	x	x		1								
Erigeron unalaschkensis (DC.) Vierh.	x	x			9							
Artemisia borealis Pall.	x	x			3	25						
Poa glauca M. Vahl.	x	x			22	21						
Stellaria longipes Goldie	x	x					150				26	
Oxytropis foliolosa Hook.	x	x						4	7			
Oxytropis terrae-novae Fern.	x	x	x		120	115						
Dryas integrifolia M. Vahl.	x	x	x	3				1				17
Epilobium latifolium L.	x	x	x		28	19	21	2				
Arnica alpina (L.) Olin ssp. *angustifolia* (Vahl) Maguire	x	x	x	1		114						
Betula glandulosa Michx.	x	x	x	3							1	
Potentilla hyparctica Malte	x	x	x	7					1			
Salix reticulata L.	x	x	x	5				50	20	55		65
Potentilla nivea L.	x	x	x		9	6			1			
Salix cordifolia Pursh.	x		x		6							10

Species	Presence Willow Thicket	Presence Shrubby Edges and Thicket Openings	Presence Open Tundra	Willow Thicket Quadrats					Shrubby Edges and Thicket Opening Quadrats			Tundra Quadrat
				1-A	2-B	3-C	4-D	5-G	6-H	7-E	8-I	9-F
Oxytropis maydelliana Trautv.		x	x									5
Salix calcicola Fern.		x	x							14		15
Pedicularis lapponica L.		x	x							1		7
Saxifraga caespitosa L. ssp. *exaratoides* (Simm.) Engl. & Irmsch. emend. Porsild		x										
Papaver radicatum Rottb.		x										
Saxifraga cernua L.		x										
Saxifraga caespitosa L. ssp. *eucaespitosa* Engl. & Irmsch.		x										
Silene acaulis L. var. *exscapa* (All.) DC.		x										
Saxifraga tricuspidata Rottb.		x										
Melandrium affine (J. Vahl) Hartm.		x										
Taraxacum lapponicum Kilhlm.		x										
Rhododendron lapponicum (L.) Wahlenb.		x							4			
Luzula nivalis (Laest.) Beurl.		x										
Campanula uniflora L.		x							1			
Cerastium alpinum L.		x										
Habenaria obtusata (Pursh) Richards var. *collectanea* Fern.		x										
Armeria maritima (Mill.) Willd. ssp. *labradorica* (Wallr.) Hult.		x										
Carex norvegica Retz.		x							2			
Stellaria monantha Hult.			x									19
Pedicularis lanata Cham. & Schlecht.			x									
Cassiope tetragona (L.) D. Don			x									
Vaccinium uliginosum L. var. *alpinum* Big.			x									
Oxyria digyna (L.) Hill			x									
Arctostaphylos alpina (L.) Spreng.			x									
Salix arctica Pall.			x									
Pedicularis hirsuta L.			x									
Saxifraga oppositifolia L.			x									
Draba alpina L.			x									
Dryopteris fragrans (L.) Schott.			x									
Phyllodoce coerulea (L.) Bab.			x									
Diapensia lapponica L.			x									
Ledum decumbens (Ait.) Lodd.			x									
Moss coverage (%)				45	10	20	10	5	0		15	1
Lichen coverage (%)				4	2	40	2	1	0		0	2
Canopy coverage (%)				65	80	75	40	25	0	5	5	0
Bare ground coverage (%)				0	10	10	5		0		20	

The affinity of the flora is undoubtedly arctic. With the exception of 2 species, *Ledum groenlandicum* and *Habenaria obtusata* var. *collectanea*, all have been recorded from the Canadian Arctic Archipelago. Both of the exceptions are wide-ranging boreal and subarctic species that have recently been collected with increasing frequency in northern Ungava (Rousseau 1966). Throughout their range they are usually found growing with coniferous trees or in habitats sheltered by boreal or subarctic shrubs.

At the time the survey was initiated the authors questioned whether a large number of boreal associates would be discovered growing under the ameliorated microclimate produced by the shrubs. It was expected that boreal relicts that had survived in the shelter of the thicket from a previous forest community that could have developed during the postglacial xerothermic, might be found. The existing complement of species does not seem to support this supposition, with the exception of the two boreal-subarctic species mentioned. In this regard it is significant that Maycock made a related discovery while botanizing in 1960 on Merry Island of the Nastapoka Group that lies just 3 miles off the southeast shore of Hudson Bay, adjacent to Great Whale River. In a few small stunted groves of spruce that had developed in the tundra, *Ledum groenlandicum* formed the shrub cover and *Habenaria obtusata* was taken nearby. These were the only boreal species in the otherwise arctic flora of the island.

The other point that should be mentioned concerning the occurrence of these boreal plants is that they may possibly be recent arrivals in the community from areas farther south, and became established because of the new conditions produced by the willows. This is assuming that the willow thickets are a recent development too.

There were also a number of cryptogams in the community. Ten species of mosses, 4 lichens and 1 fungus were collected and these were the more prevalent among those associated with the other herbs and shrubs. The following list is not considered complete and is presented to draw attention to the more conspicuous or dominant cryptogams. The fungus was growing on fallen rotted wood and was quite abundant.

FUNGI: Polyporus elegans Bull. ex. Fr.

BRYOPHYTA: *Abietinella abietina* (Hedw.) Fl.; *Drepanocladus uncinatus* (Hedw.) Warnst.; *Distichium* sp.; *Myurella tenerrima* (Brd.) Lindb.; *Hypnum revolutum* (Mitt.) Lindb.; *Hylocomium splendens* (Hedw.) BSG.; *Rhacomitrium canescens* Brid.; *Brachythecium* sp.; *Tortula ruralis* (Hedw.) Sin.; *Ditrichum flexicaule* (Schwaegr.) Hampe.

LICHENS: *Cladonia pyxidata* (L.) Hoffm.; *Cetraria nivalis* (L.) Ach.; *Peltigera canina* (L.) Willd. var. rufescens (Weis) Mudd.; *Stereocaulon tomentosum* E. Fr.

STRUCTURAL COMPOSITION AND SHADING EFFECTS

The lack of boreal elements may seem unusual, but of greater consequence is the fact that so many arctic species seem capable of withstanding the shaded environment produced by the willows. Canopy coverages estimated at levels varying from 25 to 85 per cent prevent large amounts of sunlight from reaching the ground. In Table III it can be seen that 37 species were found under these reduced light conditions in the forest. Several of these are wide-ranging species that also occur in boreal forest communities farther south as well as in arctic regions and would be expected to withstand these conditions. *Ledum groenlandicum, Epilobium angustifolium, Calamagrostis canadensis, Equisetum arvense, Carex scirpoidea, Betula glandulosa, Salix reticulata* and *Campanula rotundifolia* could be included in this group. On the other hand arctic species such as *Draba nivalis, Erigeron eriocephalus, Taraxacum lacerum, Arabis alpina, Pedicularis flammea, Potentilla hyparctica, Oxytropis foliolosa* and *O. terrae-novae* would not be expected in dense shade, yet they grew in these thickets. Many of the arctic species were somewhat etiolated, had longer internodes, were taller in stature, and often had certain pigments less well developed than normally; but others were flowering and fruiting, apparently uninfluenced by the effects of shade.

A second group of 44 species occurred in situations that were only partially shaded. Canopy coverages on the edges of the thickets and in the smaller openings in the thickets varied from 0 to 5 per cent. In the open tundra sites where there was no shading at all there was a total of 26 species. The intermediate habitats supported the largest assortment of plants, apparently selected from among those species that were capable of growing under all of the light conditions available (a small group of 8 species including *Oxytropis terrae-novae, Dryas integrifolia, Epilobium latifolium, Arnica alpina, Betula glandulosa, Potentilla hyparctica, Salix reticulata* and *Potentilla nivea*) and from those occurring in the open and shaded sites. The overlap in shaded and semi-shaded habitats was 18 species, whereas in semi-shaded and open it was only 3 species; both of these figures omitting those plants which were common to all three sites. *Salix cordifolia* was the only plant found in the shaded and open communities that was absent in the intermediate.

The information in Table III presenting the actual densities of the plants as tallied in metre quadrats in the differents sites, indicates that many were capable of growing satisfactorily under the existing conditions. Some species were vigorous enough to dominate in extensive areas on the ground under the thicket canopy and in partially shaded situations: In Table IV those species that occurred in at least one of the quadrats recorded in the three related communities are presented on the basis of average density per square metre. Several species occurred with comparatively high average densities in at least one of the three sites. *Poa glauca, Arnica alpina, Epilobium latifolium* and *Oxytropis terrae-novae* possessed high values in the willow thickets. *Equisetum arvense, Stellaria longipes* and *Epilobium angustifolium* occurred as predominant members of the understory both within and on the edges of the thickets, whereas *Salix reticulata* occurred with high values in all three communities but reached optimum influence in the open tundra. *Carex scirpoidea* and *Calamagrostis canadensis* were most prominent on the thicket edges and in openings. Of the species that attained optimum density values in the open tundra, *Salix cordifolia, Dryas integrifolia, Salix calcicola* and *Stellaria monantha* were most significant. The density values for the herbs support and expand the presence data and show a more refined picture of actual composition in the three sites.

The gradual trends in the series of quantitative data that are evident in Table IV emphasize that although the species are predominantly of arctic distribution they respond differently to the effects of shading and the protection

Table IV. Average density per square metre for species which occurred in at least one of the nine quadrats recorded in the three communities of "Willow Valley".

Species	*Willow Thicket*	*Shrubby Edges and Openings*	*Tundra*
Pedicularis flammea	0.2	—	—
Taraxacum lacerum	0.8	—	—
Cerastium beeringianum	1.0	—	—
Erigeron unalaschkensis	1.8	—	—
Stellaria edwardsii	3.6	—	—
Erigeron eriocephalus	5.2	—	—
Artemisia borealis	5.6	—	—
Festuca brachyphylla	6.6	—	—
Poa glauca	8.6	—	—
Epilobium latifolium	14.0	—	—
Arnica alpina	23.0	—	—
Oxytropis terrae-novae	47.0	—	—
Campanula rotundifolia	0.4	0.3	—
Betula glandulosa	0.6	0.3	—
Potentilla hyparctica	1.4	0.3	—
Potentilla nivea	3.0	0.3	—
Pyrola grandiflora	0.6	2.0	—
Oxytropis foliolosa	0.8	2.3	—
Polygonum viviparum	4.6	6.7	—
Equisetum arvense	10.4	6.7	—
Stellaria longipes	30.0	8.7	—
Epilobium angustifolium	8.0	9.0	—
Carex scirpoidea	0.6	71.7	—
Salix reticulata	11.0	25.0	65.0
Salix cordifolia	1.2	—	10.0
Dryas integrifolia	0.8	—	17.0
Calamagrostis canadensis	—	21.7	—
Rhododendron lapponicum	—	1.3	—
Carex norvegica	—	0.7	—
Campanula uniflora	—	0.3	—
Salix calcicola	—	4.7	15.0
Pedicularis lapponica	—	0.3	7.0
Stellaria monantha	—	—	19.0
Oxytropis maydelliana	—	—	5.0

from exposure afforded by the thicket community. The various herbs apparently find conditions most beneficial under one of the three vegetational situations investigated. It is perhaps dangerous to place too much reliance on the trends indicated in these tables, because scant information is available particularly for the tundra sites. The moisture conditions of the three sites are probably not similar enough for critical comparison, because the tundra on the elevated terraces is undoubtedly drier than the moist valley bottom. The data are nevertheless of sufficient magnitude to illustrate that it would be fruitful to investigate these relationships on a larger scale, to determine the influence of shade and protection on the tundra species. It may be that a more thorough study of a large number of the *thicket forests* in the region may yield a larger number of boreal species and tundra types that can withstand shade.

Thicket canopy structure

The composition and structure of the canopy was studied in a single 10 x 10 m. quadrat situated in one of the less mature sections of the community. It is unfortunate that a similar quadrat was not taken in the more mature forest, but the data available do present a satisfactory picture of the structure of the canopy in a younger area of the community.

Within the quadrat there were a total of 217 *Salix* stems. These varied in size from a diameter at base of 1 in. and a height of 4 ft. up to a diameter of 5 in. and a height of 9 ft. Approximately 65 per cent were *Salix alaxensis* and the remainder were *S. planifolia*. In the more mature areas the density of stems per metre was estimated to be greatly reduced and trunk diameters were considerably larger. The largest observed was 8 in. in diameter and had attained a height of slightly greater than 16 ft.

When the density of stems is considered it is realized that a cover of this thickness greatly reduces the percentage of incident light available for plant growth at the ground surface. In spite of this, as the data indicate, many of the species that dominated in the encircling open tundra communities were successfully growing in the shaded thickets.

Age studies

Several of the tree discs were unsatisfactory for age studies because the central areas were badly decomposed. This was particularly true for the largest discs and thus it may not have been too serious that some of the largest willows could not be felled for lack of proper tools. Five discs, the largest 4.25 in. diameter at 1 ft. above the ground, were suitable for examination. Four of these, the largest, were collected in "Willow Valley" and the other was cut from an isolated 7 ft. tree in Ruisseau Duquet valley. (See Fig. 1 for tree disc location sites.)

Initially it was planned that ring width measurements would be taken so that possible correlations could be ascertained between increment fluctuations and favourable or unfavourable periods of growth caused by climatic, biotic, or other influences. This proved too difficult a task because the rings were not as clearly defined as was desirable for this purpose and because the central portions of many discs were obscured by decomposition. Thus after the rings were defined and counted they were then critically examined in series and where a ring or a group of rings appeared notably smaller than those adjacent, they were so noted on a tally sheet on which the years were listed in order corresponding to the growth rings. Years of exceptionally wide increment were also so noted. Although this procedure seemed somewhat crude, it was not without value.

The oldest disc proved to be the largest. It was 59 years old, having started growth in 1904. The other discs were 50, 49, 38, and 38 years old, having apparently started to grow in 1913, 1914, 1925, and 1925 respectively (Fig. 9). The disc taken from the Ruisseau Duquet locality was 50 years old and it had a diameter slightly greater than half that of the 59-year old disc from "Willow Valley". Thus the growth in diameter or increase in girth in relation to age

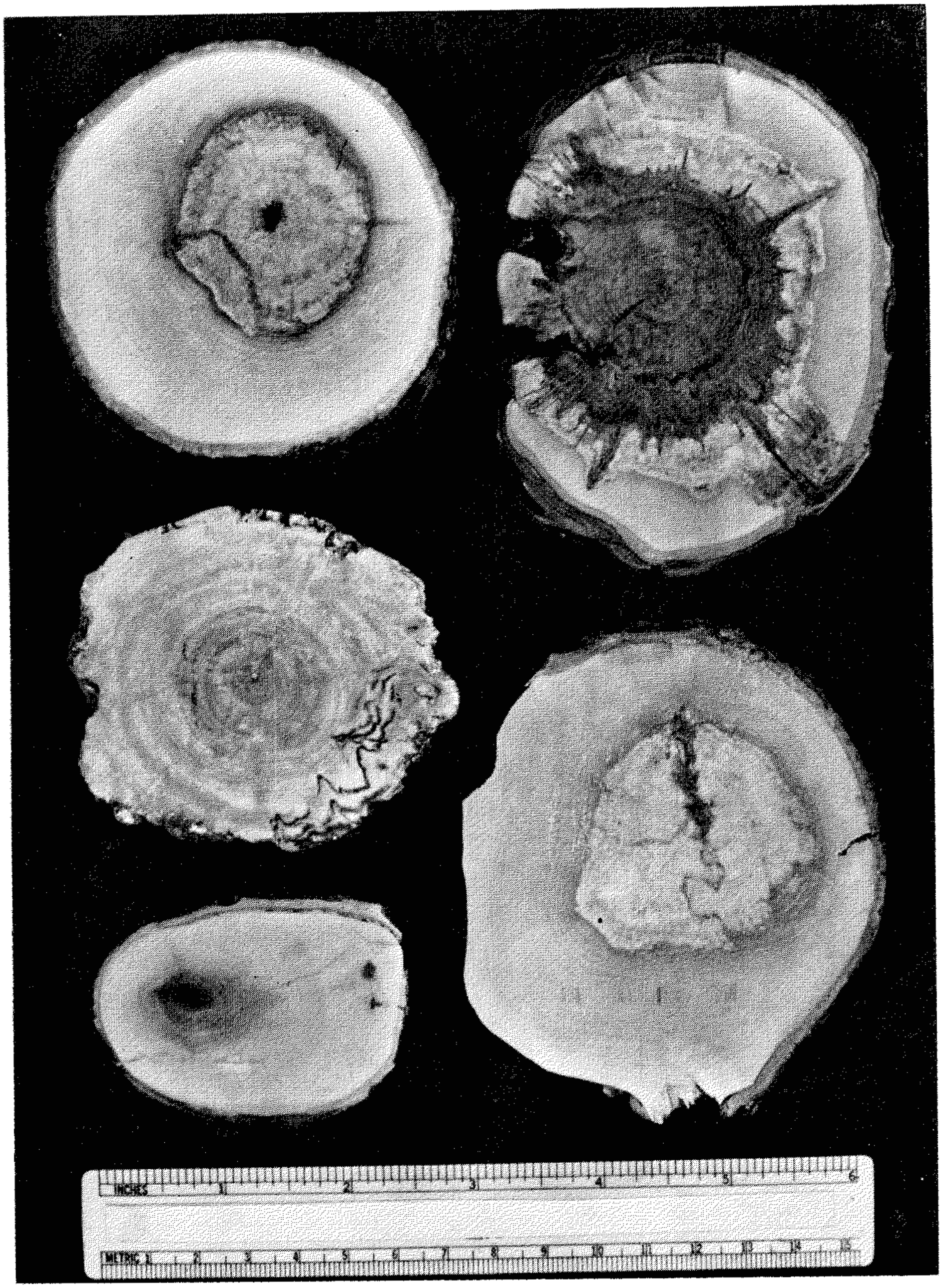

Fig. 9. Polished tree sections of *Salix alaxensis* from "Willow Valley." The three discs on the left, from top to bottom, were 59, 38 and 49 years old; the top disc on the right was 38 years old. The disc on the lower right was cut in Ruisseau Duquet, and was 50 years old.

cannot be directly compared for the different sites. Growth patterns for "Willow Valley" discs are quite variable and no direct correlation of age and diameter can be ascertained from the materials available, although it may be possible with more intensive sampling. Such information would be of limited value because the site characteristics of any stem appear to be so variable that no direct correlation would be possible. The available information indicates simply that a stem diameter of the order of 4 in. at a foot above ground level represents a growth period of 50 years. The two other discs of 3.5 in. diameter at ages of 38 years, seem to bear this out. The prominence of heartwood deterioration also suggests that a trunk diameter of 5 in. at 60 years is approaching the growth limit for the species here. It is exceptional for stems to become much larger, but in special circumstances they did grow to 8 in. The prevalence of vegetative reproduction in *Salix*, with the possibility of renewed stem growth would emphasize that the willows are probably much older than any single trunk may indicate.

The patterns of apparent ring suppression were of particular interest. Those for "Willow Valley" and Ruisseau Duquet which are 22 miles apart, correspond quite closely. Differentiated growth suppression is clearly evident for the years 1956-54, 1934-31, and 1925-24. The period 1950-54 was notably a favourable period of growth as were the years 1959-58, 1938-37, and 1920-21. The oldest discs also possessed a marked suppression period for the years between 1913 and 1910 although none of the other cores were old enough to substantiate this.

The temperature data for Cape Hopes Advance were examined for cyclic fluctuations which, if present, could be compared with the growth fluctuations of the willows in the valley. Mean monthly temperatures for May, June, July, and August were summed up and averaged from 1943 onward, the period for which data were available. The annual sums were subtracted from this average total to determine the deviations. These deviations above or below the average were compared to the growth peaks and depressions but no valid correlations were observed although the magnitude of deviation seemed significant and the values were as cyclic as the growth patterns. There are insufficient data for such a comparison but undoubtedly the major source of difficulty is that the Cape Hopes Advance records are not valid for this inland situation. The marked similarity of the growth patterns in the two separate localities prompted the attempt at correlation. The other factor to be considered is that the willows must be at their extreme climatic limit and there is little doubt that a large number of environmental factors may have a great influence on their existence and yearly growth. Thus small variations in any of these features, not just temperature, may profoundly affect growth patterns under conditions that would seem to provide the bare minimum for existence. There is however, reason to believe that more precise and more abundant ring data and climatic information might provide a clearer picture of the climatic features that are limiting and might also provide a basis for determining features of the past climate in this inland region of Ungava.

Discussion

Knowledge of the presence of this unusual arctic forest community in a region so effectively isolated from others where it would be normally established, calls forth speculation as to the reason for its existence. The descriptions of the community and its relationship to the environmental features of the site and to the gross features of the surrounding area that have been presented, permit more than a speculative discussion of the conditions that are directly responsible for its establishment, development, growth, and continuance. Some factors are more important than others in this respect.

Protection afforded by topography

Protection from rigorous climatic influences would seem to be a factor of survival and yet the reverse seems to be the case. The Murray Mining Corporation Field Report for 1962 emphasizes that the dominant winds during the winter are from the northwest which is the direction of alignment of "Willow Valley." This coincidence of exposure creates a channelling effect and intensifies wind speeds at this period. If protection from prevailing winds was the factor allowing the growth of trees, then the lack of trees in many of the deep valleys in the region that appear to offer greater protection would have to be accounted for. The unfavourable influence of strong cold winds may be effectively minimized by other factors such as an enduring protective snow cover.

The influence of aspect does not seem of importance because "Willow Valley" faces northwest and not south or southwest. The slope wood on the northeast side of the valley may be favourably situated in this respect. Geiger (1957) states that southwest-facing slopes receive the greatest intensity of insolation in mid-afternoon during summer. Ground temperatures are also higher because a greater part of the solar radiation is used in the forenoon in evaporating moisture from the top few inches of the soil. Hence it is theoretically in the afternoon that sun does its greatest work on the southwest facing slopes in "Willow Valley", provided that skies remain clear and fog does not develop, as it does near the coast, especially in August when it is frequent and dense.

Inland during the afternoon the top layers of the soil will probably be comparatively dry and thus most of the absorbed heat energy may be used in raising the ground temperature. To test these ideas ground temperatures were recorded at various places and times during the afternoons of 7, 8, and 10 July, 1962, on the northeast side (facing southwest) of "Willow Valley." There was an average ground temperature of 50°F. at 2 in. while the air temperature at 5 ft. varied from 56°F. to 71°F. This compares favourably with readings taken in a permafrost-free area, for Geiger (1957) records an average annual temperature of 9.2°C. (49°F.) at 5 cm. (2 in.) in loam in Germany. Despite the small number of measurements, they would seem to indicate a great storage of heat during the summer on the northeast slope and consequently a deep active layer above the permafrost. Unfortunately no complementary measurements could be taken on the southwest slope for comparison, because throughout the period the river was in flood and could not be crossed on foot. The asymmetrical shape of the valley would nevertheless, seem to support the theory that the depth of thaw is greater on the northeast than southwest slope, as there appears to have been greater solifluction movement on the northeast side of "Willow Valley" before stabilization by vegetation. Aspect may thus be a significant local factor in the actual location of at least a section of the thicket.

PERMAFROST AND ITS EFFECTS ON TREE GROWTH

Another factor that may have influenced the development and spread of the tall thickets is the presence of a deep active layer over the permafrost in summer, in the gravels and sands of the raised deltas and river terraces. The existence of continuous permafrost in the Asbestos Hill area has been proven by numerous drillings for the mining corporation which showed that permafrost depth is probably greater than 930 ft. Yet when pits deeper than 3 ft. were dug in the second terrace at point A and near tree disc location 2 (Fig. 2), no permafrost was encountered. The results of seismic investigations along line A-B (Fig. 2) proved that if permafrost did exist in the terrace deposits, it was more than 12 ft. below the surface. In most other valleys in the locality however, permafrost was discovered at only 6 to 12 in. below the surface in early and mid July. This was notably the case near the mouth of "Rivière à la Croix" in an area lacking tree or shrub cover. In "Willow Valley" near-surface ground ice was found only in the thick peat deposits at peat locations 1, 2, and 3 (Fig. 2) but at depths of 11 in., 8.5 in. and 2 ft., respectively.

To what extent the presence of a deep active layer is a direct consequence of the modifying influences exerted by the thickets and to what extent the condition existed before the invasion of trees, is debatable. Tikhomirov (1962) stresses the fact that the cultivation of trees in the southern tundra of the U.S.S.R. has produced a significant amelioration of the harsh microclimatic conditions. Conversely, Benninghoff (1952) in Alaska maintains that the colonization of an area by vegetation leads to a raising of permafrost level because of the insulating effects of the plants and debris during the short arctic summer. In "Willow Valley" it is probable that a deeper active layer must have existed prior to the development of the thickets, possibly as a result of the general climatic amelioration in the Arctic and the unusual local microclimatic conditions. This is supported by the statement that *Salix planifolia*, the tallest shrub in the Arctic, "is limited to areas where the deeper layers of soil remain unfrozen in an average winter." (Polunin 1940).

Although there is no proof, it is quite possible that a permanently unfrozen layer does exist in certain sites in "Willow Valley" owing to the insulating effects of very deep snow, a high storage of heat in summer, and the low susceptibility of the sands and gravels to freezing.

The presence of a deep active layer in summer has two important effects on the growth of the willows. It enables the trees to gain a sure roothold and so withstand the strong winds that occasionally attain speeds of 100 m.p.h. Tap roots were observed to have penetrated deeper than 3 ft. into the unfrozen gravel and pebbles and ensured a stable foundation. Also, despite the marked channelling of winds from the south, very few trees in the area were windthrown, even in the slope thicket. The other effect of a deep active layer is that it ensures a continuous supply of flowing water for tree roots throughout the summer. This has been stated as a necessary condition for the growth of *Salix planifolia* (Polunin 1940) and probably holds true for *S. alaxensis*.

SNOW DEPTH

The depth of winter and spring snowfall would seem to be the most important of the topoclimatological factors influencing the growth of the willows.

Polunin (1940) emphasized that *Salix planifolia* grows to a large size only in situations where the stems and branches are in part protected by a deep drift of snow. Bliss (1962) states that generally "tundra shrubs are found only where the winter snow cover prevails". Snow cover affords valuable protection to trees and shrubs during critical low temperatures and during periods of strong, often corrosive, winds. Bliss also emphasizes that, "shrub height is quite well correlated with mean winter snow depth." If this is so then it would be expected that snow accumulation would have to be extremely deep in "Willow Valley" to protect 16 ft. trees, but this is probably the case.

Unfortunately snow depth has not been measured in the valley, but in early 1962 mining camp personnel who had to trudge from Watts Lake through the snow of "Willow Valley", reported snow of considerable depth. Nevertheless, for the spring of 1961, it was recorded in the Murray Mining Corporation Report that, "the tractor train could not be used in the canyon between Watts Lake and Asbestos Hill because of rough ground and sparse snow cover." This condition was probably due to the early dispersal of snow and early break up of that year. In the same report it is mentioned that "wind sweeps across the peninsula a great deal of the time, causing the snow to pile up in large drifts in the canyons and the lee of hills".

The depth of snow in the valleys must be relatively great in the "Willow Valley" region since more than 6 ft. of snow falls annually on the plateau top, as recorded at Asbestos Hill camp. Also, the snow is of a drier type and is blown easily from the plateau tops and frozen expanse of Watts Lake by the high winds, accumulating in the 1,500 ft. depression of "Willow Valley". Heavy accumulation would occur especially on the northeast side by the slope thickets. The trees aid in this accumulation process because they trap the drifting snow, a fact of great importance in the Schefferville area of central Quebec (Matthews 1962).

Temperature influences

Weather records have been taken at Asbestos Hill mining camp (approx. 2,000 ft. a.s.l.) since 1960, although records are missing for some of the winter months. This short record indicates that temperatures on the plateau are not extreme, seldom exceeding 70°F. and rarely falling below —40°F. (McOuat *et al.* 1961). Records for 1960 and 1961 indicate a mean monthly temperature for April of 9.6°F. and for July of 48.1°F. Temperature data were collected during 1962 to compare conditions in "Willow Valley" with those of Asbestos Hill. Theoretically higher summer temperatures were expected in the valley as it is some 1,800 ft. lower than the plateau. Greater summer heat could possibly have been an important factor in the growth and establishment of the thickets.

In theory temperatures in "Willow Valley" should be approximately 5°F. higher than those at Asbestos Hill if there is a normal change of temperature of 3°F. per 1,000 ft. of altitude. When the 7 a.m. and 7.30 p.m. mean temperature differences for the sites are compared (Fig. 10) it is seen that this does not occur, there being lower temperatures in the morning (—3.5°F.) and higher temperatures (4.5°F.) in the evening in the valley. Cold air drainage into the deep valley from the plateau and valley sides at night produces a marked temperature inversion. A spectacular difference occurred on July 15 when the 7 a.m. temper-

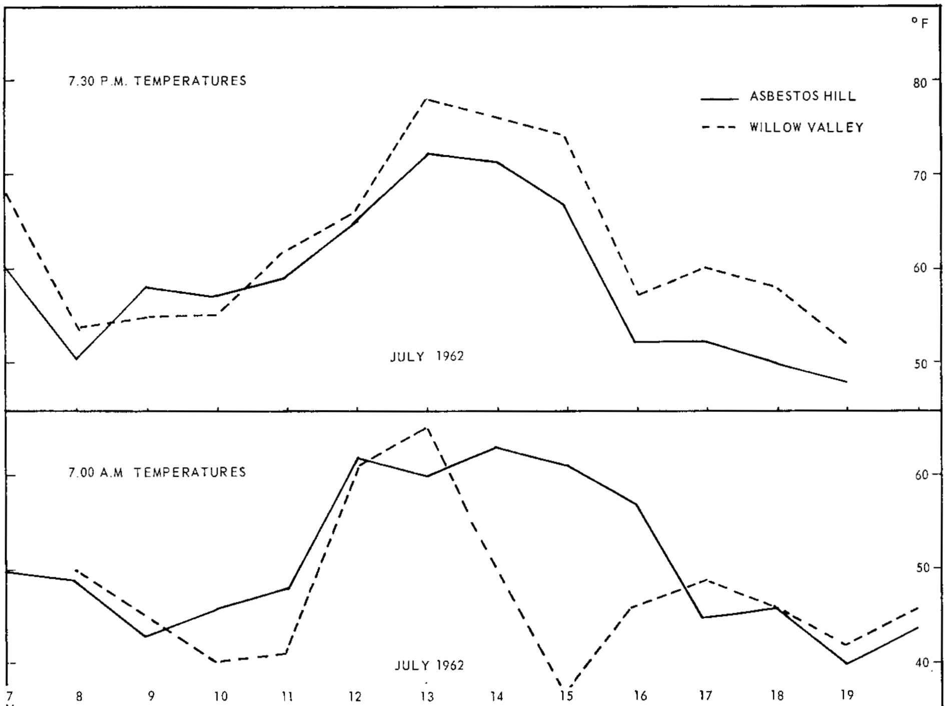

Fig. 10. Comparison of temperatures at "Willow Valley" and Asbestos Hill.

ature in the valley was only 37°F. while at Asbestos Hill it was 61°F., a difference of 24°F. Some of this reduction in temperature may have been due to microclimatic influences in the tree stand, such as cold air drainage from the crown canopy and the shading effect of the relatively dense foliage (40 per cent). In spite of these possible factors there is little doubt that general air temperatures were considerably lower in the valley than on the hill at 7 a.m.

If these temperature conditions prevail throughout the growing season then it would seem that the valley bottom would be an unfavourable site for the growth of trees, for nocturnal ground and air frosts would no doubt be more frequent than on the plateau. Nevertheless, as daytime temperatures are usually higher in the valley, this may possibly compensate for the low night temperatures and raise soil temperatures accordingly. This may be reflected in the deeper than usual active layer.

The temperatures for 1962 were probably above average, for air temperatures of over 83°F. were recorded in the valley only a few days after one of the worst snow storms of the year, on 4 July. In spite of the sudden transition from winter to summer the trees had already grown 1½ in. by 6 July and 3 to 4 in. by 13 July. Many herbs were also in bloom by this date, indicating the triggering effect of high temperatures, even for a relatively short period. The willows particularly *Salix alaxensis* flowered very heavily during July and the favourable high temperatures may have been beneficial for the production of abundant viable seed.

THE EFFECTS OF WIND

Strong winds are often cited as one of the major environmental factors that are a hazard to tree growth in subarctic and arctic regions. This factor has been held responsible for the complete lack of trees where environmental factors would seem to permit their growth. Thus if trees do exist in an arctic area it would be expected that wind velocity there would be moderate. As previously stressed, however, this is not the case in "Willow Valley" where winds up to 100 m.p.h. have frequently been experienced, the deep valley having a tendency to channel the wind, especially when it blows from the south.

That the area surrounding "Willow Valley" is extremely windy can be seen in Table V which compares the mean monthly wind speeds at Asbestos Hill and at Schefferville, in central Quebec, for the period from May to September 1961. The figures have been extracted from reports by McOuat *et al.* (1961) and Shaw (1962).

Table V. Comparison of mean monthly wind speeds in miles per hour (May to September) at Asbestos Hill and Schefferville, Quebec.

	Asbestos Hill	*Schefferville*	
	1961	1961	AVERAGE MEAN (1955-60)
May	14.2	12.0	10.0
June	14.6	11.3	10.0
July	9.4	9.8	10.4
August	17.2	11.4	10.3
September	16.6	11.8	12.3

In July 1962 when strong winds did blow, it was noticed that in the daytime temperatures were not lowered, in fact, in many instances they were raised. It would appear that the air descending from the plateau into the valley was warmed adiabatically producing a Föhn effect. In winter the effects of the winds are limited by the heavy protecting mantle of snow. There was moreover, no sign of wind influencing the level of the tree canopy which would project above the snow in winter. The uneven nature of the individual tree tops can be seen in Fig. 6. Probably the valley bottom thickets are protected from the strong southerly winds by the steep terrace edges which slope at approximately 40° and rise to more than 20 ft. (Fig. 6). That the wind has played little part in affecting tree shapes is further evidenced by the absence of any noticeable wind gap at their base and the lack of much misshapen growth or blowdown resulting from wind.

INTERRELATIONSHIPS OF LIMITING FACTORS

There is little doubt that the valley forest community barely manages to exist under the prevailing conditions although there is some evidence that even under these limiting conditions it may be extending into adjacent sections. The fact that it is subjected to the fringes of subsistence makes it difficult to select any one environmental condition as being responsible for its survival. An environmental complex is operative and it may be that many of the specific factors involved in the complex may be limiting in regard to the community. If this assumption is reasonable then it would be of great value to study the compositional and environmental characteristics of a large number of communities of this type throughout the region to gain a clearer understanding of the factors responsible. A study of initial developmental stages might well be important, because the establishment of vegetational cover itself may prove to be a factor of considerable significance in overcoming the fringe-like nature of environmental factors and allowing the community to extend itself to limits that seem impossible when viewed in relation to the prevailing ecological and climatological influences.

Of the environmental factors that seem influential in controlling the location, establishment and continued growth of the "Willow Valley" forest as it exists at present, several would seem to be particularly significant and their effects are undoubtedly collective in nature. The presence of a deeper than usual active layer and perhaps the existence in places of a permanently unfrozen layer between the active layer and the permafrost table in winter is of prime importance. These influences are undoubtedly dependent on high summer temperatures, the insulating effects of a deep accumulation of snow and the nature of the parent materials. The protective nature of the deep snow cover in winter cannot be overestimated either for its direct effect on the willows or for its indirect influences on climatic and environmental features. The availability of free flowing water during the growing season has a beneficial effect on the growth of the willows not only in providing a constant source of water and nutrients but perhaps also in producing moist aerated situations that are suitable for shrubs of this nature. These conditions are undoubtedly provided in close proximity to the stream channel and in the lower terrace sections that are often flooded.

Other factors that contribute to the successful continuance of the thickets are secondary in nature. These include the production of extensive amounts of viable seed, particularly in favourable summers such as 1962, and coupled with this the good conditions for seed germination that are provided by the soils and peats in adjacent areas which, on analysis, are shown to contain a relatively high amount of exchangeable bases. In the thickets the large number of seedlings, from both seed and vegetative sprouts, that occurred and which are spreading into adjacent areas without a shrub cover, are valid evidence of the importance of these factors, and also emphasize the influences exerted by the thicket community toward ameliorating harsh climatic conditions to give rise to favourable microclimatic situations.

The existence of high summer temperatures cannot be considered the dominant factor responsible for the "Willow Valley" forest, for if this were so it would be expected that thickets of willow would be more widespread in the deep sheltered valleys, especially along the coast where temperatures of over 70°F. were experienced at Deception Bay, Otter Lake, and Sugluk at the end of July and the beginning of August, 1962.

All the summer conditions are of great importance as their influences must be considered in relation to the growth period. The frost free period for the region is only 27 days. This is a 13-year mean for Cape Hopes Advance to the southeast. Favourable microclimatic situations may extend this complement slightly for "Willow Valley" but a growth period of 30 days would seem to be the maximum. As short a period as this is undoubtedly critical for the growth of large shrubs especially of the size of the willows involved, as a relatively large amount of photosynthetic material must be replaced annually before any growth can take place. To produce this material and then permit the growth of new twigs, leaves, and wood on the trunk, the tree, in a very short growing season, must lay down sufficient food to carry it through the year and provide for this growth expansion. In this light the existing climatic conditions are surely near borderline for growth phenomena of this magnitude. It is not unrealistic to imagine that several consecutive growing seasons of short duration, or during which sunlight might be greatly reduced or temperature levels be well below normal, could lead to a serious depletion of food reserves, to a marked reduction in growth, and perhaps even to rapid die-back of the thickets. Such an argument speaks against a single environmental factor as holding complete dominance, and supports the concept of a complex of limiting but perhaps compensating factors. The willows, their patterns of growth and their present vigorous appearance also indicate that such a hypothetical situation has not arisen, at least not within the past 60 or perhaps 75 years, and in the light of evidence to be presented below perhaps even for a much more extended period of time.

Conclusions

Significance of the *Willow Forest*

There are several important considerations in connexion with the *willow forest* of extreme Northern Ungava. The first is simply that this unusual phenomenon exists, has been discovered and described, and that others may also be available for critical investigation in the same region or elsewhere; the second is related to the extreme conditions under which the community has developed and survived, and involves an evaluation of these critical factors; the third is the significance of the forest in relation to the historical background of the region, particularly in terms of the events since Pleistocene glaciation; the last is the question of the practical value of present knowledge that might be profitably extended by a more intensive study of thickets in the region. The first two aspects have been extensively treated above and the concluding remarks are presented largely in reference to the other two considerations.

Historical significance of the community

The oldest trunks that were critically examined from the area were of the order of 60 years. Several unexamined trunks were larger and if, as is indicated from the materials available, there is a rough relationship between size and age (although this does not necessarily follow in this situation), these larger specimens may well be considerably older. Nevertheless, on the basis of the heartwood deterioration in the specimens examined it appears that an age of 75 to 100 years is maximum under the existing conditions. The presence of fallen trunks attested to this assumption. The growth habits of these willows and the evidence available from excavations that uncovered several layers of buried wood, undoubtedly of similar origin, indicate that the existence of the willow community might well have spanned a period of time much longer than 100 years. The breakage of old stems is actually a stimulus to the further production of stems, especially in the case of the genus *Salix*.

On purely theoretical grounds it might be suggested that the willow forest is a depauperate relic of a much more extensive interglacial community that has survived the effects of the glacial advances during the Pleistocene period. From geomorphological evidence, however, this would seem impossible as there is every reason to believe that the "Watts Lake-Murray Lake Trough" was glaciated intensively during the maximum of the last glaciation, although, as Matthews (1962a) points out, certain upland areas, such as the Asbestos Hill region might have remained as nunataks. A more reasonable supposition is that the forest was first established during the hypsithermal interval (between 9,000 B.P. and 2,600 B.P.) having survived the climatic changes that have occurred since that period.

The surprising stage of maturity that the community has attained in relation to the surrounding vegetation seems to point to a long period of occupation. The growth features of the willows, the presence of a relatively well developed soil layer, and the existence of buried wood layers suggests that the willows have been growing here for long periods, either sporadically or continuously. The woody layers may be the equivalent of a woody peat found on the southeast side of "Cross Creek Valley," 2 ft. below the surface of the 20 ft. terrace (above Watts Lake) and covered with alternating layers of pebbles, silt and peat. It occurs at a point where at present there is an absence of trees, thus implying a greater extent of the "proto Cross Creek" forest than that of the present thickets in the valley. As already mentioned, a similar woody peat layer and fossil soil was discovered in an ice-cored peat mound at peat location 2, (Fig. 2) in "Willow Valley." As it is usually understood that arctic peat takes a long time to form, and as more than 2 ft. of peat overlaid the woody layer, it was at first considered that the ancient forest indicated could be related to one of the older thermal maxima. That this is possibly not the case has become apparent from analyses of the pollen content of two peat deposits just over 2 ft. thick, taken at 37 ft. and 382 ft. above sea level from the southern end of Sugluk Inlet and from a radiocarbon date of 1625 $\pm$ 175 years B.P. obtained on the basal samples of peat from 382 ft. The peat was dated by Isotopes Incorporated (sample No. I-727-J.D.I.-62-2F). Seemingly both peat deposits started to form immediately after a period when pine and spruce trees grew much further north than at the present time, as in both cases the pine and spruce pollen from the basal deposits form a higher percentage of the total tree pollen than was expected for an area 300 miles north of the tree line and about 900 miles from the nearest pine forest. Moreover, the pollen diagrams indicate a marked increase in the percentage of willow pollen upwards from the base of the diagrams. In the case of the 382 ft. deposit the willow pollen is most abundant at the 8 in. level, c. 400-500 years B.P.

Although it was impossible to produce pollen diagrams for the peat of the ice-cored peat mound in "Willow Valley" there is every reason to believe that the peat started to form at about the same time as that in the Sugluk area, as a result of a general climatic deterioration. Hence it is likely that the more extensive willow forest existed 2,000 years B.P. On this basis it is possible to theorize that the thicket community first developed during the equivalent of the so-called pine period of southern Canada but achieved its greatest dimensions during the equivalent of the Middle Ages of Europe. It is equally possible that the ice free Asbestos Hill area acted as a plant refuge during the maximum of the last glaciation thereby allowing the early recolonization of parts of "Willow Valley" by arctic plants immediately following deglaciation. The existence of a well developed substrate early in post glacial times may have permitted the development of the forest community during the hypsithermal interval and the favourable climatic situation may have allowed the forest to survive subsequent rigorous climatic changes until the present. Whether or not a few spruce and pine trees actually grew in the sheltered valleys during the 'pine period' has still to be proved.

Although it might be expected that there would be a greater boreal representation among the plant occupants, such being actually expected in view of the extraordinary environmental conditions, even before relict status was considered, this in no way invalidates the above thesis. Boreal elements, in fact, could well have been decimated in unfavourable climatic periods during the interval since the xerothermic, or simply replaced in competition by the tundra species that seem to be flourishing in the present environment. If boreal species were reduced in number reinvasion may be an extremely slow process even if conditions were currently favourable because, for one thing, all of the rivers in the intervening region to the present treeline flow in a southward direction. The communities are also so small and scattered that even if propagules were entering the region with considerable frequency, their chances of falling on favourable ground in the thickets would be very slight.

Practical considerations

The "Willow Valley" site represents a rather unique ecological situation and one that may yield much profitable information of practical value. The existing vegetation is considerably advanced in maturity in relation to the immediate surroundings. The site and the ecosystem involved are perpetuating and perhaps extending a complex group of environmental influences that may eventually permit the establishment of plants of a more boreal nature. The area should be resurveyed at intervals to determine whether the structural and floristic features developed during at least the past hundred years have advanced beyond what at present is to be found. Such information, whether it will indicate advancement or degradation, would be of significance in formulating long term climatic changes in northern Ungava. The degree to which the scope of such a project could be expanded into adjacent areas would determine the extent of useful climatic indices produced. Protection of the communities involved would have to be assured.

Because of the marked increase in growth of the tree-like willows during the 1930's and 1940's, and their spread on to the surrounding tundra, the thicket community would seem to support the idea that since the end of the nineteenth century arctic Quebec has experienced a climatic amelioration similar to that in Labrador (Wenner 1947) and other parts of the Arctic. Wenner graphically showed that the mean annual temperature at Hebron, Nain, and Hopedale, on the Labrador coast, has risen steadily since the turn of the century. In fact he calculated that at Nain the mean annual temperature rose 2°C. (3.5°F.) between 1883 and 1938. This was held responsible for desiccation of many swamps in Labrador and the invasion of such by more xerophilous vegetation, while in the Kaumajet mountains glacierettes have retreated. Similar proof of this climatic change in northern Quebec is the occurrence of a cirque glacierette, approximately halfway between Sugluk and Cape Wolstenholme, which shows evidence of recent retreat from its 6 ft. high terminal moraine. The recent nature of this retreat is attested to by the lack of vegetation, except extremely small lichens (*Rhizocarpon geograficum*), on the morainic material.

It is noteworthy that North American workers have not been specifically concerned with the quantitative investigation of arctic and subarctic thicket communities, and the factors responsible for their existence. The Russian literature abounds in sporadic reports of relic forest or thicket stands north of the treeline (Chugunov 1955; Tikhomirov and Shtepa 1956; Tikhomirov 1957; Starikov 1961; Tikhomirov 1962). Although many of these are simple factual reports of their existence, some appear to have looked critically at the reasons for their disjunct occurrence. Almost all are described as relicts although it is not clear that all are considered as phenomena of past climatic or vegetational optima, and doubtful if all may be explained on this basis. It is important that interest in these communities is developing elsewhere in arctic regions even if so far the desire is chiefly to learn of their distribution and frequency.

Several research workers in North America have attempted to deduce vegetational trends in relation to past or present trends in climatic features, from studying features of vegetation, particularly treelines (Griggs 1934; Marr 1948). Most investigators, however, seem to have forsaken such straightforward methods and are pursuing the more elaborate studies of pollen analysis and radiocarbon dating. It would seem reasonable to begin relating some of these latter measurements to critical quantitative ecological studies of the vegetation that sits on top of these stratified features, and to remember that vegetation represents the present capabilities of a group of plants of coping with a set of past and present circumstances.

Lastly, it is worth considering the practical value of understanding the climatic features responsible for the growth of thicket vegetation of this type. A knowledge of the threshold limits might permit the establishment, by artificial means, of thicket communities that might survive and flourish in the favourable microclimate that they would produce. This would be a valuable practical tool to enliven the immediate environments of towns and villages established as a result of colonizing the North.

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