Ber. d. Reinh.-Tüxen-Ges. 12, 131-151. Hannover 2000

Vegetation zones and biodiversity of the North-American Arctic

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1. Introduction

The circumpolar land beyond the northern limit of natural tree growth is generally considered as Arctic. Its southern border roughly coincides with the 10°C July isotherm. Natural tree growth is absent primarily due to insufficient summer warmth. Thus the rather warm inland part of South Greenland with stunted tree growth and nearly entire Iceland where grazing prevents natural tree growth are excluded from the Arctic (Figs. 1 and 6).

In many aspects flora and vegetation within the circumpolar Arctic is rather similar obviously due to the strong convergent impact of the rather extreme climatological conditions in past and present. However regional variation exists from east to west and south to north due to differences in configuration of land and sea, relief, substrate, climate and glacial history.

This contribution mainly deals with latitudinal variation within the North-American part of the Arctic with emphasis on Greenland. It addresses floristics, vegetation, zonation approaches from a syntaxonomical point of view and species richness.

The nomenclature of the vascular plants is in accordance with Böcher et al. (1978). For the species occurring outside Greenland Porsild & Cody (1980) is followed. Nomenclature of higher syntaxa follows Dierssen (1996) however not so our concepts of the classes *Caricetea curvulae, Koelerio-Corynephoretea* and *Loiseleurio-Vaccinietea.*

2. General features of the Arctic territory

The delimitation of the Arctic and subdivision as agreed on by a majority of the CAVM (Circumpolar Arctic Vegetation Mapping) group (see Walker et al. 1995) is depicted in Fig. 1 (cf. Elvebakk et al. 1999). Many arctic regions are alpine (e.g. nearly the entire Greenland) but the endless lowlands and plains (e.g. in Alaska and Siberia) probably stronger portrays the typical features of the Arctic lands. Variation in geomorphology, substrate (acidic, non-acidic), climate (north-south and coast-inland) and glacial history (glaciated or not) cause biotic and abiotic patterns on different scales.

Major vegetation types of the landscape include tundras (vegetation where plant cover is complete and where woody species, sedges and grasses dominate), polar semi-deserts (where vegetation cover is less complete and where cushion plants, herbs and cryptogams dominate) and polar deserts (Aleksandrova 1988), including herb barrens and snow flush vegetation (Bliss 1997). In addition grasslands and coastal salt marshes occur. Mosses and lichens are prominent.

Throughout the Arctic lands soils are permanently frozen (permafrost), with only the upper part (active layer) thawing each summer. Freezing and thawing of the upper soil result into the formation of patterned ground including circles, polygons, nets, hummocks, steps, stone

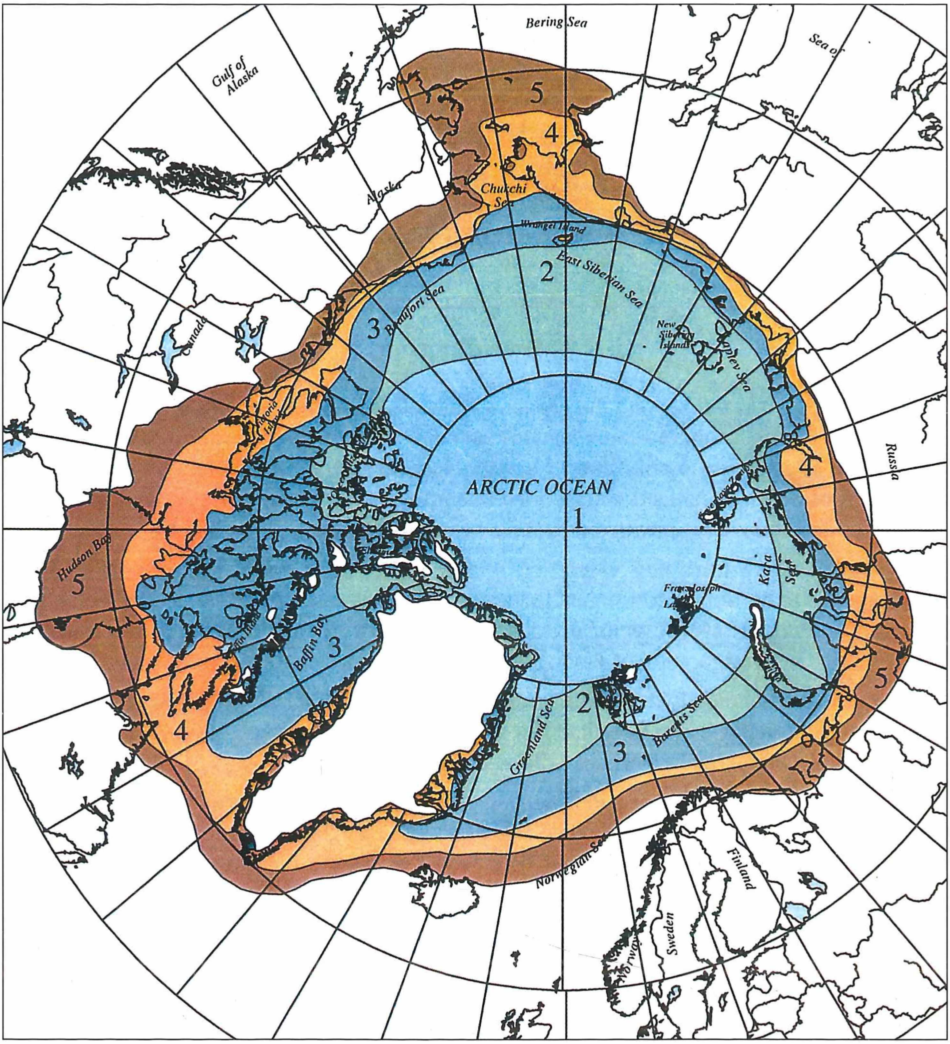

Fig. 1: Subdivision of the Arctic territory according to ELVEBAKK et al. (1999). Names of the zones have been changed by the present authors. 1 Arctic Herb Zone, 2 Northern Arctic Dwarf Shrub Zone, 3 Middle Arctic Dwarf Shrub Zone, 4 Southern Arctic Dwarf Shrub Zone and 5 Arctic Shrub Zone.

stripes and solifluction lobes which are all pronounced features of Arctic landscapes. They strongly influence the vegetation pattern.

Species numbers are comparatively low, especially in the North. The total amount of native bryophyte species is estimated 600-700 (LONGTON 1988), the lichen flora might comprise about 2000 species (THOMSON 1972) and the number of flowering plants species might be estimated at about 900 (POLUNIN 1959) of which 700 occur in the Low Arctic and 350 in the High Arctic of North-America (BLISS 1997). The species number of mosses and lichens might be likely three times as high as that of the vascular plants. Species diversity, vegetation cover and height generally decrease with increasing latitude.

Due to low temperatures chemical and biological processes are slow, thus nutrient availability for plants is rather low. Development of soil horizons is less pronounced. Deep organic soils (histosols) can be found in poorly drained lowlands in the southern parts. In well drained upland sites and in the North organic horizons are hardly developed (entisols). See further BLISS (1997), BLISS & MATVEYEVA (1992) and CHERNOV & MATVEYEVA (1997).

3. Flora

3.1 Status

The Arctic is considered by YURTSEV (1994) as a separate floristic region. In continental sectors the southern boundary coincides with the northern limit of the Taiga, in oceanic sectors it crosses treeless areas. Thus some areas in the North-Pacific regions and North-Atlantic regions, such as Faroe Islands, Iceland and the southern part of Greenland as well as northernmost Scandinavia are excluded because the high proportion of „southern" species alien to the circumpolar arctic area. Thus according to floristical criteria the Arctic is smaller than the Arctic defined in the Introduction (Fig. 1).

The floristic integrity of the Arctic is very high, even on the species level. The circumpolar species account for over 35% to over 80% of local Arctic floras apart from other species with wide distribution in the circumpolar region (YURTSEV 1994). Several arguments support the concept of a separate floristic region. No less than 10% of species characteristic of the Arctic are endemic. There are even a few widespread endemic and subendemic genera (*Arctophila, Dupontia, Parrya* s.str., *Phippsia, Pleuropogon* s.str.) as well as several endemic and subendemic sections in genera such as *Cerastium, Draba, Gastrolychnis, Oxytropis, Papaver, Poa, Puccinellia* and *Taraxacum.*

Moreover the Arctic flora has a peculiar taxonomic structure: few species per genus and family; lack of phyletic lineages (which are typical for the Boreal region), even at higher taxonomic levels, e.g. the lack of Gymnosperms. Moreover the number of mosses and lichens relative to the vascular plants is high.

Other arguments are the differences with the plants of the Boreal floras in respect of ecophysiological and morphological features (growth-forms), different vectors of evolution and modes of speciation and flora genesis. Recently CRAWFORD (1999) emphasised the high level of intraspecific variation in the Arctic flora (*Arctagrostis latifolia, Armeria maritima, Carex bigelowii, Draba* species, *Dryas octopetala, Saxifraga* species, *Silene acaulis*) in this peripheral region of the world (cf. also MURRAY 1994). „Thus the Arctic flora is a taxonomically, ecologically, biologically, and genetically distinctive complex of young and dynamic species, that occupy a vast natural area" (YURTSEV 1994).

Sectorial differences in the Arctic Floristic Region are reflected in its subdivision into 5 flora provinces: European-West-Siberian, East-Siberian and Chukotka, Alaska, Canada-Greenland and Baffin-Labrador (YURTSEV 1994).

3.2 Species diversity

There is convincing evidence that species richness of vascular plant floras within the Arctic is strongly affected by summer temperatures (e.g. EDLUND & ALT 1989, YOUNG 1971). EDLUND & ALT (1989) found strong congruencies between species diversity, species dominance, species distribution and mean July temperature in °C (mJT) in the Queen Elizabeth Islands, Northwest Territories, Canada. They distinguished 4 vegetation zones: Herb Zone (no woody plants and sedges, 1-35 species, mJT less than 3°C), Herb-Shrub Transition Zone (herb dominated, shrubs and sedges present but not dominant; wetlands dominated by grasses, 35-60 species, mJT 3-4°C), Prostrate Shrub Zone (dominated by *Salix arctica* and/or *Dryas integrifolia*, wetlands dominated by sedges, 60-100 species, mJT 4-5°C) and Enriched Prostrate

Shrub Zone (dominated by shrubs as previously, but more additional species, more than 100 species, mJT 5-8°C).

A study of the vascular flora of St. Lawrence Island, Alaska in comparison with other local circumpolar arctic floras resulted into a subdivision of the Arctic into 4 floristic zones (YOUNG 1971). A strong correlation was found between floristic zones and the sum of the mean temperatures in °C of months with a mean temperature above 0°C (=a°C, summer warmth). There was neither a correlation with mean annual temperature °C nor with precipitation and humidity. Moreover species numbers were influenced rather by coast-inland effects than strict historical or geographical factors. YOUNG's 4 floristic circumpolar zones are characterised by the sum of the mean temperatures of months with a mean temperature above 0 °C (=a°C), species number, northern distribution limits and distribution pattern of vascular plant species. From north to south the following zones are distinguished:

Zone 1: Less than 50 species, flora impoverished, no vascular cryptogams, almost only circumpolar species, a°C: 0-6°C;

Zone 2: Typical flora 75-125 species, many circumpolar or wide-ranging species, 7 species of vascular cryptogams, a°C: 6-12°C;

Zone 3: Typical flora well over 100 species, isolated sites 150 species, less isolated even more than 250 species. Differentiation in sectors more pronounced than in zone 2, a°C: 12-20°C;

Zone 4: Typical flora well over 200 species, up to 500 species, strong sectorial differences, a°C: 20-35°C.

3.3 Greenland

Flora and vegetation of Greenland are confined to mostly narrow coastal ice-free fringes who constitute only about 14% of the total area, which is covered for about 86% by a central ice-cap.

The vascular plant flora of Greenland is well know. BÖCHER (1938) and BÖCHER et al. (1959, 1978) compiled results from studies before the seventies. Important later contributions are by BAY (1992), FEILBERG (1984), FREDSKILD (1996) and SCHWARZENBACH (2000). Total number of native species might be about 500 (485 in BÖCHER et al. 1959).

We tried to correlate species numbers of vascular plant floras with some climate parameters. Tab. 1 shows species numbers of regions (derived from important floristic studies in past and present including own data) with weather stations in Greenland, all situated below 100 m altitude, and a number of climate parameter (mainly derived from the Danish Meteorological Institute in Charlottenlund (ANONYMOUS 1961-1967)) (Tab. 1, Figs. 2 and 3). Species number appeared to be (highly) correlated with mean temperature of the warmest month in °C, sum of mean temperatures of the months June, July and August in °C, mean annual temperature in °C, but the strongest with the sum of mean temperatures of all months with mean temperature above 0°C (=a°C). There were no congruencies with precipitation and humidity. Our results confirm the findings of EDLUND & ALT (1989) and YOUNG (1971). Thus vascular plant species diversity in local floras of Greenland seems primarily be controlled by summer warmth as expressed by a°C.

Poor local floras occur in the cold outer coastal areas of the northern parts of Greenland, rich floras in Southwest Greenland and the inland in the South albeit substrate diversity (e.g. gneiss, granite, basalt, sandstone, limestone) in many parts of northern Greenland is even more pronounced than in the southern part of Greenland (with almost only old acidic gneisses and granites). Thus summer warmth obviously has a stronger impact on species diversity of local floras than substrate diversity.

Tab. 1: Climate parameters (4-13) measured during several years (period in brackets) at weather stations in Greenland and numbers of vascular plant species of floras near the stations (14).

Column 8: Mean humidity index June-August, sum of mean precipitation in mm in June-August divided by the sum of mean temperature in °C June-August.

Column 9: a P mm is sum of mean precipitation (mm) in months with mean temperature °C above 0.

Column 10: a°C is sum of mean temperatures of months with mean temperature °C above 0.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Nr	Weather Station	Location	mean annual T°C	mean annual P mm	sum mean P mm jn-au	sum mean T°C jn-au	mean hum index jn-au	a P mm	a °C	a P mm/ a °C	mean T °C jl-au	T °C wmst mnth	number vasc.pl species
1	Station Nord (61-67)	81°36'N, 16°40'W	-16,7	154	35	4,1	8,5	35	5,4	6,5	1,4	3,1	39
2	Danmarks Havn (61-67)	76°46'N, 18°46'W	-12,4	111	26	6,5	4	26	6,5	4	2,2	3,7	34
3	Dundas (61-67)	76°34'N, 68°48'W	-10,6	121	47	8,7	5,4	47	8,7	5,4	2,9	4	112
4	Daneborg (61-67)	74°18'N, 20°13'W	-10,4	206	43	8,3	5,2	43	8,3	5,2	2,8	3,8	135
5	Upernavik (61-67)	72°47'N, 56°10'W	-6,8	271	80	11,7	6,8	128	12,6	10,2	3,9	6	98
6	Mesters Vig (61-67)	72°15'N, 23°54'W	-9,8	266	62	13,4	4,6	62	13,4	4,6	4,5	6	134
7	Umanak (61-67)	70°41'N, 52°00'W	-3,5	132	37	19,7	1,9	46	22,2	2,1	6,6	7,7	107
8	Kap Tobin (61-67)	70°25'N, 21°58'W	-7,9	438	97	6	16,2	97	6	16,2	2	2,8	
9	Godhavn (61-67)	69°15'N, 53°31'W	-2,9	434	132	17,6	7,5	222	20,4	10,9	5,9	7,1	212
10	Jakobshavn (61-67)	69°13'N, 51°03'W	-3,3	231	84	20,5	4,1	147	23,2	6,3	6,8	8	149
11	S Strömfjord (61-90)	67°00'N, 50°40'W	-5,7	140	53	27,9	1,9	88	34,5	2,6	9,3	10,6	184
12	Holsteinsborg (61-67)	66°55'N, 53°40'W	-2,9	344	112	16,7	6,7	185	20,3	9,1	5,9	6,8	191
13	Angmagssalik (61-67)	65°36'N, 37°34'W	-1,4	917	131	17,7	7,4	227	21,6	10,5	5,9	7	170
14	Kapisigdlit (39-56)	64°27'N, 50°20'W	-0,7	255		18					6	10,9	191
15	Godthab (61-67)	64°10'N, 51°45'W	-0,6	846	265	18	14,7	457	23,1	19,8	5,5	7	155
16	Tingmiarmiut (61-67)	62°32'N, 42°08'W	-1	1508	258	15,5	16,6	476	19,1	24,9	9,6	6,2	138
17	Frederikshab (61-67)	62°00'N, 49°43'W	0	890	253	16,4	15,4	465	23,3	20	7,1	6,2	224
18	Nassarssuaq (61-67)	61°11'N, 45°25'W	1,9	590	168	28,9	5,8	331	42,3	7,8	7,3	10,5	309
19	Narssaq (61-67)	60°54'N, 45°58'W	1,4	924	295	22	13	559	31,7	17,6	6,2	7,9	269
20	Julianehab (61-67)	60°43'N, 46°03'W	1,5	859	273	21,4	12,8	519	32,9	15,8	5,2	8,1	237
21	Pr Christians Sund (61-67)	60°02'N, 43°07'W	1,1	2589	515	18,5	27,8	1360	28,3	48,1	9,7	7,2	149

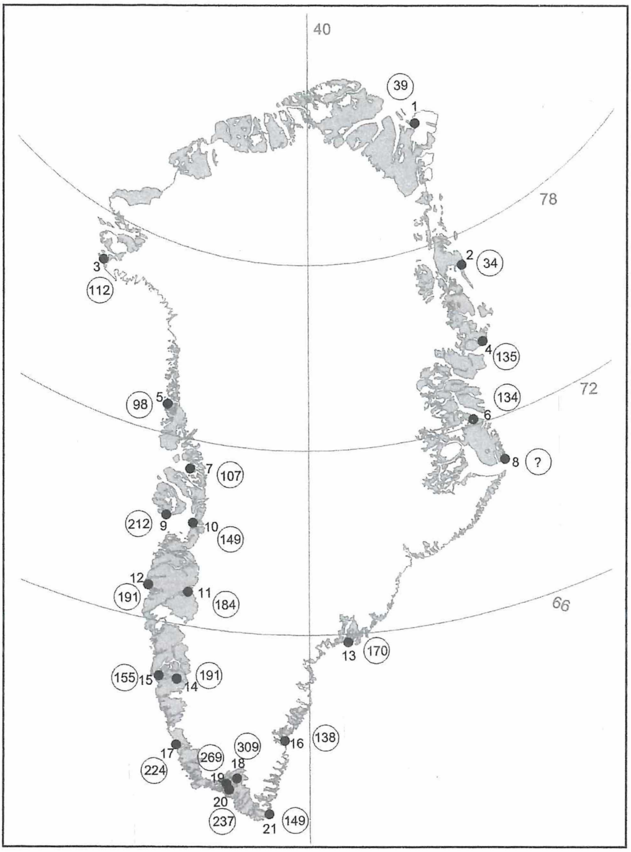

Fig. 2: Map of Greenland showing locations (numbers) of weather stations and numbers of vascular plant species in nearby floras (in circles).

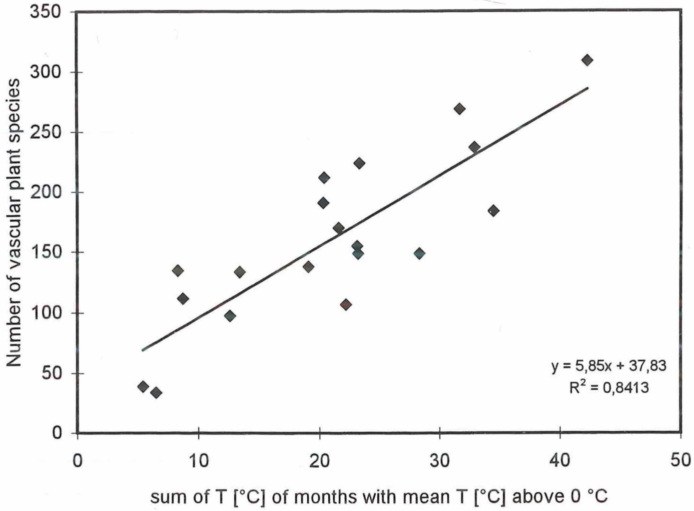

Fig. 3: Linear regression analysis of vascular plant species numbers of local floras and sum of mean temperature of montts with mean temperature above 0°C (a°C).

4. Vegetation

4.1 General features of arctic vegetation types

Circumpolar comparisons have been presented by a.o. ALEKSANDROVA (1980), BLISS & MATVEYEVA (1992) and YURTSEV (1994), while ALEKSANDROVA (1988) and CHERNOV & MATVEYEVA (1997) reviewed arctic ecosystems of Russia, and BLISS (1997) did so for North-America.

Vegetation pattern of the North-American Arctic and the Russian Arctic is different due to strong differences in configurations of land and sea (Alaska and mainland of Canada constitute a continent; Northwest Territories, now pro major part Nunavut, is an extended group of islands in the Arctic Ocean, which are low and flat in the West, high and alpine in the East; Greenland is an island with ice-free land confined to coastal areas; the Russian Arctic is mainly a huge continent with some scattered islands). Moreover refugial and postglacial immigration routes are different. However in spite of local differences in flora and vegetation pattern Arctic vegetation shows many strong circumpolar convergencies on levels of synusiae, phytocoenoses and formations. This is very pronounced in the northern parts of the Arctic and mainly due to the overruling influence of the extreme climate.

Although syntaxomical approaches to the circumpolar Arctic are comparatively young the circumpolar distribution of classes *Thlaspietea rotundifolii, Carici-Kobresietea, Loiseleurio-Vaccinietea, Salicetea herbaceae, Scheuchzerio-Caricetea* and *Mulgedio-Aconitetea* could be demonstrated (cf. WALKER et al. 1995). This should stimulate further international co-operation in the development of an uniform circumpolar vegetation-classification system as is initiated by the CAVM group.

The vegetation of the entire Arctic territory is physiognomically characterised by the absence of trees, dominance of chamaephytes and hemicryptophytes, mosses and lichens, and almost absence of therophytes. Species richness of some vegetation types (e.g. *Carici-Kobresietea* communities) is extremely high by the many bryophytes and lichens (cf. GELTING 1955, LÜNTERBUSCH & DANIELS 2000; see also BÜLTMANN & DANIELS 2000 and chapter 3.2). Over 60 species are commonly found in relevés of a few square meters.

4.2 Major classes of the North-American Arctic

The Low-Arctic (sensu BLISS 1997) is characterised by low shrub tundra with several willow species (probably belonging to *Salicetea purpureae, Mulgedio-Aconitetea* or *Loiseleurio-Vaccinietea*), dwarf shrub heath tundra (*Loiseleurio-Vaccinietea*, see also DANIELS 1982), dwarf shrub heath-tussock tundra (probably *Oxycocco-Sphagnetea*, see also WALKER et al. 1994), graminoid-moss tundra (mires) (*Scheuchzerio-Caricetea*) and cushion plant-cryptogam semi-deserts with *Dryas* species (*Carici-Kobresietea*).

In the High-Arctic (sensu BLISS 1997) occur: graminoid-moss tundra (mire) (*Scheuchzerio-Caricetea*), dwarf shrub heath tundra (especially with *Cassiope tetragona, Salix arctica, Vaccinium uliginosum* ssp. *microphyllum, Rhododendron lapponicum, Betula nana*) (*Scheuchzerio-Caricetea/Carici-Kobresietea*), tussock tundra (with *Eriophorum vaginatum, Vaccinium vitis-idea* ssp. *minus*) (*Oxycocco-Sphagnetea*?) and sporadically low shrub tundra (0,5-2,0 m high; built up by *Salix alaxensis* and *S. pulchra*) (*Scheuchzerio-Caricetea* or *Salicetea purpureae*?). The polar semi-deserts are represented by cushion plant-cryptogam semi-deserts on gravelly raised beaches (*Carici-Kobresietea*) and cryptogam-herb semi-deserts on sandy-silty clay soils with black organic crust, many small herbs, without dwarf shrubs and sedges, but with abundant mosses (*Salicetea herbaceae, Saxifrago-Ranunculion*). The polar deserts consist of herb barrens (*Thlaspietea rotundifolii*) and snow flush communities (*Salicetea herbaceae, Saxifrago-Ranunculion*).

Salt marshes (*Juncetea maritimi, Puccinellion phryganodis*) and dry beach vegetation (*Honckenyo-Elymetea*) locally occur mainly in the southern parts of the Arctic (cf. DE MOLENAAR 1974, THANNHEISER & WILLERS 1988), just as grasslands of *Calamagrostis neglecta* (*Scheuchzerio-Caricetea* or *Honckenyo-Elymetea*?) and *C. purpurascens* steppes. Syntaxonomically this latter vegetation type most certainly should be considered as a new class provisionally named here *Calamagrostietea purpurascentis*. This syntaxon is characterised by a set of good character and differential species (a.o. *Calamagrostis purpurascens, Carex supina* ssp. *spaniocarpa, Arabis holboellii, Erigeron compositus, Caloplaca tominii* Savicz, *Collema substellatum* H. Magn. and *Didymodon rigidulus* Hedw.). It has a distinct ecology and distribution ((East-Siberian-)North-American), and an own Pleistocene history (see also BÖCHER 1954). This class surely is a „good class" according to the concept of PIGNATTI et al. (1995). A first syntaxonomical synopsis of the vegetation of (sub)oceanic low arctic Greenland included the following classes: *Asplenietea trichomanis, Thlaspietea rotundifolii, Caricetea curvulae, Loiseleurio-Vaccinietea, Carici-Kobresietea, Salicetea herbaceae, Mulgedio-Aconitetea, Montio-Cardaminetea, Scheuchzerio-Caricetea, Oxycocco-Sphagnetea, Honckenyo-Elymetea, Juncetea maritimi (*syn. *Asteretea), Littorelletea* and *Potametea* (DANIELS 1994).

5. Latitudinal zonation schemes

5.1 Survey of approaches

In their recent papers WALKER (1999b) and ELVEBAKK (1999) reviewed existing subdivision concepts and schemes of the Arctic (a.o. ALEKSANDROVA 1980). Moreover new zonation approaches were proposed. Tab. 2 summarises major subdivision systems in Russia, North America and Fennoscandia. WALKER (1999b) prefers 4 arctic subzones which are named Cushion Forb, Prostrate Dwarf Shrub, Erect Dwarf Shrub and Low Shrub after the dominant „plant functional type" in the zonal situation (Tab. 3).

Fig. 1 depicts the subdivision of the Arctic recently published by ELVEBAKK et al. (1999). The five bioclimatic (sub)zones are essentially characterised by temperature regimes (mJT) as found along latitudinal (north-south) as well as along coast-inland (low-high summer temperature) gradients. These differences in climate are reflected in differences in life- and growth forms in mesic (zonal) sites, abundances of species in the landscape and sequences of vegetation types along dry-wet gradients (Figs. 4 and 5). The (sub)zones are named Arctic Polar Desert Zone, Northern Arctic Tundra Zone, Middle Arctic Tundra Zone, Southern Arctic Tundra Zone and Arctic Shrub Tundra. We follow this 5 subzone approach and their characterisation, however prefer a different nomenclature (Fig. 6). Our nomenclature avoids the conflicting terms desert and tundra. It focuses on three different growth forms and the variation in the large dwarf shrub region is expressed by geographical terms.

(1) Arctic Herb Zone: entirely herbaceous, primarily characterised by the absence of woody plants and Carices. Vascular plant cover is very low (<5%). *Papaver dahlianum* agg. is characteristic in dry, *Phippsia algida* in moist sites. *Saxifraga* species are prominent; mJT 0-2,5°C (Fig. 7: a, b).

(2) Northern Arctic Dwarf Shrub Zone: transitional between zone 1 and zone 3. Prostrate dwarf shrubs such as *Dryas* species occur on exposed ridges, *Salix* (*arctica* or *polaris*) in snowbeds. Carices occur; mJT 2,5-4°C (Fig. 7: c, d).

(3) Middle Arctic Dwarf Shrub Zone: *Dryas* species occur on dry ridges, *Cassiope tetragona* in zonal sites, herbs in late snowbeds. Mires with pleurocarpous mosses and Carices are well developed; mJT 4-6°C (Fig. 7: e, f).

(4) Southern Arctic Dwarf Shrub Zone: Prostrate dwarf shrubs occur on dry ridges (*Loise-*

Tab. 2: Survey of approximate equivalent subdivisions of the Arctic in Russia, North America and Fennoscandia (taken from WALKER 1999b).

Subzone	RUSSIA			NORTH AMERICA			FENNOSCANDIA	
	Alexandrova (1980)	**Yurtsev (1994)**	**Matveyeva (1998)**	**Polunin (1951)**	**Edlund and Alt (1989) Edlund, (1996)**	**Bliss 1997**	**Tuhkanen (1986)**	**Elvebakk (1985)**
1. Cushion forb	Northern Polar Desert	High Arctic Tundra	Polar Desert (1.5-2°C)	High Arctic	Herbaceous and cryptogam (1-3°C, 50-150 TDD)	High Arctic	Inner polar zone C=0.0	Arctic Polar Desert Zone
	Southern Polar Desert						Outer polar zone C=0.5	
2. Prostrate dwarf shrub	Northern Arctic Tundra	Arctic Tundra—northern variant	Arctic Tundra (5-6°C)	Middle Arctic	Herb-prostrate shrub transition (3-4°C, 150-250 TDD)		Northern arctic zone C=1.0	Northern Arctic Tundra Zone
					Prostrate shrub (4-6°C, 250-350 TDD)			Middle Arctic Tundra Zone
	Middle Arctic Tundra	Arctic Tundra —southern variant	Typical Tundra (8-10°C)		Dwarf and prostrate shrub (5-7°C, >350 TDD)		Middle arctic zone C=1.75	Southern Arctic Tundra Zone
	Southern Arctic Tundra							
3. Erect dwarf shrub	Northern Subarctic Tundra	Northern Hypoarctic Tundra		Low Arctic		Low Arctic	Southern arctic zone C=2.5	Hemiarctic Zone
	Middle Subarctic Tundra				Low erect shrub (7-10°C)			
4. Low shrub	Southern Subarctic Tundra	Southern Hypoarctic Tundra	Southern Tundra (10-12°C)					

Tab. 3: Summary of climate parameters and vegetation features of the 4 Arctic vegetation subzones (taken from WALKER 1999b).

Subzone	Mean July Temp at southern subzone boundary (°C) [compromise value]	Sum of mean monthly temper-atures above freezing at southern bound-ary (°C)	Vertical structure of plant cover	Horizontal structure of plant cover	**Total phytomass (abovegound+ belowground and live + dead) (t ha^{-1})**	Net annual production (aboveground + belowground (t ha^{-1} yr^{-1})	Number of vascular plant species in local floras
1. Cushion forb	2-3 [3]	6	Mostly barren. In favorable microsites, 1 lichen or moss layer <2 cm tall, very scattered vascular plants hardly exceeding the moss layer; no woody plants	<5% cover of vascular plants, up to 40% cover by cryptogams mostly associated with cracks in polygonal patterns and protected microsites. No closed root systems	3	0.3	<50
2. Prostrate dwarf shrub	5-7 [6]	12	2 layers, moss layer 3-5 cm thick and herbaceous layer 5-10 cm tall, prostrate and hemi-prostrate dwarf shrubs	5-50% cover of vascular plants, open patchy vegetation	20	2.3	75-125
3. Erect dwarf shrub	8-10 [9]	20	2 layers, moss layer 5-10 cm thick and herbaceous/dwarf-shrub layer 10-40 cm tall	50-80% cover of vascular plants, interrupted closed vegetation	57	3.3	150-250
4. Low shrub	10-12 [12]	35	2-3 layers, moss layer 5-10 cm thick, herbaceous/dwarf-shrub layer 20-50 cm tall, sometimes with low-shrub layer to 80 cm	80-100% cover of vascular plants, closed canopy	107	3.8	200 to >450

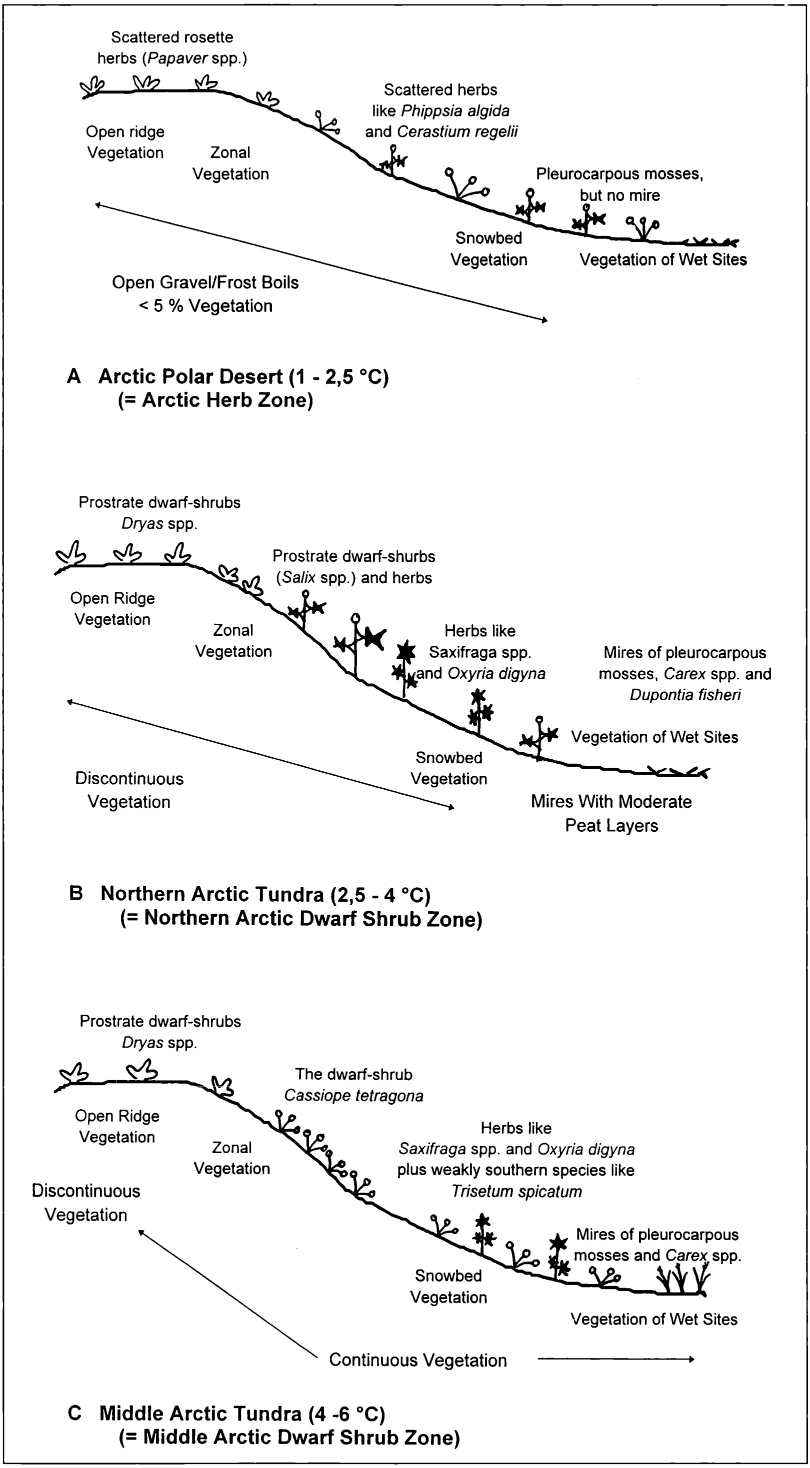

Fig. 4: Generalised zonation of vegetation types along a dry-wet gradient in the Arctic Polar Desert, Northern Arctic Tundra and Middle Arctic Tundra according to ELVEBAKK (1999).

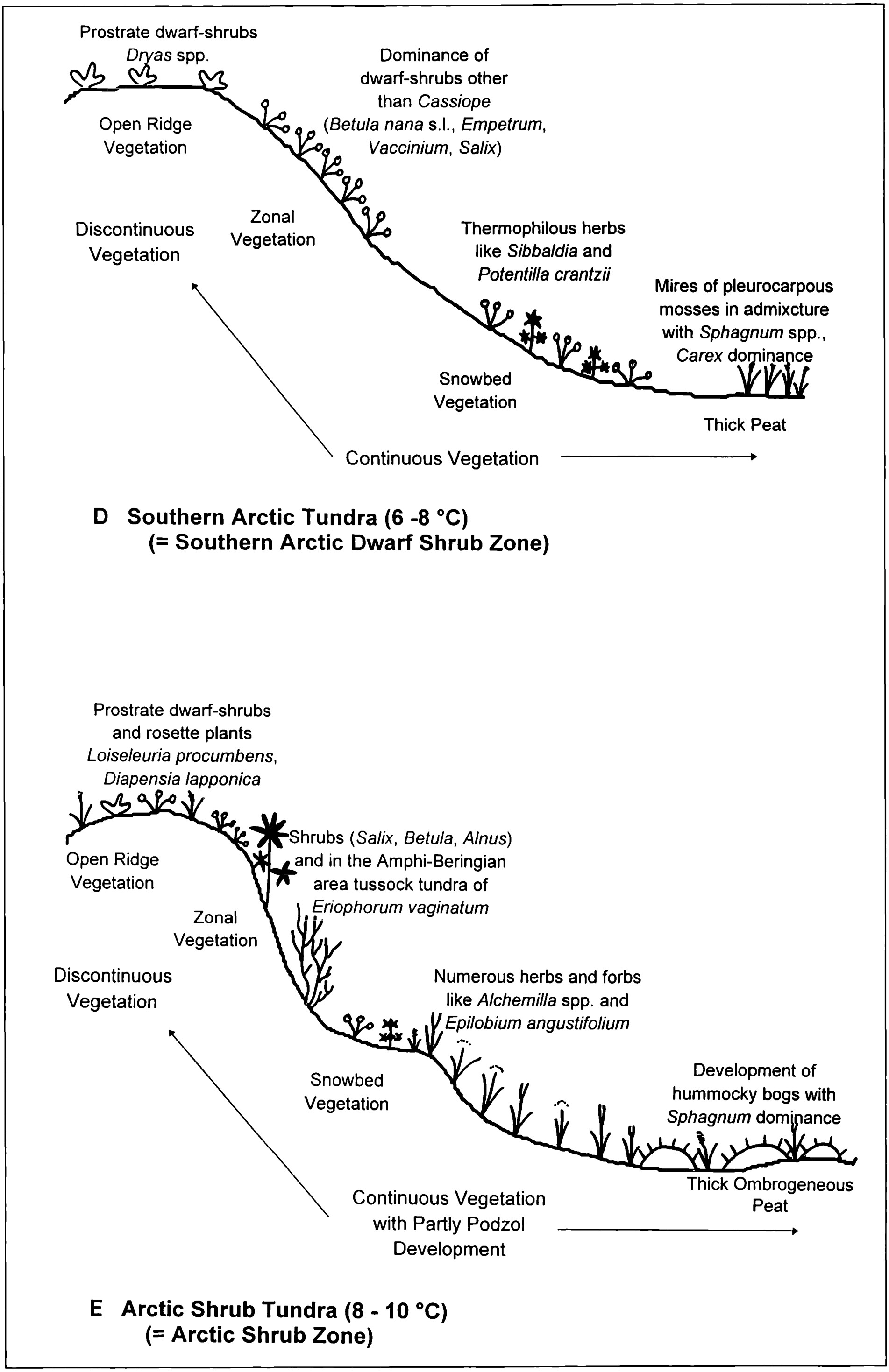

Fig. 5: Generalised zonation of vegetation types along a dry-wet gradient in the Southern Arctic Tundra and Arctic Shrub Tundra according to ELVEBAKK (1999).

leuria procumbens, Diapensia lapponica on acidic substrates; *Dryas* spec. on non-acidic substrates), erect dwarf shrubs other than *Cassiope tetragona*, such as *Empetrum nigrum* ssp. *hermaphroditum, Phyllodoce coerulea, Betula nana, Ledum palustre* ssp. *decumbens, Vaccinium uliginosum* ssp. *microphyllum, Salix glauca* ssp. *callicarpaea* dominate in zonal sites. Snowbed vegetation is well developed. Mire vegetation with *Sphagnum* species occur on acidic substrates. Low shrub vegetation and tall forbs are found along water in sheltered sites; mJT 6-8°C (Fig. 7: g, h).

(5) Arctic Shrub Zone: Dwarf shrubs dominate on dry ridges, low shrubs (0,5-2m) such as *Salix* and *Betula glandulosa* occur in zonal sites. Hummocky bogs with some boreal species are well developed; mJT 8-10°C (Fig. 7: i, j).

Fig. 6 depicts a slightly modified subdivision of Greenland. The boundaries of the zones are rather preliminary due to lack of relevant knowledge in particular from northern and inland areas. The Arctic Shrub Zone is confined to warm inland areas being well developed in the

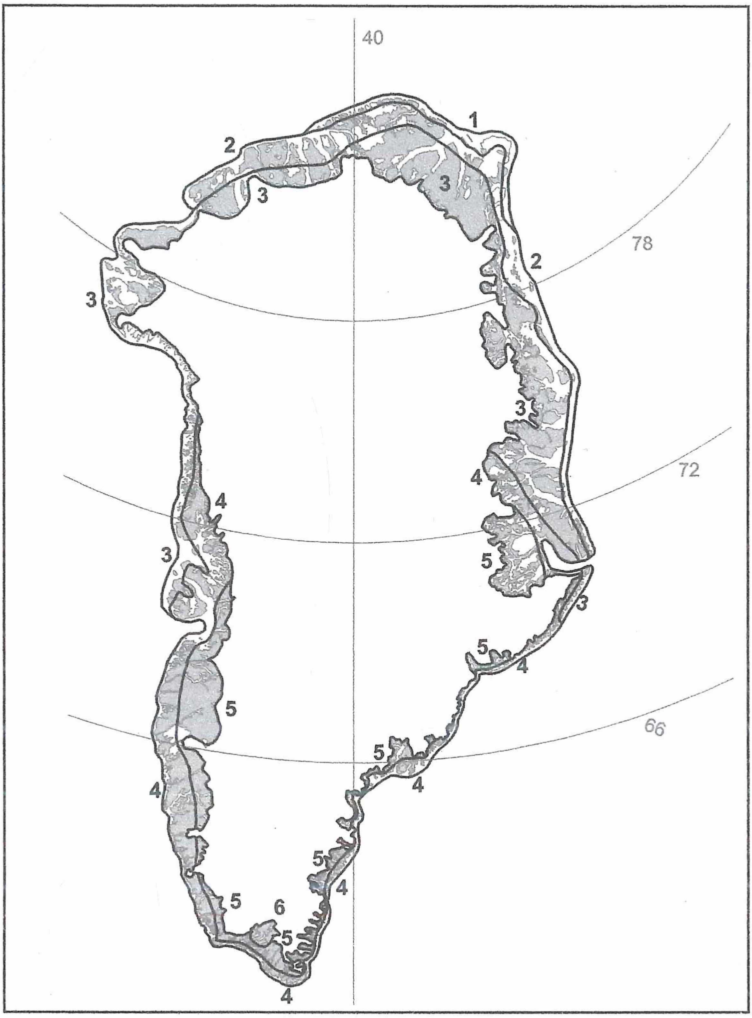

Fig. 6: Zonal subdivision of Greenland. 1 Arctic Herb Zone, 2 Northern Arctic Dwarf Shrub Zone, 3 Middle Arctic Dwarf Shrub Zone, 4 Southern Arctic Dwarf Shrub Zone and 5 Arctic Shrub Zone. 6 Boreal enclave in the inland in the South.

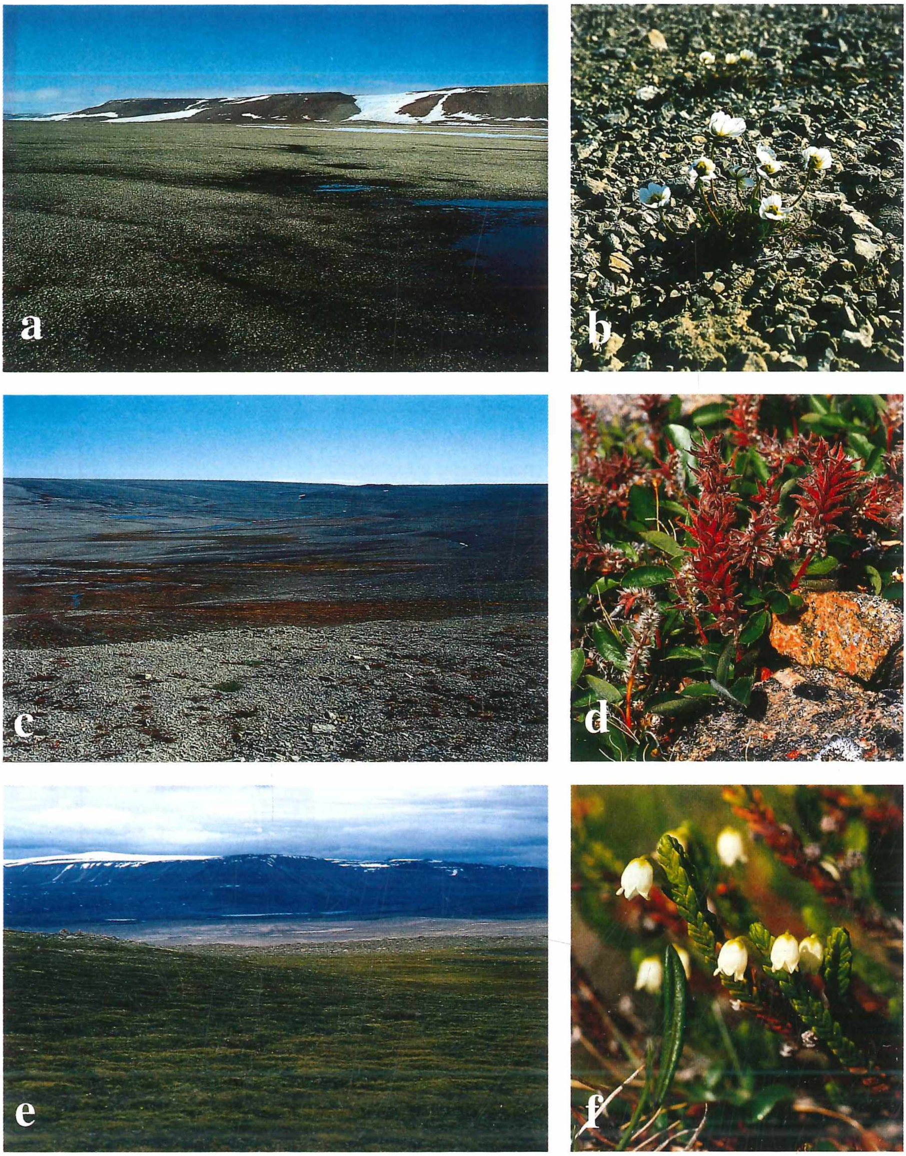

Fig. 7a: Landscape in the Arctic Herb Zone near the coast of eastern North Greenland, July 1993, courtesy Dr. C. Bay.

Fig. 7b: *Papaver dahlianum*, Ellesmere Island, Canada, August 1999.

Fig. 7c: Landscape in the Northern Arctic Dwarf Shrub Zone Cornwallis Island, Canada, August 1999.

Fig. 7d: *Salix arctica*, Ellesmere Island, July 1992.

Fig. 7e: Landscape in the Middle Arctic Dwarf Shrub Zone, Inland of eastern North Greenland, July 1995.

Fig. 7f: *Cassiope tetragona* in West Greenland, August 1992.

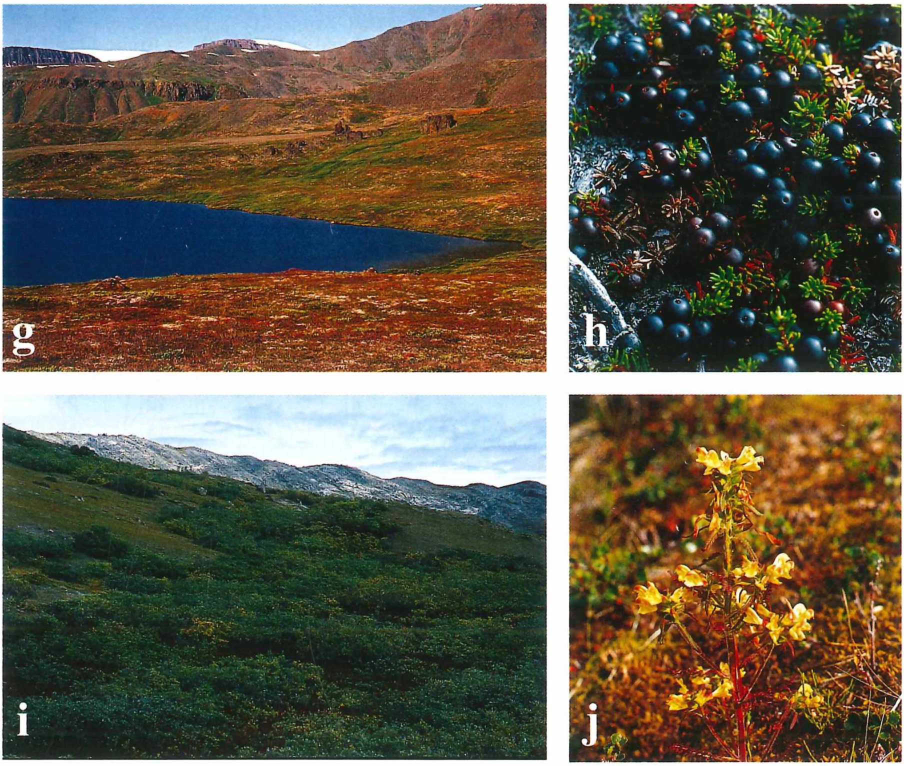

Fig. 7g: Landscape in Southern Arctic Dwarf Shrub Zone, West Greenland August 1992.
Fig. 7h: *Empetrum nigrum* ssp. *hermaphroditum*, West Greenland, August 1998.
Fig. 7i: Landscape of the Arctic Shrub Zone, inland Southwest Greenland, August 1998.
Fig. 7j: *Pedicularis labradorica*, inland Southwest Greenland, September 1993.

southern part of West Greenland. The innermost parts of the Scoresby Sund area in East Greenland very probably also belong to this zone. It is fragmentarily developed in inland localities of the southeast coast of Greenland. Due to the lower summer temperatures northwards the Southern Arctic Dwarf Shrub Zone retreats from the coast being replaced by the Middle Arctic Dwarf Shrub Zone. The very cold outermost fringes of the coast of East and Northeast Greenland belong to the Northern Arctic Dwarf Shrub Zone. However this zone is absent in Northwest Greenland, where the climate is less harsh. The Arctic Herb Zone is confined to the outermost coast of eastern North Greenland, where summer temperatures are extremely low due to frequent clouds and fog which shields off insolation (cf. BAY 1997, EDLUND & ALT 1989).

5.2 Syntaxonomical aspects of the vegetation zones of Greenland

Syntaxonomical approaches to subdivision of the Arctic are very scant, however promising as was shown by e.g. ELVEBAKK (1985), THANNHEISER (1987) and WALKER (1999a).

Tab. 4 shows an inventory of classes which are known from 6 lowland regions in Greenland. These regions are rather well known (mainly BAY 1997, BÖCHER 1954, DANIELS 1982, 1994, DANIELS & ALSTRUP 1996, DE MOLENAAR 1974, 1976, FREDSKILD, 1998, LÜNTERBUSCH

Tab. 4: Occurrences of syntaxa (classes) in several localities in Greenland as examples of the different zones:
1 Station Nord in the Arctic Herb Zone, 2 Amdrup Land in the Northern Arctic Dwarf Shrub Zone, 3 Inland of eastern North Greenland and localities in Northeast Greenland belonging to the Middle Arctic Dwarf Shrub Zone, 4 Coastal Angmagssalik District belonging to the Southern Arctic Dwarf Shrub Zone and 5 Inland around Söndre Strömfjord in Southwest Greenland (Arctic Shrub Zone). Fragmentary or less common occurrence in brackets (x).

Zone	1	2	3	3	4	5
Name	AHZ	NADZ	MADZ	MADZ	SADZ	ASZ
Locality	Station	Amdrup	Centrum	NEG	Ammas	SSF
	Nord	Land	Soe		salik	
	81°36'	ca 81°N	80°10'N	75-72°N	ca 65°N	67°N
	Nc	Nc	Ni	NEG(c)	SEG(c)	WGi
Author	CBay	CBay	FDan	BFred	FDan	TBöch
Number of classes	2	4	7	12	20	19
Minimum number of associations	2	4	11	13	45	45
Thlaspietea	x	x	x	x	x	x
Salicetea herbaceae	x	x	x	x	x	(x)
Carici-Kobresietea		(x)	x	x	x	x
Scheuchzerio-Caricetea		(x)	x	x	x	x
Montio-Cardaminetea			(x)	(x)	x	x
Calamagrostietea purpurascentis			(x)	x	(x)	x
Loiseleurio-Vaccinietea			x	x	x	x
Juncetea maritimi				x	x	(x)
Phragmitetea				x	x	x
Honckenyo-Elymetea				(x)	(x)	(x)
Asplenietea				(x)	(x)	(x)
Isoeto-Nanojuncetea				(x)	(x)	(x)
Salicetea purpureae ?					x	x
Potametea					x	x
Mulgedio-Aconitetea					x	x
Oxycocco-Sphagnetea					(x)	x
Koelerio-Corynephoretea					(x)	(x)
Littorelletea uniflorae					(x)	(x)
Utricularietea					(x)	(x)
Caricetea curvulae					x	

et al. 1997; see also FREDSKILD 1992). Two regions belong to the Middle Arctic Dwarf Shrub Zone, the other zones are represented each by one region.

In the Arctic Herb Zone (1) only two classes occur: *Thlaspietea rotundifolii* and *Salicetea herbaceae* represented each by one association: *Papaveretum dahlianae* Hoffmann 1968 and *Phippsietum algidae-concinnatae* Nordh. 1943 (derived from BAY 1997).

In the Northern Arctic Dwarf Shrub Zone (2) the same associations and *Salix arctica* snowbeds are found, but additionally fragmentarily developed communities of the classes *Scheuchzerio-Caricetea* and *Carici-Kobresietea* occur: *Carici-Dryadetum* Dan. 1982 and *Drepanoclado-Caricetum stantis* (sensu DIERSSEN 1996) (derived from BAY 1997). Thus four classes and at least 4 associations occur.

In the Middle Arctic Dwarf Shrub Zone (3) in the inland of eastern North Greenland at least eleven associations occur in the inland of eastern North Greenland belonging to 7 classes, the previous four and *Montio-Cardaminetea, Calamagrostietea purpurascentis* prov. and

Loiseleurio-Vaccinietea. (*Pleuropogon sabinei* vegetation is provisionally classified in the *Scheuchzerio-Caricetea*) (DANIELS 1999, DANIELS & ALSTRUP 1996).

In Northeast Greenland the zone is well represented. Minimum number of associations is 13 just as the number of classes. Apart from the previous 7 classes, salt marsh associations of the *Juncetea maritimi* occur now, just as vegetation types of the classes *Phragmitetea* (represented by the *Hippuridetum vulgaris* Rübel 1912), *Honckenyo-Elymetea, Asplenietea* and *Isoeto-Nanojuncetea* (cf. FREDSKILD 1998).

The Southern Arctic Dwarf Shrub Zone (4) in coastal Southeast Greenland has at least 45 associations spread over 19 classes. New occurrences are *Salicetea purpureae* (?), *Mulgedio-Aconitetea, Potametea, Caricetea curvulae, Oxycocco-Sphagnetea, Littorelletea uniflorae* and *Utricularietea intermedio-minoris*.

The Arctic Shrub Zone (5) in the inland of southern West Greenland has approximately the same diversity as zone 4, however the classes *Oxycocco-Sphagnetea* and *Calamagrostietea purpurascentis* prov. are well represented now, while the *Salicetea herbaceae* class is not prominent (BÖCHER 1954).

Thus diversity in terms of plant communities (associations) and classes increases as expected from the Arctic Herb Zone to the Southern Arctic Dwarf Shrub Zone and Arctic Shrub Zone. *Thlaspietea rotundifolii* and *Salicetea herbaceae* occur in all zones; *Carici-Kobresietea* and *Scheuchzerio-Caricetea* are with many vegetation types well developed in the Middle and Southern Arctic Dwarf Shrub and Arctic Shrub Zones. There is much syntaxonomical similarity on the class level between the latter two zones; moreover both zones have several differentiating classes against the other 3 zones.

6. Some examples of species richness of arctic plant communities

Species diversity of vascular plants is known to decline from temperate to arctic regions (see chapter 3.2). Species diversity of cryptogams however remains about the same (e. g. 1674 lichen species in Germany including the alpine parts (WIRTH 1994), 919 in Denmark (ALSTRUP & SÖCHTING 1989) and at least 1013 in Greenland (unpublished checklist). Also MATVEYEVA (1998) observed a rather stable composition of crytogams from south to north in the Russian arctic tundra with a change of the proportions of vascular plants/mosses/lichens from 1/0.9/1.1 in the Southern to 1/1.5/1.8 in the Northern Tundra Zone and 1/2/3 in the Polar Desert.

On the community level and if the cryptogams are considered species richness tends to be higher in the Arctic than in temperate areas as was for example shown by comparative studies of lichen dominated vegetation (cf. BÜLTMANN & DANIELS 2000) (Tab. 5). Very extreme habitats in the Arctic such as snow beds or extremely wind swept sites are poorer in species than moderate habitats. In lichen snow beds e.g. *Cetrarietum delisei* (Res.-Holm. 1920) Dahl 1957 17 species/m^2 are found, in bryophyte snow beds 23 species; in moderate *Empetrum n.* ssp. *hermaphroditum-Betula nana-Vaccinium uliginosum* ssp. *microphyllum* heaths 32 species occur (mean species richness calculated from 5 one square meter plots each)(unpublished data from West-Greenland). MATVEYEVA (1998) found a significant reduction of cryptogam species number only for the High Arctic.

The decline in species richness from circumneutral to acidic substrates which is well known for temperate regions, exists in the Arctic too. For example species richness of the wind-exposed heath community *Sphaerophoro-Vaccinietum* Dan. 1982 on acidic substrate is 36, that of the windexposed *Dryas*-vegetation on neutral soil 50; of *Empetrum n.* ssp. *hermaphroditum-Betula nana-Vaccinium u.* ssp. *microphyllum* heath on acidic substrate 32 and of

Tab. 5: Comparison of species richness of several vegetation types dominated by terricolous lichens in Germany, Denmark, Finland and Southeast Greenland

	total species richness per 0,25 m^2			phanerogam species richness per 0,25 m^2			N
	max.	mean	min.	max.	mean	min.	
Germany	26	16,3	4	15	4,4	0	111
Denmark	41	17,7	4	21	5,2	0	85
Finland	39	16,7	4	11	2,1	0	140
Greenland	71	31,3	9	13	4,7	0	152

Cassiope tetragona-heath with *Dryas* on neutral substrate 43. Species richness is calculated from 5 one square meter plots each (unpublished data from West-Greenland). The species richness on circumneutral soil can be extraordinarily high in the Arctic. More than 60 species can be found in plots of about 4 square meter (see LÜNTERBUSCH & DANIELS 2000).

As reason for the high species richness in the Arctic on the community level the high diversity of micro-habitats mostly caused by small scale disturbances is assumed. The importance of habitat diversity on species richness on the community level has been shown by SHMIDA & WILSON (1985) for desert vegetation and by GOULD & WALKER (1999) for a river valley system in the Canadian Arctic.

Summary

An overview is presented of flora and vegetation zonation within the North-American Arctic with major emphasis on Greenland. Vascular plant species diversity in Greenland appears to be strongly correlated with summer temperature as expressed by the sum of mean temperatures in °C of months with mean temperature above 0°C. This is in conformity with previous studies in the Alaskan and Canadian Arctic. A recent bioclimatic subdivision of the Arctic is slightly modified for Greenland. An alternative nomenclature is proposed and the zones are syntaxonomically described by their classes. With the decline in summer temperature the number of vascular plant species and syntaxa decrease. However total species richness remains high or even increases in many vegetation types if mosses and lichens are considered adequately.

Zusammenfassung

Es wird ein Überblick über Flora und Vegetationszonierung der nordamerikanischen Arktis am Beispiel von Grönland gegeben. Die Diversität der Gefäßpflanzen Grönlands korreliert gut mit der Sommertemperatur, ausgedrückt als Summe der mittleren Temperaturen in °C der Monate mit einer mittleren Temperatur über 0°C. Das stimmt überein mit bestehenden Studien aus den arktischen Regionen Alaskas und Kanadas. Eine rezente bioklimatische Unterteilung der Arktis wurde am Beispiel von Grönland modifiziert. Eine alternative Nomenklatur wird vorgeschlagen und die Zonen werden anhand ihrer Klassen syntaxonomisch dargestellt. Mit abnehmender Sommerwärme verringert sich die Anzahl der Gefäßpflanzen-Arten und Syntaxa. Der Artenreichtum bleibt für die Bestände der meisten Vegetationseinheiten jedoch hoch oder nimmt sogar zu, wenn Kryptogamen angemessen berücksichtigt werden.

Acknowledgements

Thanks are due to the German Research Foundation and to the project leader of the Circumpolar Arctic Vegetation Mapping Project, Prof. Dr. D.A. Walker, and Dr. W.A. Gould, University of Fairbanks, Institute of Arctic Biology, Alaska for financial support. F.J.A. Daniels and M. Wilhelm thank Prof. Walker and his staff for stimulating discussions, help and advice during a three weeks stay in Fairbanks.

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