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ECOLOGICAL CHARACTERIZATION OF SOME SELECTED VASCULAR SPECIES IN THE ARCTIC ENVIRONMENT OF NY-ÅLESUND, SVALBARD, IN RELATION TO SOIL MOISTURE CONDITIONS

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Abstract: An attempt has been made to characterize and categorize some selected vascular species in the Ny-Ålesund area, Svalbard, in relation to soil moisture conditions. A total of sixty relevés were established to describe the floristic structures of plant communities. At each relevé site, one soil core sample in a 100 m*l* metal container was collected to determine soil physical properties. Samples were oven-dried for 48 hours at 105°C. Moisture content was measured and soil moisture index was calculated for each relevé. Based on the index, sixty relevés were divided into five soil moisture classes. Throughout the sixty relevés, twenty-five species of vascular plants were recognized. Of them, eleven species were selected for this study. They were *Salix polaris, Oxyria digyna, Polygonum viviparum, Cerastium arcticum, C. regelii, Saxifraga caespitosa, S. cernua, S. nivalis, S. oppositifolia, Dryas octopetala*, and *Cassiope tetragona*. These were the species that occurred in more than eleven relevés out of the sixty. Their frequencies against the soil moisture classes were counted. Ecological distribution curves were constructed for the species. From the distribution pattern, especially the amplitude and the mode position on the moisture classes, the species were classified into six categories as follows, *i.e.*, euryhygrotopic xerophyte, euryhygrotopic mesophyte, euryhygrotopic hygrophyte, stenohygrotopic xerophyte, stenohygrotopic mesophyte, and stenohygrotopic hygrophyte.

key words: arctic plants, ecological characteristics, soil moisture, Svalbard, vascular plants

Introduction

In the Arctic, where the environment is extremely harsh (SAVILE, 1972; BILLINGS, 1974; BLISS, 1988; STONEHOUSE, 1989), *in situ* occurrence of plants is very much regulated by subtle environmental conditions such as microtopography, slight differences of availability of soil nutrients, soil water, soil aeration, amount and duration of snow stay, and so forth. Although in the Arctic, the flora of vascular plants is generally simple with a relatively small number of species, occurrence of species is determined in a complicated way by local habitat conditions. As a result, arctic vegetation varies substantially from place to place,

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even in a short distance, reflecting complex microenvironmental conditions and responses of the component species.

Regarding the ecological distribution of vascular species, a number of attempts have been made, mostly in temperate regions, to determine distribution patterns in relation to habitat conditions (ELLENBERG, 1950, 1953; AICHINGER, 1967; see MULLER-DOMBOIS and ELLENBERG, 1974, for more details). In the Arctic, however, not many studies have been conducted along this line. HARTMANN (1980) described vegetation types of Spitzbergen and discussed, in very general terms, species distribution in relation to soil conditions. SOHLBERG and BLISS (1984) studied the distribution of arctic plant communities on King Christian Island, Canada, and found that microenvironment was a decisive factor in species distribution. ELVEBAKK (1985), studying the phytosociology of Svalbard, recognized that the ecological distribution of vascular plants was closely regulated by soil chemistry in relation to topography. DAWSON and BLISS (1987) also studied salt marsh vegetation in the Truelove Lowland, Devon Island, Canada, and revealed that soil salinity and water potential regulated species distribution. All these studies, however, described relations in general terms. RAZZHIVIN (1995) studied the vegetation of far northeastern Asia, mostly the Chukotka Peninsula and the area just west of it, in Russia, demonstrated the ecological distribution of arctic vascular plants along with a soil reaction (pH) gradient and classified species into seven categories based on their response to soil pH. MINAMI *et al.* (1996) studied the ecological distribution of bryophytes in Ny-Ålesund in relation to soil chemical characteristics and recognized that occurrences of such bryophytes as *Hylocomium splendens, Rhacomitrium lanuginosum, Pottia heimii*, and *Bryum cryophilum* were regulated by soil chemistry.

The present study examines how arctic plants are distributed along a soil moisture gradient, taking some selected vascular plants occurring in Ny-Ålesund, Svalbard, as examples. It also attempts to categorize and characterize them according to their ecological distribution pattern in relation to the soil moisture condition.

Study Area and Its General Environmental Characteristics

The study area is located near Ny-Ålesund, Spitzbergen Island, northwestern Svalbard (Fig. 1). It is approximately 5–10 km northwest of the old coal-mining town Ny-Ålesund, and immediate west of Rabben (78°55′ 80″N, 11°52′11″E). The elevation ranges roughly from 0 to 50 m above sea level. Climate is typically oceanic arctic with a mean July temperature of 4.7°C at Ny-Ålesund and generally 200–400 mm of annual total precipitation for Svalbard (ELVEBAKK and SPJELKAVIK, 1995). Fog is frequent due to proximity to the ocean.

The geomorphology of the area is basically a confluent glacial outwash plain of the West Brøgger Glacier and the South Brøgger Glacier. Terrain configuration is rolling and gently undulating (Fig. 2). Landforms include colluvial talus, lateral and terminal moraines, glacial outwash, glacial fluvial, and some alluvial sand bars. Soil texture is very variable, from extremely coarse gravelly on lateral moraine to extremely fine in the fluvial deposits. Geology is dominated by Carboniferous and Permian sedimentary sandstone, and calcareous and dolomitic substrates. Reddish mid-Carboniferous sandstone near the Brøgger Glacier and reddish meltwater from it is noticeable (HJELLE, 1993).

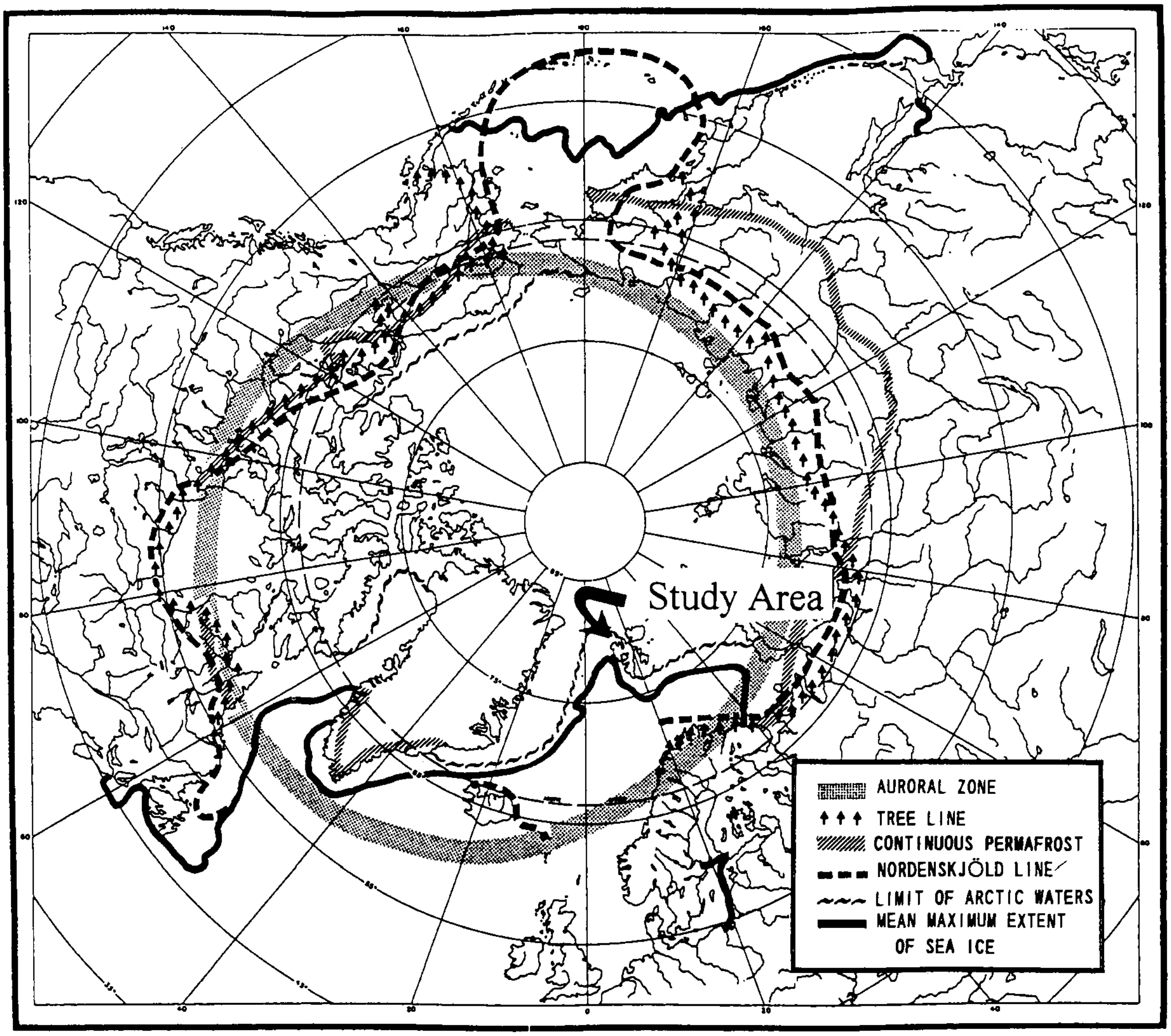

Fig. 1. A circumpolar map showing the study area and general environmental characteristics of the Arctic region (Base map from SATER, 1969).

Permafrost is extensive as the study area belongs to the continuous permafrost zone (SATER, 1969). Soils are poorly developed due primarily to the relatively young stage of development after deglaciation and intense cryoturbation. Horizon differentiation is not discernible in most soils in the area. Most soils observed were Regosolic (Turbic or Static) Cryosols.

Vegetation is represented by poorly developed arctic tundra. Cover of vascular plants is low and a vast area is almost devoid of vegetation. *Saxifraga oppositifolia, Salix polaris*, and *Cerastium arcticum* are the most commonly occurring vascular plants. Vegetative cover of cryptogams, however, may often reach as high as 100%, particularly in mature plant communities.

Methods and Procedures

Vegetation sampling

A relevé (sample plot to describe plant community structure) of 2×2 m quadrat was

Fig. 2. General landscape of the study area showing a large outwash plain in the foreground and the South Brøgger Glacier in the background (photo by S. KOJIMA, 1997).

Table 1. Domin-Krajina's cover classes (KRAJINA, 1933).

Class	Description
+	solitary, very low dominance (0–1% of the relevé)
1	seldom, very low dominance (1–2% of the relevé)
2	very scattered, low dominance (2–3% of the relevé)
3	scattered, low dominance (3–5% of the relevé)
4	covering 5–10% of the relevé
5	covering 10–20% of the relevé
6	covering 20–33% of the relevé
7	covering 33–50% of the relevé
8	covering 50–75% of the relevé
9	covering 75–99% of the relevé
10	overwhelming dominance, covering 100% of the relevé

employed to describe vegetation. After an extensive reconnaissance of the area, relevés were established. The relevé sites were chosen to represent as many different kinds of plant communities of the area as were distinguishable. All the vascular plants in a relevé were recorded and their cover was assessed in Domin-Krajina cover classes (Table 1). For vascular plants which were difficult to determine in the field, specimens were collected.

They were later determined in the laboratory. Epithets basically followed RONNING (1996). HULTÉN (1968) was also occasionally referred to.

Soil sample collection and physical property analyses

At each relevé site, soil samples were collected for determination of physical properties. For analyses of physical properties such as water content, bulk density, and three-phase determination, a soil core sample was collected. A metal core container of 100 ml volume was gently but firmly pressed to the soil surface and inserted to depth of approximately 10 cm using a core extractor. Care was taken not to disturb the natural soils conditions as much as possible. The samples were to represent natural physical conditions of the rhizosphere at collection time. Cores were lidded and tightly sealed with cellophane tape. They were weighed fresh and then oven-dried for 48 hours at 105°C. After drying, they were immediately reweighed to obtain the weight loss, which indicated the water content.

Soil physical properties were calculated by the following formulae:

$$Mc = Wf - Wd$$
$$BD = Wd/100$$
$$Sc = Wd/2.65$$
$$Ps = 100 - Sc$$
$$Ac = 100 - (Mc + Sc).$$

where Ac: air content (volume %); BD: bulk density of soil; Mc: moisture content (volume %); Ps: pore space (volume %); Sc: soil solid content (volume %); Wf: fresh weight of soil (g); and Wd: oven-dried weight of soil (g).

Soil moisture index (Mi) was calculated to express the moisture status of the habitat based on moisture content and pore space. It was a measure of soil moisture status in the sense of how much pore space was actually filled by water in the field condition. It was calculated as follows:

$$Mi = (Mc/Ps) \times 100.$$

Mi ranges from 0, where there is no water at all in the soil, to 100, where the soil is completely saturated with water. Moisture indices were calculated for all the samples representing the relevés.

Results and Discussion

Distribution of moisture index of all the relevé sites

A total of 60 relevés were established throughout the study area. The moisture index of all the relevé sites was calculated. It ranged from 29 to 100 with an average of 67.5. The moisture indices were divided into five soil moisture classes. The relevé sites were divided and grouped so that the moisture indices were more or less distributed in a bell-shaped curve. Then the moisture classes (SMC) were determined as follows: SMC 5: Mi more than 95; SMC 4: Mi 95–78; SMC 3: Mi 77–60; SMC 2: Mi 59–42; SMC 1: Mi less than 41. Frequencies of moisture indices of the 60 relevé sites were plotted against the SMCs. They showed a curve almost like a normal distribution when they were connected with a spline (Fig. 3).

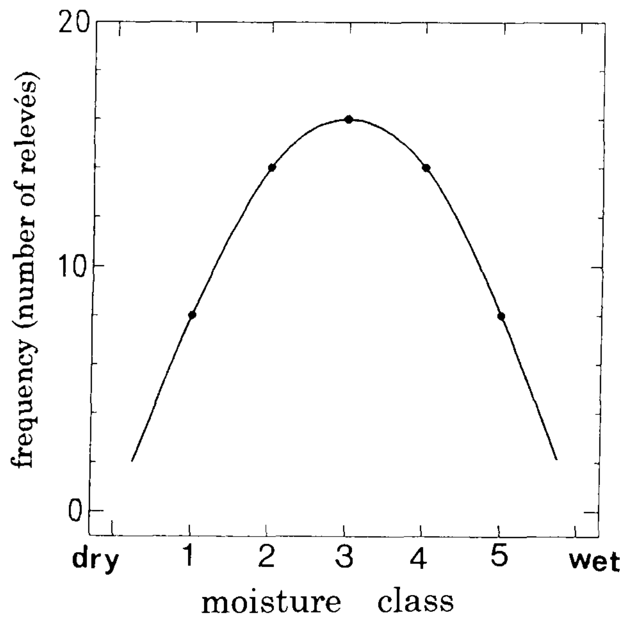

Fig. 3. Frequency distribution of the sixty relevés against the soil moisture classes.

Ecological amplitudes of the selected species

A total of twenty-five species of vascular plants were recognized through the 60 relevés (see Appendix). Out of them, eleven species were selected for constructing ecological distribution curves along a soil moisture gradient. They were *Salix polaris, Oxyria digyna, Polygonum viviparum, Cerastium arcticum, C. regelii, Saxifraga caespitosa, S. cernua, S. nivalis, S. oppositifolia, Dryas octopetala*, and *Cassiope tetragona*. These species occurred in more than eleven relevés out of the sixty. This was, so to speak, the minimum number of relevés needed to draw a frequency curve. For each species, an ecological distribution curve was constructed based on a number of relevés at each soil moisture class. It was a spline curve connecting the frequencies at each soil moisture class and extending beyond actual soil moisture classes to the ordinate values of zero at both ends. Such a spline curve showed schematically each species' ecological amplitude and distribution pattern along the soil moisture gradient. The freqency distribution curve of all the 60 relevé sites was overlaid on the ecological distribution curves to show graphically how each species corresponded, or not, to the whole moisture distribution of the study area. Figure 4 presents the ecological distribution curves of the eleven species.

Ecological characterization of the selected species

Ecological amplitudes of species along a certain environmental gradient greatly vary from species to species. Some have a broad amplitude while others are narrow. Krajina (1969) attempted to categorize ecological characteristics of forest trees of British Columbia, Canada, based on their amplitudes to soil nutritional status.

Figure 5 is a conceptual scheme illustrating and categorizing ecological characteristics on the basis of species' response to soil moisture gradient (hygrotope). Species were classified into two broad categories, *i.e.*, euryhygrotopic and stenohygrotopic. The former is a species possessing a broad amplitude with respect to the soil moisture gradient and the latter is the one with a narrow amplitude. Each category is further divided into three

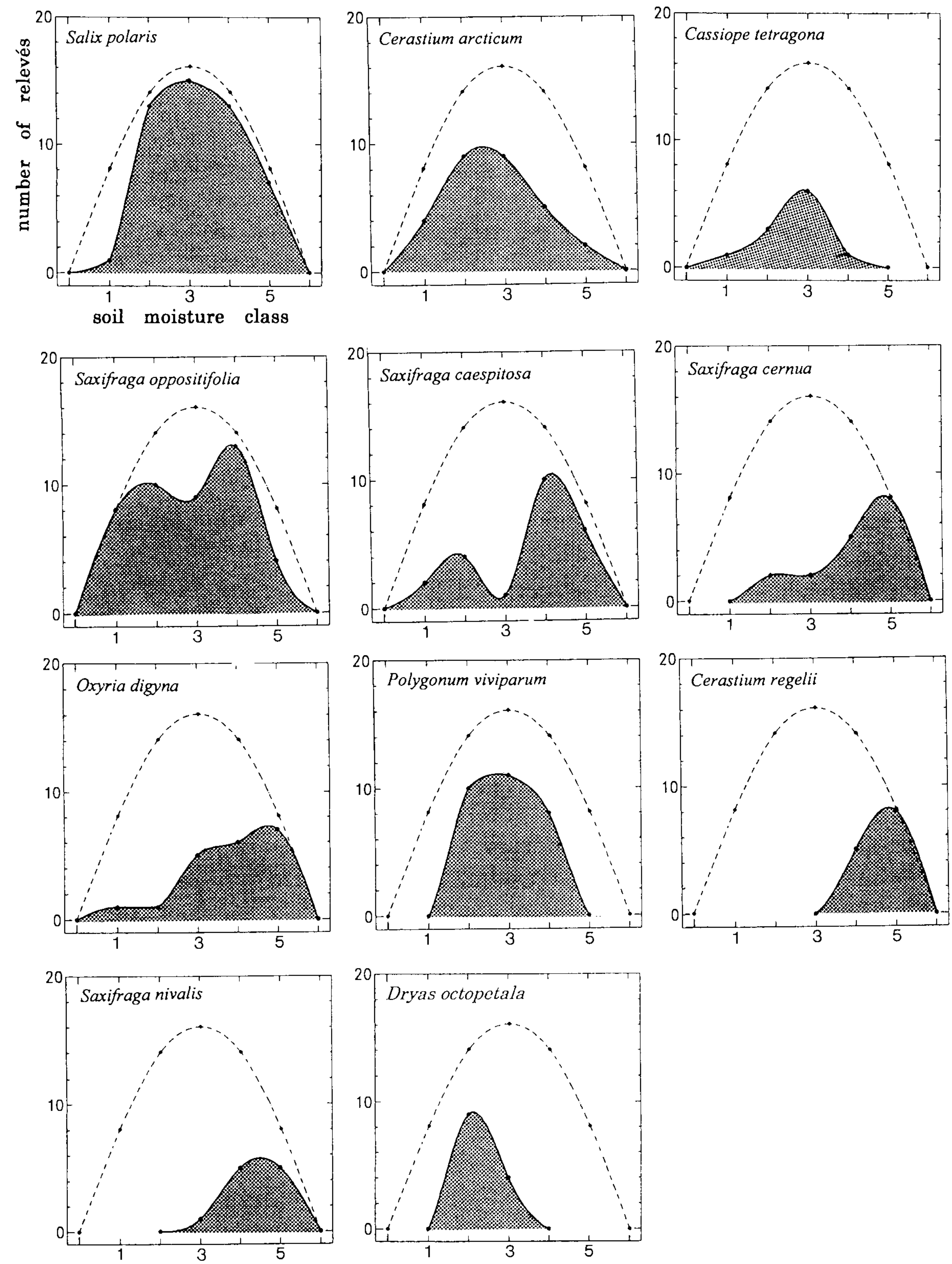

Fig. 4. Ecological distribution of the eleven species against the soil moisture classes. The vertical axis represents the number of relevés containing the particular species and the horizontal axis the soil moisture classes. A broken curve indicates frequency distribution of all sixty relevés. Soil moisture class 5 represents the wettest habitats while class 1 the driest habitats.

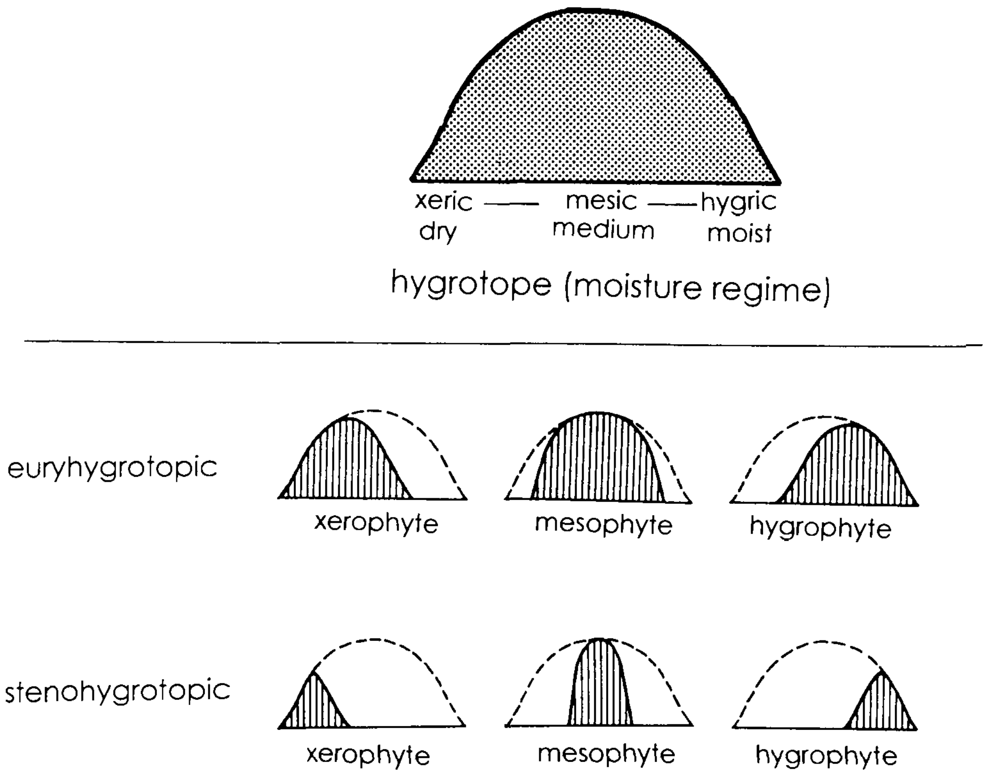

Fig. 5. A conceptual scheme illustrating a classification of species based on the ecological amplitudes in relation to soil moisture condition.

groups, *i.e.*, xerophyte, mesophyte, and hygrophyte, based on the position of their mode. A xerophyte is a species with a mode at the dry position on the moisture gradient, a mesophyte is one with a mode at an intermediate position, and a hygrophyte is one with a mode at the wet position on the gradient. By combining the two characteristics, *i.e.*, width of amplitude and mode position, species can be classified into any one of the six categories shown in Fig. 5.

The above-mentioned eleven species were classified into six categories. In this study, "euryhygrotopic" included those species with amplitude covering more than three soil moisture classes while "stenohygrotopic" was those with amplitudes covering less than three classes. Xerophyte was species with a mode at SMC either 1 or 2: mesophyte was those with a mode at SMC 3: and hygrophyte was those with a mode at SMC 4 or 5. Table 2 presents the classification of the eleven species. This classification fits the occurrence pattern in the field and, therefore, accords to the field observations.

There were some species which showed a bimodal distribution such as *Saxifraga caespitosa* and *S. oppositifolia*. The reason for the bimodality cannot be well explained. Three hypotheses may be supposed: 1. haphazard incidence due to sample size, 2. competition with other species, and 3. mingling of two different ecological races. In case 1, such a bimodal distribution may disappear if sufficient samples are included. In the second case, much more aggressive species might have suppressed occurrence of the species at the depressed position. In the third case, two genetically different populations may occur together but show different responses to the soil moisture gradient. In this case, it is possible that factors other than soil moisture might produce the bimodal distribution.

Table 2. A summary table of ecological classification of the selected species.

	Xerophyte	Mesophyte	Hygrophyte
Euryhygrotopic		*Cassiope tetragona* *Cerastium arcticum* *Salix polaris*	*Saxifraga oppositifolia* *S. cernua* *S. caespitosa* *Oxyria digyna*
Stenohygrotopic	*Dryas octopetala*	*Polygonum viviparum*	*Cerastium regelii* *Saxifraga nivalis*

The real reason, however, cannot be known at this stage.

Concluding Remarks

The vascular flora of the study area is rather simple. In all of Svalbard, RONNING (1996) recognized only 171 species. And yet, their ecological distribution and habitat segregation are quite intricate; some inhabit extremely dry habitats such as rock outcrops and coarse gravel heaves, others on extremely poorly-drained water-saturated habitats, and some even in shallow stagnant waters. At the same time, some species exhibit relatively generous amplitude while others have fairly rigid habitat requirement. From our observations, *Draba nivalis, Carex misandra* and *Dryas octopetala* tend to occur in well-drained xeric habitats, while *Cerastium regellii, Saxifraga nivalis*, and *Poa hartzii* grow in poorly-drained habitats. *Cassiope tetragona* seems to represent more or less mesic habitats. There are some species which have generally broad amplitude occurring in a wide range of moisture conditions. They are *Oxyria digyna, Saxifraga oppositifolia, S. caespitosa*, and *S. cernua*. The ecological characteristics of species generate diverse plant community differentiation in field conditions and consequently determine the physiognomical characteristics of the vegetation. In the present study, only soil physical properties, in particular, soil moisture condition or conversely soil aeration, were taken into account to explain species distribution. In this study, soil moisture conditions were more or less normally distributed, *i.e.*, soil samples were concentrated in mesic conditions and, therefore, the number of extremely dry and moist soils was decreased. Such a variation of soil moisture may be primarily attributed to microtopography and partly to soil texture. Needless to say, however, soil chemistry is also important. It is necessary to incorporate chemical characteristics so as to obtain more holistic figures regarding the ecological distribution of the species and vegetation differentiation.

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Appendix

List of vascular plants recognized in the sixty relevés. Species are arranged in alphabetical order of generic and specific names. Family names are shown in parentheses.

1. *Cardamine bellidifolia* L. (Cruciferae)
2. *Carex misandra* R. BR. (Cyperaceae)
3. *Cassiope tetragona* (L.) D. DON (Ericaceae)
4. *Cerastium arcticum* LGE. (Caryophyllaceae)
5. *Cerastium regellii* OSTENF. (Caryophyllaceae)
6. *Draba nivalis* LILJEBL. (Cruciferae)
7. *Dryas octopetala* L. (Rosaceae)
8. *Equisetum arvense* L. (Equisetaceae)
9. *Equisetum scirpoides* MICHX. (Equisetaceae)

10. *Luzula arctica* BLYTT (Juncaceae)
11. *Luzula confusa* LINDEB. (Juncaceae)
12. *Lycopodium selago* L. (Lycopodiaceae)
13. *Minuartia rossii* (R. BR.) GRAEBN. (Caryophyllaceae)
14. *Oxyria digyna* (L.) HILL (Polygonaceae)
15. *Papaver dahlianum* NORDH. (Papaveraceae)
16. *Poa arctica* R. BR. (Graminae)
17. *Poa hartzii* GAND. (Graminae)
18. *Polygonum viviparum* L. (Polygonaceae)
19. *Salix polaris* WAHLENB. (Salicaceae)
20. *Saxifraga caespitosa* L. (Saxifragaceae)
21. *Saxifraga cernua* L. (Saxifragaceae)
22. *Saxifraga nivalis* L. (Saxifragaceae)
23. *Saxifraga oppositifolia* L. (Saxifragaceae)
24. *Silene acaulis* L. (Caryophyllaceae)
25. *Stellaria crassipes* HULT. (Caryophyllaceae)