THE REAL ARCTIC: SUGGESTIONS FOR ITS DELIMITATION, SUBDIVISION AND CHARACTERIZATION*

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(With one Figure in the Text)

Delimitation

Although in the biological sciences satisfactory definition is often difficult or even impossible, that is no excuse for not attempting to be precise. A bad blot in the literature is the persistent vagueness surrounding the use of the term 'arctic', whether it be employed in the adjectival form (in which case it is not now customary to capitalize the initial letter) or as a substantive implying a region, viz., the Arctic. It is common for an author to term a plant (or its range) arctic when it reaches an area which according to his conception (or mere copying) constitutes part of the Arctic; but what this last is, where it begins or ends, evidently varies greatly in different authors' minds. Indeed the concept has come to be little more than relative, and, consequently, of limited value at best or, at worst, dangerously misguiding. Accordingly it seems necessary to attempt a precise (and as far as possible concise) definition or at least delimitation of the Arctic as a region, variable though it is in character in different component parts, and to exclude from citation as truly arctic those entities which are not known to reach it.

Unfortunately such single criteria as the Arctic Circle, which in theory governs the presence or absence of 'midnight sun', are practically useless for our purpose and indeed are apt to be seriously misleading. Nor is the common conception of the Arctic as a 'cold desert' particularly helpful or even sound: for although the total precipitation is commonly of the order of magnitude of that of some deserts, the relative humidity is high and evaporation slight. With the usually hard-frozen subsoil to support surface moisture in summer, the land in many flat areas tends to be swampy and even in drier ones to be embellished every summer with flowers as well as an abundance of mosses and lichens—which is scarcely in conformity with our ideas of a desert!

Without attempting to lay down the law in any respect—and indeed in the belief that my efforts will be improved upon hereafter—I am prompted by special needs and requests, following field experience in many and various arctic and subarctic areas extending over more than twenty years, to propose a set of tentative criteria for delimiting the truly arctic region from those lying to the south. At least I have used these criteria in effecting a delimitation for the purpose of my own work and deductions, following much consideration and consultation; and although suspecting that in time increased knowledge of local flora, precipitation, total heat, and the incidence of frosts as well as the combination of wind and cold known as 'windchill' will add solidity to the picture, and knowing full well that increased local knowledge will add to its precision, I have come to accept as truly arctic only certain areas of land, fresh water, and adjacent sea. These are in general those

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that lie north of whichever of the following is situated farthest north in each sector of the northern hemisphere: (1) a line 80 km. (50 miles) north of the northern limit of coniferous forest or at least more or less continuous *taiga*, i.e. terrain with sparsely scattered trees; (2) north of the present-day northern limit of at least microphanerophytic growth (i.e., of trees 2–8 m. in height but excluding straggling bushes in unusually favourable situations), the northern extremities of tongues or outliers separated by not more than fifteen degrees of longitude being united across; or (3) north of the northern Nordenskiöld line, which is determined by the formula $V = 9 - 0{\cdot}1K$, where V is the mean of the warmest month and K is the mean of the coldest month, both in degrees Centigrade. This last is an empirical line which, however, seems an improvement at least on the old 10° C. (50° F.) isotherm of the warmest month as it gives some consideration also to other temperature aspects.

In the restricted sense to which it seems desirable to limit the term, the Arctic is thus the region lying to the north-poleward of an imaginary but by no means meaningless line. Its character is too impossibly complex and infinitely variable from place to place to define scientifically, at least in our present state of ignorance: but in general it may be said to be treeless, with the winters largely dark and cold and the mean temperature of the warmest month *plus* one-tenth of the mean of the coldest month over a cycle of years not more than 9° C., with high windchill and less than 50 days between spring and fall frosts, with the subsoil in most places permanently frozen and frost-heaving and allied phenomena important, with an annual precipitation normally below 500 mm. (19·8 in.) and largely in the form of snow which drifts and is packed tightly by the wind, with the soils generally moist in summer but the air of low absolute humidity, and with sheltered salt as well as fresh water frozen over for much of the winter. But still there are some exceptions of areas which fail to comply in one or two respects but from general consideration seem for the time being best included within the arctic region.

In the accompanying circumpolar map I have attempted to indicate (by dots) the northern limit of coniferous tree growth exclusive of minor outliers, so covering much of the basis of the first criterion previously mentioned and also of the second except in some places where arborescent dicotyledonous growth occurs. I have also indicated the Nordenskiöld line (by long dashes), with some modification in a very few places to include anomalous areas. The arctic region is then taken as starting immediately north of whichever of these resultant lines lies the farthest north on any meridian, this boundary line being smoothed out (by alternate dots and short dashes) where tongues or outliers suggest that it should be, or similarly modified in accordance with other considerations such as special knowledge of local conditions.

SUBDIVISION INTO SECTORS

For purposes of phytogeographical citation it has been found convenient to divide the arctic region so delimited into ten sectors ranging eastward as follows: (I) from 10° W. to 40° E. longitude, including Jan Mayen, Bear Island, and the Spitsbergen Archipelago; (II) from 40° E. to the midwaters of the gulf of Ob, i.e. about 73° E. longitude, so including the Franz Josef Archipelago and Novaya Zemlya and the islands and northernmost mainland lying to their south; (III) from the midwaters of the Gulf of Ob to Anabar River, i.e. about 113° E. longitude; (IV) from the Anabar to near the mouth of Kolima River,

i.e. about 162° E. longitude; (V) from near the mouth of the Kolima to Bering Strait in about 169° W. longitude but excluding St Lawrence Island; (VI) from St Lawrence Island and westernmost Alaska to the north-eastern extremity of Yukon Territory, i.e. about 136° W. longitude; (VII) western arctic Canada extending eastward to a line starting in the south just west of the west coast of Hudson Bay in latitude 60° N., skirting the heads of

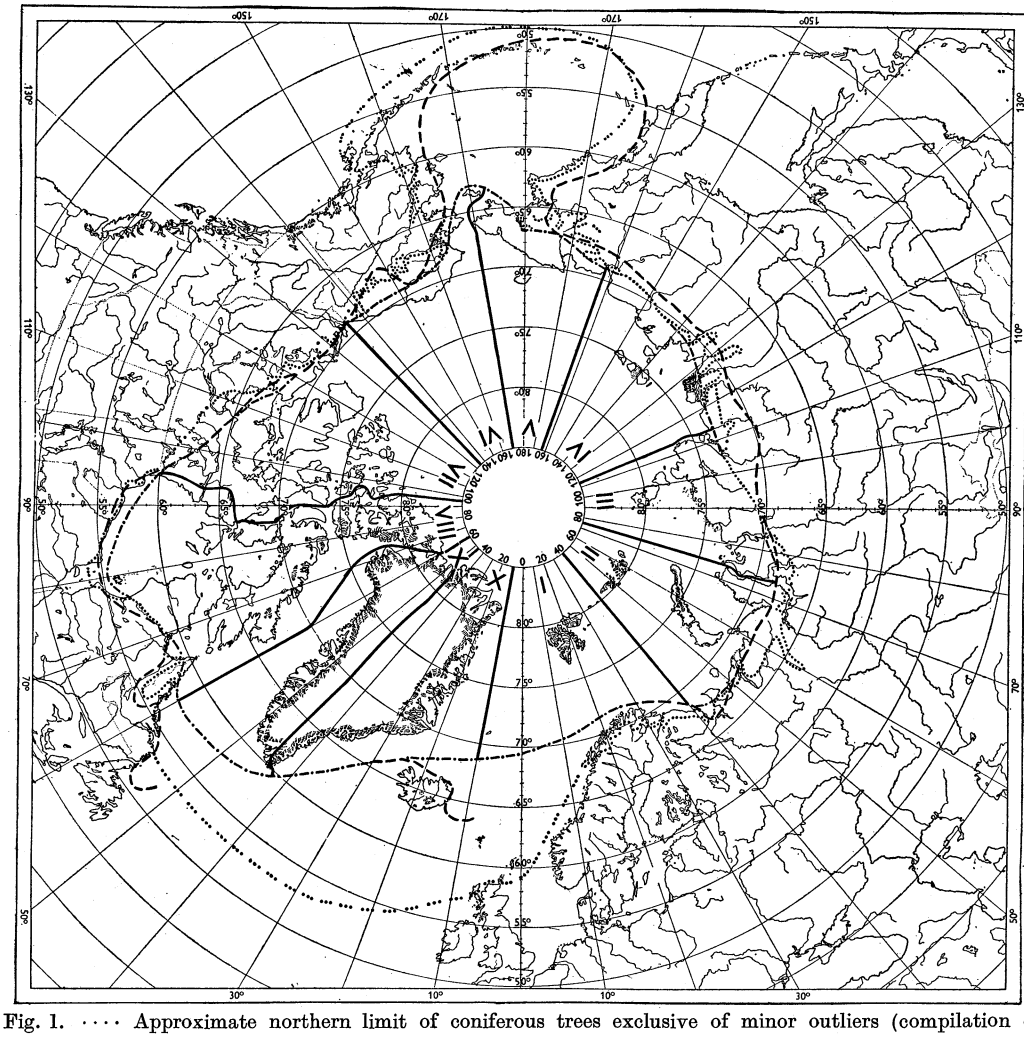

Fig. 1. ···· Approximate northern limit of coniferous trees exclusive of minor outliers (compilation of N. Polunin up to June 1950. Gaps around single dots, or dots in groups of three, indicate that trees are absent locally. ---- Nordenskiöld line (compilation of F. K. Hare up to June 1950) slightly modified. ·–·– Southern boundary of arctic region when not given by either of above criteria. —— Meridional boundaries of the ten arctic sectors (indicated by Roman numerals).

Dawson and Rankin inlets and of Wager Bay before running overland to Committee Bay, and proceeding north through the midwaters of Prince Regent Inlet and Wellington Channel and Belcher and Sverdrup channels; (VIII) the Canadian Eastern Arctic comprising the remainder of arctic Canada and hence including the whole of Melville Peninsula and Ellesmere, Axel Heiberg, Devon, Baffin and Southampton islands; (IX) West Greenland including the islands of the extreme south, and the north coast eastward to the

midwaters of Victoria Fjord (about 46° W. longitude); (X) East Greenland comprising the remainder of that great land-mass. The sectors are indicated on the accompanying map, though only approximately in some cases (especially the division between VII and VIII).

It would seem unwise to accept as truly circumpolar any entity that is not known to occur in each of these ten sectors, even as it would seem incorrect to consider as truly arctic any that does not extend north of the above-described limit.

ARCTIC VEGETATIONAL ZONES

Even in our restricted sense, the Arctic is a vast and variable region; and now that we have ventured to propose some means of delimitation and geographico-longitudinal subdivision, albeit very tentatively and for our own purposes, it seems desirable to attempt a biologico-latitudinal subdivision into what may be termed low-arctic, middle-arctic, and high-arctic zones for vegetational characterization.

Let us first consider the middle-arctic zone which extends around the world between the other two. It may be exemplified by much of central Novaya Zemlya or the northernmost parts of the mainland of Siberia, by central and northern Baffin Island, or by Greenland around the seventieth parallel. Its latitudinal limits, like the southern boundary of the Arctic as a whole, vary widely in different sectors with varying climatic and other local conditions, but it is in general adequately characterized about its centre. At sea the water during peaks of photosynthetic productivity may be coloured to the extent of being almost soupy-brown with diatoms etc., and the ice-pans are apt to be dirty-looking or pinkish owing to the growth of various Algae including sometimes quite sizable colonial forms. Near shore there may be dense beds of Phaeophyceae, including Laminariaceae 10 or more metres long where the bottom is suitable for their holdfasts; for in the real Arctic it is in the sea, where conditions remain relatively even, that life abounds, rather than on land. Associated with the giant kelps and their allies are often a wide array of other Algae. But in contrast to the situation on temperate sea-shores, the intertidal belt tends to be largely devoid of big Algae (even where the substratum is suitable for their attachment) owing to the grinding action and winter investment of ice.

As in other parts of the world, the sea-shores above high tide-mark in the middle-arctic zone are extremely variable and may be virtually barren or, in sheltered and stable places, indistinguishable in plant denizens from the hinterland. Usually, however, where the substratum is suitably sandy or gravelly, some characteristic strand plants are to be found, and, in sheltered muddy places, miniature salt-marshes dominated by an almost constant assemblage of plants that are normally restricted to such habitats. The most important of these are *Puccinellia phryganodes* which, low down, may form almost pure matted beds, *Carex ursina*, phases of *Carex salina* and *Cochlearia*, and *Stellaria humifusa*. Characteristic of sandy shores are the northern representatives of *Arenaria peploides*, *Mertensia maritima*, and, particularly, our familiar sand-binding *Elymus arenarius*. Raised beaches are often noticeable and may persist for several hundred feet above the present level of the sea, affording flat or fluted surfaces of assorted material that may be very different for plant colonization from the parent rock or comminuted soil around. Frequently they are limy owing to admixture of marine shells.

Away from any evident influence of the sea in our middle-arctic land, we may find in the most favourable situations of soil and shelter, where conditions are 'fresh' and snow

lies sufficiently to give a protective blanket in winter, a quite thick 'heath' of the northern representatives of *Vaccinium uliginosum*, *Empetrum nigrum*, and *Ledum palustre*. With included sedges, grasses, and forbs, such heath may form a luxuriant investment many centimetres high. On occasional south-facing slopes with a lasting supply of percolating ground-water, willows, sometimes associated with dwarf birches, may form a scrub up to about half a metre in height. In contrast, dry and eroded ridges may be very poorly vegetated, and, like rock and boulder faces, support little more than lowly cryptogams—though near the sea any prominence is apt to be visited by predators and scavengers and, owing to their manuring, etc., to support a luxuriant and usually grassy sward very locally. The damper heaths and willow scrub tend to be consolidated by a subdominant mossy sward, the drier areas by a lichen-rich one; indeed lichens or occasionally mosses may actually predominate over considerable tracts.

Covering far more of the lowland terrain than heath and scrub in most middle-arctic places are marshy areas of various sorts and degrees of swampiness. They are dominated by such coarse plants as *Carex aquatilis*, *Arctagrostis*, and *Eriophorum angustifolium* with its characteristic white inflorescences, and tend to be consolidated by mosses and creeping willows. Though normally the soil is shallow, most marshes show some slight deposition of peaty muck beneath the surface which is often hillocky owing to frost-heaving or tussocky growth, with corresponding microclimatic and microhabitat effects. Thus in contrast to the high-arctic, most middle-arctic areas have the general run of their lowlands occupied by closed vegetation. Even if the surface is parched during dry weather in summer, water is usually plentiful just beneath, being held up by the permanently frozen subsoil—hence the frequency and extent of marshy areas.

Another feature of the middle-arctic zone is the paucity of perennial snow-banks except in the mountains. However, about steep slopes and in depressions and behind ridges where the snow drifts deeply every winter, there may be found characteristic late-snow patches where its progressively later melting towards the centre has led to the establishment of a zoned series of subclimaxes. The primary effects of this deeply drifted snow are threefold: in giving shelter, in supplying water, and in reducing the length of the growing-season. Toward the periphery of such areas, where the drift forms a protective insulating blanket in winter but melts relatively early in summer, there is usually a luxuriant *Vaccinium* heath and, farther in, a conspicuous dark one dominated by *Cassiope tetragona*. Farther in still, where the snow disappears so late that the growing-season is drastically reduced, *Salix herbacea* is the characteristic dominant, while about the centre of the patches, where the snow melts so late that the effective part of summer may be reduced to a few weeks or even days, there is usually a sparsely open assemblage of Saxifragae, Drabae, Ranunculi, *Oxyria digyna* and other quickly-flowering herbs which have at least some chance of setting and ripening seed before winter comes again. Many of them fail to do this and have to reproduce largely or entirely by vegetative means. There may be even more than the already-mentioned zones recognizable in relation to snow drifts—especially in the south. Thus their centres, where the snow melts latest or perhaps not at all in a cool summer after a winter of heavy snowfall and deep drifting, are often almost barren, with lichens little in evidence and the surface light-coloured, although mosses may occur in fair numbers—usually as sterile tussocks or thin mats. Here tiny tufts of *Phippsia algida* are often the only representatives of the elsewhere dominant Vasculares, but a fair array of microscopic or filamentous Algae may form a thin investment

on the undersides of stones and on patches of mud that remain damp from the melting snow. Better growths of Bryophyta and Algae are usually to be found in the run-off below such melting snow-patches which act as a reservoir of fresh, cool water.

Fresh-water habitats comprise the other main set encountered in the lowlands. Among them the streams are apt to be raging torrents when the snow melts in early summer and, consequently, poorly vegetated, although in sluggish eddies and pools there may be long dark tassels of aquatic mosses besides numerous microscopic and filamentous Algae. Especially well represented are the diatoms and desmids. Similar plant life is usually to be found in fresh-water lakes, which may occupy a considerable proportion of the area and support dark-brown beds of aquatic mosses encrusted with diatoms, etc. About their margins where the substratum is suitably soft for rooting, there may be luxuriant beds of, particularly, *Carex aquatilis* and *Eriophorum angustifolium*, stretching out into the water to a depth of not more than about half a metre, and frequently accompanied by aquatic mosses, etc., while about the shores where the level is apt to recede in summer there may be an abundance of colonial Cyanophyceae and other soil Algae.

Finally we must consider the mountains which form such a feature of many middle-arctic lands, and whose exposed summits tend to be vegetated chiefly by lichens, although mosses are usually to be found in crevices and a few hardy vascular plants, such as *Luzula confusa* and *Hierochloe alpina*, frequently persist. Any not too steep slope around is apt to be a sparsely-open 'barren' characterized by such hardy plants as *Saxifraga oppositifolia*, *Dryas*, Drabae, and *Papaver radicatum*, with patches of such mosses as *Rhacomitrium lanuginosum*, and prostrate gnarled bushlets of *Salix arctica*.

At high altitudes, snow-patches tend to be frequent and ice-caps to persist, so that late-snow and other special areas and communities are plentiful and often extensive, the terrain taking on the aspect rather of the general run of country farther north. Thus also does the middle-arctic zone merge into the high-arctic one in the north, even as it does into the low-arctic belt to the south. However, it may be observed that whereas in the low-arctic the terrain from a distance normally looks greenish or brownish as a result of being largely covered with vegetation, and in the middle-arctic there is still usually an evident softening by plant growth except in exposed or otherwise inhospitable situations, in the high-arctic such manifestations are practically always lacking except over very limited areas.

Most land areas that lie north of the seventy-fifth parallel of latitude may be considered high-arctic, as may some to the south such as Prince of Wales Island. Good examples are Ellesmere, the north coast of Greenland, and Spitsbergen. The general aspect in those top-of-the-world lands is apt to be desolate in the extreme, with most of the terrain occupied, for example, by sparsely vegetated *Papaver* or *Saxifraga* 'barrens' with, perhaps, a few tussocks of *Dryas* or various grasses on well-drained banks and very occasionally a limited tract of poor and thin *Vaccinium* or *Empetrum* heath developed under the most favourable conditions of shelter, soil, and southerly prospect. But often one can trek for days without encountering such a 'heath'. Thus most areas have scarcely a plant to be seen, and the only at all extensive tracts of more or less closed vegetation are apt to be marshy, the tallest plants of the region being their dominant grasses, sedges, or Eriophora which, however, rarely exceed 30 cm. (1 ft.) in height. There are no real bushes or even ground-shrubs more than a few centimetres high, and in general mosses form a large part of the vegetation in damp areas and lichens in dry ones. Sphagna are usually little in evidence and bogs of any depth nowhere to be found, although the soil reaction may be distinctly

acid and the feet in summer sink as much as 30 cm. into a swamp before reaching hard frozen subsoil. But although in most areas plants tend to be scarcely at all in evidence, taking very little hold of the surface, the total flora in reality is usually considerable; especially may a wide array of Algae and other lowly forms be collected even at the highest latitudes of land, as well as in the sea where life is relatively plentiful and the planktonic forms enable large mammals to flourish.

For plant life on the land in the high-arctic the struggle is rather with the inimical forces of nature than with ranker competitors, and so the flora as well as vegetation tends to be remarkably reduced as compared even with the middle-arctic zone. Thus, for example, only a few of the hardier salt-marsh and other strand plants persist, while the late-snow zones are commonly reduced to two or three. Indeed owing to the general reduction of the growing-season to a few weeks, much of the land takes on a late-snow aspect, with *Cassiope tetragona* the chief ground-shrub and quickly flowering Saxifragae, Ranunculi, and dwarf Salices widely important. In these circumstances of very small vegetable turnover there is little humus accumulation or true soil formation—in spite of the extreme slowness of decay under the prevailingly cool or frozen conditions. Other noteworthy features include the ubiquity and very various manifestations of frost-heaving and sorting which leads to all manner of 'polygon' and other soil phenomena such as solifluction streaks, and the lack of disturbance by man but the presence here and there of extraordinary concentrations of nesting wildfowl or sea-birds—for example on certain cliffs which they revisit year after year, and which, with their immediate surroundings, come to support a remarkably luxuriant grassy or cryptogamic sward.

By gradual amelioration of climatic and other conditions, increases in diversity of the flora and in numbers of individuals, and greater luxuriance of growth and of the resultant vegetation, the high-arctic zone to its south passes into the middle-arctic and this in turn into the low-arctic. Here the flora is usually considerable, some two hundred different species of vascular plants and three or four times as many cryptogams being discernible (or at least procurable by a general botanist) in any major area that includes the usual wide range of different habitats. These very approximate figures might perhaps be reduced by about a quarter for middle-arctic areas and by a half or more farther north. On the other hand, the vegetable productivity on land increases more markedly than the totality of species as we travel south, and in the low-arctic belt the terrain tends to be quite evidently covered with vegetation. Marshy areas often show considerable humus accumulation and appear straw-coloured owing to the luxuriant growth of their dominants, and heathy areas may be brilliantly tinted when the leaves of deciduous shrubs change colour before falling in autumn. In unusually favourable areas the willows, *Alnus*, and *Betula* may form a tangled scrub 2 or more metres high. Persistent patches of drifted snow normally disappear by the middle of July except in the mountains, where their areas may show five or six more or less well-marked zones of vegetation—related to the later and later disappearance of the snow, persistence of water, and limitation of the growing-season as the centre of the patch is approached, so that in the very centre only the most rapidly developing (often high-arctic) plants can persist. Just here may be found the blossoms of quickly developing species even at the very end of summer.

The low-arctic is exemplified by most of the northernmost mainland areas of America, by southern portions of the Canadian Arctic Archipelago, by southern Greenland, and by much of the coastal strip and hinterland of Siberia and north-eastern Europe. Here trees

are of course absent but a luxuriant tangled scrub of Amentiferae a metre or more high may be found in sheltered situations, with stragglers rising sometimes considerably higher. Sphagna are often plentiful and may contribute to bogs of fair depth and acidity. Mossy marshes and lichen-rich heaths may be extensive, as may 'Reindeer-moss' swards of Cladoniae and other lichens. But still in exposed places, especially in the uplands, rigorous conditions prevail and it is chiefly here that the open-soil plants such as *Saxifraga oppositifolia* persist. For although they tend to be weak in competition and hence ousted by ranker types from the more favourable lowland habitats, they are strong in combating the forces of a rigorous climate—whether this be in the Far North or in the south on mountains where conditions are in several respects comparable.

To the south of the southern boundary of the Arctic as we have delimited it, lies the subarctic zone of, usually, in the north sparsely scattered open forest dominated by often scrubby but arborescent *Larix*, *Picea*, *Pinus*, or occasionally *Betula* or *Populus*. This forms the 'taiga' or still more patchy 'forest tundra' which merges into the more properly consolidated northern coniferous forest that already is well developed in most places north of the southern limit of permanently frozen subsoil, the so-called 'permafrost'—which limit some authorities take as the southern boundary of the subarctic zone. Associated with the trees, even where they are sparse and scrubby, is a wealth of plants and animals that persist scarcely if at all to the north of the limit of arborescent growth—which immediately introduces a different microclimatic regime with all its attendant possibilities and actualities, and accordingly seems to form the most natural and worthy boundary between the subarctic region and the tundra extending away to the north and poleward. It is chiefly where the trees have been cleared, or local exposure or unsuitable substratum conditions appear to account for their absence, that climatic criteria have to be invoked to help us delimit the arctic region.

VASCULAR PLANT FLORA

This is not the place for an enumeration of the flora of the Arctic or for consideration of the ranges of the taxonomic groups involved. Such a floristic enumeration and detailed phytogeographical treatment presents many difficulties, starting with those of travel to the lands concerned and work in the institutions possessing the almost innumerable pertinent specimens. However, I have been working towards such a compilation off and on for rather many years, and am preparing a provisional account for *Encyclopedia Arctica*. Meanwhile it may be of interest to note that, taking in general a rather broad and conservative view of the limits of the various taxa, and including some recent introductions, there are so far known to grow in the Arctic as delimited above nearly 900 species of vascular plants belonging to some 230 genera representing 65 families.