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Environment and Site Descriptions of an Ecological Baseline Study in the Canadian Arctic: The Tundra Northwest Expedition 1999 (Nunavut and Northwest Territories, Canada)

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Abstract: As a product of the terrestrial research group, this paper provides basic information and results from the Swedish expedition "Tundra Northwest" 1999 for biodiversity in vegetation. It also serves to introduce further papers on soils, soil organisms and vegetation. The expedition was based on a mobile platform, the Canadian icebreaker "Louis St. Laurent", and took place from July to end of August 1999. The route went through the Canadian Arctic Archipelago and was designed to cover latitudinal and longitudinal gradients from east to west as well as from south to north. The gradients allowed to obtain a synoptic view of arctic ecological features during a single season at the 17 sites visited throughout the archipelago.

Zusammenfassung: Mit diesem Beitrag werden grundlegende Informationen zur schwedischen Expedition "Tundra Northwest 1999" mit besonderer Berücksichtigung der Felduntersuchungen gegeben. Angefügt sind erste Ergebnisse zur Biodi-versität der Vegetation. Diese Arbeitsgruppe untersuchte vornehmlich Böden, Bodenbiologie und Muster der verschiedenen Pflanzengesellschaften. Diese vom Eisbrecher „Louis St. Laurent" als Standquartier aus durchgeführte Expedition dauerte von Mitte Juli bis Ende August 1999 und wurde in zwei Abschnitten durchgeführt. Ziel war eine synoptische Erfassung ökologischer Faktoren innerhalb einer Saison auf 17 Stationen des kanadischen arktischen Archipels. Dieser Beitrag führt ein in eine Reihe von Untersuchungen, die auf den hier vorgestellten Stationen basieren.

INTRODUCTION

The general objective of the Tundra Northwest Expedition 1999 (TNW-99) was to conduct systematic and ecological studies in the North American tundra along latitudinal and longitudinal gradients within a single season. The ship-based expedition was divided into two legs – Leg 1 from Ungava Peninsula to southern Banks Island and Leg 2 from Ivvavik, northern Yukon, to Baffin Island – with continuous projects, and partial overlap in personnel. In total, about 70 scientists participated in 42 scientific projects. The scientific programme comprised five major themes (Grönlund 1999, Molau et al. 1999):

A: Trophic interactions in the tundra;
B: Biodiversity;
C: Migration, dispersal, and functional adaptations;
D: Trophic structure in freshwater ecosystems;
E: Impacts of climate change and pollution.

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Many studies predict that the greatest impact of global change will be on the polar region (ACIA 2004) and in this context some questions are becoming more and more pressing:

- How will the plant communities present today in the Arctic change in response to longer (or shorter) growing seasons, to dryer (or wetter) summers, or to intensive grazing?
- Are some plant communities more likely to respond to change by the establishment of new individuals? Which ones? Why?
- Can we expect new species to colonize the northern regions? Which area should we monitor to measure such changes?
- Could some species already present in the soil, although in a dormant stage, contribute rapidly to vegetation change?

This, especially, since we know that the cold conditions in the Arctic may favour the persistence of viable seeds in the soil for extended periods of time (e.g., McGraw et al. 1991). The questions are complex and must be addressed by specialists studying different aspects of the ecosystem.

The TNW-99 expedition provided the opportunity to take concerted action, and the researchers set out to collect the baseline data required to answer some of these questions. This paper reports on findings from Theme B: Biodiversity. The collaborative effort under the biodiversity theme aimed at documenting the present-day vegetation patterns along geographical and ecological transects, allowing formation of a comprehensive data base on soils, soil biology and vegetation in arctic environments. With this information at hand, it should be possible to interpret interactions between climate, vegetation and soils, and to get a better understanding of the interaction between bioclimatic and phytogeographic zonations. In addition, a proposed re-visitation of the sites in 25 or 50 years has the potential to provide us with a key to understand what happens to the arctic environment under climate change.

The overall scientific aims of the concerted action of the biodiversity theme were:

(1) to study changes and patterns in species richness and diversity along geographical gradients (latitude and especially longitude, which has been largely ignored up to now);
(2) to relate the patterns in species richness and diversity to abiotic and ecological factors by contrasting dry and mesic habitats and to biogeographical factors by selecting sites with varying glacial history;

(3) to assess the similarity of species richness and species diversity across groups of organisms both within and among sites (e.g., diversity in vascular plants and mycorrhizal fungi), and across functional as well as taxonomic groups; and
(4) to estimate sampling efficiency for diversity estimates (by comparison with the total species richness recorded from the area).

The scientists contributing to the topic (B) Biodiversity also worked on individual projects, with objectives clustering into three topics: (i) small scale biodiversity, (ii) genetic diversity and (iii) comparative phylogeography. The results from individual projects can be used to assess the variation in species richness and composition at a small scale (1-2000 m), within as well as among sites and groups of organisms. Special emphasis was placed on soil properties and soil microbes, i.e., bacteria, fungi, cyanobacteria, soil algae and small soil-dwelling animals, as well as soil organic matter. These data were used as a link between the above-ground and below-ground biomass. Individual results can also be used to assess the genetic diversity within populations of selected organisms at a local scale (1-10 km) and among populations at the landscape scale (>100 km). By comparing such information among selected organisms it may be possible to detect, for example, glacial refugia in the area and / or migration routes. A direct comparison between genetic and species diversity at each site is also interesting from a methodological point of view.

One of the most interesting questions relating to the climate-change issue is whether or not the arctic vegetation possesses the ability to respond quickly to environmental changes. The biodiversity of any ecosystem includes all the species present in the standing crop (i.e., juvenile and adult populations) and the pool of species stored in dormant stages (e.g., seed banks of plants or cysts and long-lived larval stages in insects). Seed banks are the result of seed accumulation due to past seed production on the site and of seed arrival by dispersal (e.g., by wind or animals). Seed banks are essential to the development of vegetation; if a new species is to establish on a site its seeds have to be, at least for a time, part of the seed bank. In our efforts to understand the diversity and dynamics of terrestrial arctic ecosystems, a better knowledge of what is stored in arctic soils is essential in order to predict how the vegetation can respond to change.

Part of the biodiversity theme addresses this question by quantifying the seeds present in the soil of two adjacent plant communities (one with abundant plant cover and the other with sparse vegetation) at each site visited throughout the Canadian Arctic (Larsson & Lévesque 2002).

This paper, then, provides basic site information and results collected in a team effort of the biodiversity theme on the Swedish TNW-99 expedition. A number of studies reporting on vegetation and soils, carried out under the "International Biological Programme" (IBP) or other programs exist (e.g., Brown et al. 1980, Bliss et al. 1981, Svoboda & Freedman 1994) but they all have more local perspectives. The large-scale investigation described here is unique.

GENERAL DESCRIPTION OF THE AREA VISITED

The Arctic Region, here defined as the area above the northern tree line, covers about 30 % of Canada and about 5.5 % of the worldwide land surface (Brown et al. 1980). It can be divided into five bioclimatic zones according to the consensus agreed upon by the Panarctic Flora Project (Elvebakk et al. 1999; Fig. 1). The nomenclature proposed is:
Zone A: Arctic polar desert zone (northern High Arctic zone);
Zone B: Northern arctic tundra zone (middle High Arctic zone);
Zone C: Middle arctic tundra zone (southern High Arctic zone);
Zone D: Southern arctic tundra zone (northern Low Arctic zone), and
Zone E: Arctic shrub-tundra zone (southern Low Arctic zone).

Elvebakk et al. (1999) define the zones as follows:
Zone A has a desert-like appearance with widely scattered phanerogams which do not experience rhizosphere competition; the cover is mostly below 5 %. Locally cryptogams can present a more closed cover, but only in azonal situations. The arctic polar desert zone has a very short growing season and only poor soil development (Everett et al. 1981). Scattered herbs of genera such as *Saxifraga, Draba, Cerastium, Papaver* and *Phippsia* are the most common.

Zone B typically comprises a component of prostrate shrubs like *Dryas* spp. and *Salix* spp. The plant cover is discontinuous but not desert-like (except in extremely calcareous areas of arctic Canada). Mires with *Carex* and *Eriophorum* are present and peat accumulation occurs.

Zone C is dominated by the dwarf shrub *Cassiope tetragona.* The vegetation is generally closed, and minerotrophic fens often cover large areas. *Epilobium latifolium* communities are characteristic along rivers.

Zone D is still dominated by dwarf shrubs but species of the genera *Betula, Empetrum, Salix,* and *Vaccinium* are replacing *Cassiope tetragona.* Peat is accumulated in mires and tussock tundra dominated by Eriophorum vaginatum covers extensive areas.

Zone E has ridge vegetation of *Loiseleuria* and *Diapensia* on weakly acidic soils and of *Dryas* on calcareous bedrock. A distinct podzol is being formed and shrubs of *Betula, Salix,* and *Alnus* reach heights of more than 0.5 m. Bogs are largely composed of *Sphagnum,* and in the Beringian area tussock tundra dominates the landscape as in zone D.

Glacial history

Three major ice sheets were present in North America during the Last Glacial Maximum (LGM), ~18 ^{14}C ka BP (Clark & Mix 2002). The Laurentide ice sheet was the largest and had its center over Hudson Bay and adjacent central Canada. In the northern part of the Canadian Arctic Archipelago, the Inuitian ice sheet formed. The third ice sheet, the Cordilleran ice sheet, built up over the mountains of western Canada. These three independent ice sheets are considered to have been more or less in coalescence during LGM (Clark & Mix 2002, Marshall et al. 2002, Dyke et al. 2002). Beringia, defined by the

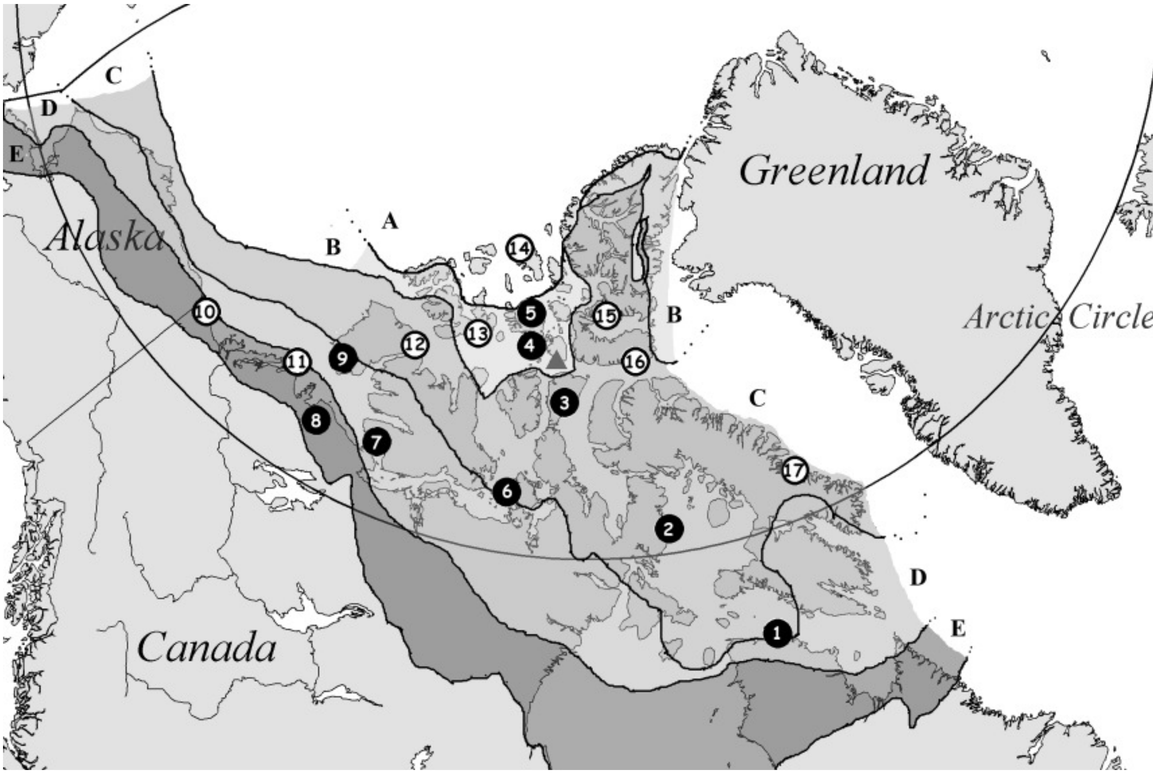

Fig. 1: Sampling sites in the Canadian Arctic visited during the "Tundra Northwest 1999" expedition. Circles numbered 1 through 9 = sites visited during Leg 1; Circles, numbered 10 through 17 = sites visited during Leg 2. Solid-drawn lines = borders between the five bioclimatic zones proposed by ELVEBAKK et al. (1999). A = Arctic polar desert, B = northern Arctic tundra, C = middle Arctic tundra, D = southern Arctic tundra, and E = Arctic shrub-tundra.

Abb. 1: Probenorte in der Kanadischen Arktis während der Expedition "Tundra Northwest 1999". Die Stationen 1-9 (Kreise) waren Teil des ersten Fahrtabschnittes, die Stationen 10-17 lagen im zweiten Fahrtabschnitt. Die Einteilung der bioklimatischen Zonen erfolgte nach ELVEBAKK et al. (1999) in A = Arktische Polarwüste, B = nördliche Arktische Tundra, C = mittlere Arktische Tundra, D = südliche Arktische Tundra, E = Arktische Strauchtundra.

Swedish botanist Eric Hultén (HULTÉN 1937), is situated between the rivers Lena (125 °E) in northern Russia and Mackenzie (130 °W) in northwestern America. It is believed to have served as a major arctic refugium during the Wisconsinan glaciation. In the western part of the Canadian Arctic Archipelago, Banks Island, Prince Patrick Island and most of Melville Island also remained unglaciated (DYKE et al. 2002) and, hence, formed additional refugia for the duration of the stadial. To the east, there may also have been nunataks along the coast of Ellesmere Island (ENGLAND 1999) and ice-free glacial forelands on Baffin Island (MILLER et al. 2002).

Based on the available information on glaciation history, some of the sites visited on the TNW-99 expedition are considered to have been vegetated for at least 50,000 years and maybe longer. These are Banks Island south (Site 9) and Ivvavik (Site 10). It also cannot be excluded that the site on Baffin Island (Site 17) was revegetated from a partly local gene pool. The ice retreated from the west towards the east, starting c. 18 ka BP, melting away from the Hudson Bay area c. 5 ka BP. Hence, the sites visited represent a variety of glacial histories resulting in the large-scale biogeographic pattern we see today.

Geological and physiographic setting

Underlying the eastern arctic islands (Baffin, and the eastern parts of Devon and Ellesmere islands) are granitic rocks of the Canadian Shield. The terrain is mountainous and dramatic, with steep-sided fjords, glaciers and ice caps, and peaks reaching 1900 to 2300 m in elevation. The central and western islands are by comparison low-lying and subdued (generally <500 m), the hills flat-topped, and underlain mostly by sedimentary rocks. In general, the soils of the granitic eastern islands are acidic, while those of the west are calcareous and very basic (pH >8). However, there are isolated pockets of acidic soils in the western islands, where an acidic bedrock forms the parent material (cf. BÖLTER et al. 2006).

Climate

The major climatic regions of northern Canada have been split into five sections (MAXWELL 1981) with significant differences in temperature ranges, precipitation and net radiation (BLISS 1997). Mean July temperatures vary according to locations, from 10 °C near the mainland coast and southern Victoria Island, to less than 5 °C in the central islands. The length of the frost-free season also varies with latitude and longitude, with the longest growing seasons in the south and western regions (e.g., southern Banks Island, Ivvavik National Park on the north slope of the Yukon), from more than 100 frost-free days near the tree-line at 60 °N to less than 30 at Alert, 82 °N on Ellesmere Island.

Precipitation is relatively low across the Canadian Arctic

(≤200 mm annually), with local variations due to proximity to open water and elevation. The lowest amounts of precipitation are received in the central islands, while annual values >300 mm are typical in the mountainous regions of Ellesmere, Devon and Baffin islands. The majority of the precipitation falls as snow in winter. Most of the Canadian Arctic Archipelago receives less than 100 cm snow per year, higher amounts only being found in central (100-200 cm) and eastern (200-300 cm) Baffin Island (French & Slaymaker 1993).

The harsh climate conditions pose various stress factors for the living world in the Arctic. There are frequent freeze-thaw cycles in the upper soil horizons from spring to autumn, dry – wet situations, as well as strong gradients in nutrients and habitats. Tussock tundra sites near Barrow (Alaska) are described as the most biologically inactive areas due to their low nutrient availability (Cheng et al. 1998). Arctic plants and soil-dwelling organisms have obviously developed ways to cope with these hard environmental conditions. Extremes in temperature and moisture or nutrient availability need an adaptation to wide ranges of environmental conditions. This holds especially true for surface horizons, deeper layers down to 1 m may be in favour of isolation effects and nutrient enrichment from leaching, Michaelson et al. (1996) found increased values of nutrients by a factor of 2.5.

Soils

High Arctic environments exhibit mostly well-drained soils (Rieger 1974), a fact which is true for most areas on fjells in our studies. Woodley & Svoboda (1994) further state that such areas often become xeric after snowmelt, and for that reason become covered by drought-resistant lichen assemblages rather than higher plants. Dry sites are generally unfavourable environments for plant and animal life. And low temperatures and poor humidity in combination with elevated salt content and intense UV radiation hamper microbial life in the upper layers. Primary producers in these habitats are mostly restricted to lichens, algae and few cyanobacteria, which provide some nutrients for heterotrophic organisms.

The region is dominated by Cryosols, which show permafrost within 1 or 2 m. Biologically, this region is generally described as tundra and arctic desert. Nevertheless, it holds the largest carbon resources on earth, accounting for about 14 % of total carbon (Post et al. 1982, Gilmanov & Oechel 1995). The large amount of accumulated carbon reflects the long period of sequestration between production and decomposition, the soil here functioning as a sink. Tarnocai (2004) and Smith & Veldhuis (2004) have recent reviews on the soils of the Canadian Arctic. Further data from this cruise have been published by Bölter (1999) and Bölter et al. (2006).

Vegetation

The diversity and distribution of the present-day arctic flora are highly influenced by the climatic changes that occurred during the Quaternary. During periods of glaciation certain areas remained ice-free and served as a northern refugia for arctic and boreal biota, in which taxa have resided for a long time and experienced genome evolution (Abbott et al. 2003). The Canadian Arctic is a patchwork of individual islands with distinct habitats which host distinct populations of plants and animals at scales of meters or below (Rieger 1974). Vegetation patterns and plant growth forms may change drastically within distances of just a few meters due to small-scale patterns of topography and variation in hydrology and soil chemistry (Bliss 1981, Bliss & Svoboda 1984, Gebauer et al. 1995, Chapin et al. 1988). Plant growth and distribution in arctic environments are strongly influenced by the duration of the snow-free period, which is related to topography, just as they are by the general constraints of soil temperature, soil moisture and nutrient availability (Press et al. 1998).

The gently sloped hills characteristic of many of the islands provide the basis for a mosaic of favourable microclimates in a matrix of scarcely vegetated land. In small areas, often just a few square meters in size, with ameliorated climatic conditions, plant growth is prolonged and there is more time for microbial activity. These micro-ecosystems are like oases with high diversity and intensive flowering. Very often the oases are associated with colonies of lemmings, or a dead musk-ox, that release nitrogen (Elliott & Svoboda 1994, Cockell et al. 2001). Consequently, gradients and differences between local aspects and individual habitats can be as large as between different regions. Further, variation in mineralogy of the parent material is much wider than in pedological features (Pawlik & Brewer 1975). However, correlations between soil mineral content and vascular plant cover are hard to establish (Edlund 1983).

Relatively flat terrain in combination with a shallow active layer above the permafrost table prevent rapid runoff of melting water, keep soil moisture high for long periods and thus form the so-called mesic sites. These areas are covered by meadows with taller plants. Soils can have a thick brown top layer penetrated by roots down to 30 cm or even more. Elevated areas become dry and are dominated by cushion plant-lichen communities. It has been demonstrated that the micro relief is an important determinant of community type at Alexandra Fjord (Batten & Svoboda 1994) and in Alaska (Peterson & Billings 1980). This has been attributed to drainage in response to relief patterns (Webber 1978).

Mesic and wet meadow communities with grasses or sedges are the most productive landscapes in this area (Wielgolaski et al. 1981, Henry et al. 1990), which can be related to sufficient water support throughout the growing season. These meadows also serve as the important forage grounds for geese, caribou and musk-ox and as habitats for lemming and hare. During the thaw period, wet conditions prevail, and this situation is valid for more than 80 % of the tundra region (Rieger 1974). As forage grounds for animals they are important wet areas in the Canadian High Arctic, although they occupy just 6 % of this land (Bliss & Gold 1994), at the maximum.

SITE DESCRIPTIONS AND SAMPLING

The TNW-99 expedition took place during the summer of 1999 (June 18 to September 4) by an international party of scientists from Sweden, Norway, Finland, Germany, Canada and the United States. The expedition was organized and sponsored by the Swedish Polar Research Secretariat in cooperation with the Federal Government of Canada and the Territorial Governments of Nunavut and the Northwest Territories. The Canadian Coast Guard icebreaker “Louis St. Laurent” was used as a mobile research platform. Helicopters took the scientists to and from shore.

Figure 1 shows the localities visited during the TNW-99. Localities numbered 1-9 were visited on Leg 1, localities numbered 10-17 on Leg 2. The sites are distributed from the arctic shrub-tundra zone (Zone E) in the south to the arctic polar desert zone (Zone A) in the north (ELVEBAKK et al. 1999), and from the most recently deglaciated areas around Hudson Bay (≈5 ka BP) in the east to the Beringian refugium (>50 ka BP) in the west (DYKE et al. 2002). Table 1 lists the sites, their position and altitude as well as the dates for each visit. Table 2 gives a general description of each site. It contains information compiled from data collected during the expedition according to a common sampling protocol and data from basic literature sources about Canadian ecosystems. Figures 2-4 depict photographs of dry and mesic spots of the landing sites which were chosen as areas for sampling and vegetation mapping; Figures 5-9 show some examples from soil profiles of sampling spots, details of related soil descriptions can be found in BÖLTER et al. (2006).

Site/Location	Date	Latitude (N)	Longitude (W)	Moist.	Alt. (m)	Z
1 Ungava Peninsula	2.7.99	62°22.25	73°47.76	mesic	60	D
2 Melville	5.7.99	67°35.02	81°42.20	dry	140	C
Peninsula	5.7.99	67°53.11	81°43.02	mesic	90	
3 Somerset	10.7.99	72°55.38	93°27.02	dry	85	C
Island	10.7.99	72°55.31	93°26.73	mesic	70	
R Resolute	12.7.99	74°41.99	94°49.78	dry	30	B
4 Bathurst	13.7.99	75°04.42	98°30.98	dry	150	B
Island south	13.7.99	75°04.34	98°31.01	mesic	110	
5 Bathurst Island east	16.7.99	76°26.22	97°56.64	mesic	20	B
6 King	20.7.99	69°06.66	98°55.09	dry	10	C
William Isl.	20.7.99	69°06.06	98°55.90	mesic	5	
7 Wollaston	23.7.99	69°26.46	114°43.50	dry	200	D
Peninsula	23.7.99	69°26.40	114°43.51	mesic	180	
8 Paulatuk	26.7.99	69°45.84	122°02.84	dry	110	E
	26.7.99	69°45.85	122°03.02	mesic	80	
9 Banks	28.7.99	71°43.01	123°44.14	dry	290	D
Island south	28.7.99	71°42.96	123°44.36	mesic	250	
10 Ivvavik	04.8.99	69°25.10	139°38.40	dry	290	E
11 Cape	08.8.99	70°29	127°50	dry	n.d.	E
Bathurst	08.8.99	70°29	127°50	mesic	n.d.	
12 Banks	10.8.99	73°37.32	115°52.02	dry	30	C
Island north	10.8.99	73°37.33	115°51.43	mesic	20	
13 Melville	13.8.99	75°06.35	107°38.11	dry	30	B
Island	13.8.99	75°06.37	107°38.35	mesic	30	
14 Ellef	18.8.99	78°55.59	104°38.21	dry	100	A
Rignes Island	18.8.99	78°55.54	104°38.34	mesic	100	
15 Ellesmere	22.8.99	76°31.00	86°46.08	dry	180	C
Isl. south	22.8.99	76°31.07	86°46.01	mesic	180	
16 Devon	25.8.99	74°32.49	82°47.19	dry	60	C
Island south	25.8.99	74°32.49	82°47.10	mesic	60	
17 Baffin	30.8.99	68°26.21	66°49.24	dry	50	C
Island east	30.8.99	68°26.22	66°49.24	mesic	50	

Tab. 1: Locations visited during the TNW-99 exppedition. Sites 1-9 refer to Leg 1, Sites 10-17 to Leg 2, A-E of column Z refer to the bioclimatic zonations in Figure 1.

Tab. 1: Positionen der Standorte der TNW-99 Expedition. Standorte 1-9 gehören zum Abschnitt 1 der Reise, Standorte 10-17 zum Abschnitt 2; in der Spalte Z sind die bioklimatischen Zonen A-E für die jeweiligen Standorte angegeben (s. Abb. 1).

Site No	**1**
Landing site	Ungava Peninsula (Quebec)
Position	62°20'N, 73°40'W
Date	July 2-3 1999
Terr. ecozone*	Northern Ungava Region (Region 31), low arctic, tann -8.5, tsum 3, twin -20, pann 200-300, continuous permafrost, granitic bedrock, cryosols, marine and moraine deposits.
Site remarks	mostly wet sites, "mesic" only along slopes with heath, willows, grasses. Heavily grazed vegetation. At higher altititudes only patchy vegetation, large snow fields at northern slopes. Frost patterns only weak in lowlands.
Mesic site	
Position (GPS)	62°22.25'N, 73°47.76'W
Altitude	60 m
Frost patterns	no
Slope	direction W, 2-3°
Drainage	well
Permafrost depth	65 cm
Plant cover	>100 %
Dominant spec.	*Cassiope tetragona, Vaccinium vitis-idaea, V. uliginosum, Salix herbacea*
Soil crust	no
Roots down to	30 cm
Soil animals	nematodes
Soil type	Haplorthel
Stone content	>30 %
Animal faeces:	caribou
Site No	**2**
Landing site	Melville Peninsula, Cape Robert Brown (Keewatin, Nunavut)
Position	67°30'N, 81°30'W
Date:	July 5-6, 1999
Terr. ecozone*	Foxe Basin Plain (Region 25), mid-arctic, tann -11, tsum 2, twin -23, pann 100, continuous permafrost, cryosols, marine and glacial deposits.
Site remarks	Landscape with hills and gentle slopes, steep slopes near the river. Vegetation with heath, grasses and mosses, on dry areas dominated by moss/lichen cushions. Only weak frost patterns in wet areas with frost boils and slight polygons.
Mesic site	
Position (GPS)	67°35.11'N, 81°43.02'W
Altitude	90 m
Frost patterns	weak polygon structures
Slop	direction W, 1-2°
Drainage	not well drained, water logged in depressions
Permafrost depth	35 cm
Plant cover	100 %
Dominant spec.	*Cassiope tetragona, Dryas integrifolia, Salix arctica, Carex bigelowii*
Soil crust	no
Roots down to	20 cm
Soil animals	nematodes
Soil type	Haplorthel
Stone content	<5 %
Animal faeces	caribou, hare
Dry site	
Position (GPS)	67°35.02'N, 81°42.2'W
Altitude	140 m
Frost patterns	frost boils
Slope	direction / dipping 0°
Drainage	well drained
Permafrost depth	65 cm
Plant cover	85 %
Dominant spec.	*Cassiope tetragona, Dryas integrifolia, Saxifraga oppositifolia, Salix arctica*
Soil crust	moss / lichen, 2 cm
Roots down to	20 cm
Soil animals	nematodes, rotatores
Soil type	Haplorthel
Stone content	20
Animal faeces	caribou

Site No	**3**
Landing site	Somerset Island, Creswell Bay (Baffin, Nunavut)
Position	72°55'N, 93°15'W
Date	July 10-11, 1999
Terr. ecozone*	Lancaster Plateau (Region 13), arctic, tann -13, tsum 2, twin -26.5, pann 100-200, continuous permafrost, sedimentary rocks, regosolic cryosols on colluv., alluv., morainal and marine sediments.
Site remarks	Landscape with poorly vegetated hills with gravelly surfaces and large wet depressions with dense cover of grasses. Mesic sites at slopes. Frost patterns of boils and weak polygons (d = 1-2 m), stripes.
Mesic site	
Position (GPS)	72°55.31'N, 93°26.73'W
Altitude	70 m
Frost patterns	slight polygons
Slope	direction S, 3°
Drainage	well
Permafrost depth	40 cm
Plant cover	100 %
Dominant spec.	*Carex misandra, C. stans, Arctagrostis latifolia, Eriophorum angustifolium, Dryas integrifolia, Salix arctica*
Soil crust	no
Roots down to	25 cm
Soil animals	nematodes
Soil type	Psammoturbel
Stone contents	>30 %
Animal faeces	muskox
Dry site	
Position (GPS)	72°55.38'N, 93°27.02'W
Altitude	85 m
Frost patterns	soil stripes
Slope	direction S, 3°
Drainage	well
Permafrost depth	55 cm
Plant cover	10 %
Dominant spec.	*Dryas integrifolia, Salix arctica, Saxifraga oppositifolia, Carex rupestris*
Soil crust	no
Roots down to	15 cm
Soil animals:	nematodes, collemboles
Soil type	Haplorthel
Stone content	>30 %
Animal faeces	muskox

Site No	**4**
Landing site	Bathurst Island South, Dyke Acland Bay (Baffin, Nunavut)
Position	75°05'N, 99°W
Date	July 13-14, 1999
Terr. ecozone*	Parry Islands Plateau (Region 12), high arctic, tann -17.5, tsum -1.5, twin -31, pann 100-150, continuous permafrost, palaeozoic carbonates and sandstones, cryosols on morainal and colluvial deposits.
Site remarks	Hills with fjells, weak to steep slopes with poor vegetation. Valleys and depression wet and well covered mainly by mosses and grasses, mesic sites at slopes. Weak polygones only in wet and mesic sites, frost patterns mostly as stripes.
Mesic site	
Position (GPS)	75°04.34'N, 98°31.01'W
Altitude	110 m
Frost patterns	weak polygons
Slope	direction SW, 1-2°
Drainage	mostly poor, water logged, mesic sites at slopes
Permafrost depth	50 cm
Plant cover	100 %
Dominant spec.	Common: *Hierochloe alpinum, Carex aquatilis, C. misandra, Eriophorum angustifolium, E. scheuchzeri, Arctagrostis latifolia, Draba corymbosa, D. lactea, Saxifraga spp., Salix arctica*
Soil crust	no
Roots down to	25 cm
Soil animals	nematodes, collemboles
Soil type	Haplorthel
Stone content	<10 %
Animal faeces	no

Dry site	
Position (GPS)	75°04.42'N, 98°30.81'W
Altitude	150 m
Frost patterns	weak, small polygones, stripes
Slope	direction SW, 2°
Drainage	well
Permafrost depth	45 cm
Plant cover	5 %
Dominant spec.	*Dryas integrifolia* dominated; *Salix arctica, Papaver radicatum, Draba corymbosum, Saxifraga oppositifolia* also common
Soil crust	no
Roots down to	10 cm
Soil animals	nematodes
Soil type	Haplorthel
Stone content	>70 %
Animal faeces	no

Site No	**5**
Landing site	Bathurst Island North (Baffin, Nunavut)
Position	76°26'N, 99°50'W
Date	July 16, 1999
Terr. ecozone*	c.f. Site 4
Site remarks	Flat area with slight hills. Vegetation dominated by mosses and lichens, frost patterns as small polygons and stripes.
Mesic site	
Position (GPS)	76°26.22'N, 97°56.64'W
Altitude	20 m
Frost patterns	small polygons (d = 20-50 cm)
Slope	direction / dipping 0°
Drainage	well
Permafrost depth	45 cm
Plant cover	90 %
Dominant spec.	*Saxifraga oppositifolia*
Soil crust	moss / lichen, 3-4 cm
Roots down to	15 cm
Soil animals	nematodes
Soil type	Psammoturbel
Stone content	<10 %
Animal faeces	none

Site No	**6**
Landing site	King William Island, Graham Gore Peninsula (Kitikmeot, Nunavut)
Position	69°N, 99°10'W
Date	July 20-21, 1999
Terr. ecozone*	Victoria Island Lowlands (Region 18), mid-arctic, tann -14, tsum 1.5, twin -29, pann 100-150, palaeozoic and proterozoic carbonate rocks, cryosols, continuous permafrost, glacial deposits.
Site remarks	Landscape of raised beaches and thereof derived terraces. Flat areas (weak depressions) vegetated with mosses and lichens, elevated areas mostly barren. Coarse, strong calcaerous material.
Mesic site	
Position (GPS)	69°06.06'N, 98°55.90'W
Altitude	5 m
Frost patterns	weak polygons, hummocks
Slope	direction / dipping 0°
Drainage	well
Permafrost depth	n.d., large boulders at 50 cm
Plant cover	100 %
Dominant spec.	common *Poa arctica, P. abbreviata, Carex misandra, C. scirpoidea, Dryas integrifolia, Saxifraga tricuspidata, Draba corymbosa, Salix arctica*
Soil crust	no
Roots down to	30 cm
Soil animals	nematodes
Soil type	Haplorthel
Stone content	>70 %
Animal faeces	no
Dry site	
Position (GPS)	69°06.66'N, 98°55.09'W
Altitude	10 m
Frost patterns	no stripes, weak polygons
Slope	direction / dipping 0°
Drainage	well

Permafrost depth	80 cm
Plant cover	5 %
Dominant spec.	*Dryas integrifolia, Saxifraga tricuspidata, S. oppositifolia, Draba corymbosa, Papaver radicatum, Salix arctica*
Soil crust	3 cm
Roots down to	15 cm
Soil animals	no
Soil type	Haplorthel
Stone content	>70 %
Animal faeces	no
Site No	**7**
Landing site	Wollaston Peninsula, Victoria Island, Falaise Bay (Kitikmeot, Nunavut)
Position	69°25'N, 115°W
Date	July 23-25, 1999
Terr. ecozone*	see Site 6
Site remarks	Landscape with strong elevations as hills with barren soils, lowlands and low slopes covered with grasses. Weak frost patterns, mostly stripes at fjells.
<u>Mesic site</u>	
Position (GPS)	69°26.40'N, 114°43.51'W
Altitude	180 m
Frost patterns	slight hummocks
Slope	direction S, 6-8°
Drainage	well
Permafrost depth	>100 cm
Plant cove	90 %
Dominant spec.	*Salix arctica, S. reticulata, Dryas integrifolia*
Soil crust	no
Roots down to	40 cm
Soil animals	nematodes, rotifers
Soil type	Psammorthel
Stone content	10-75 % with increasing depth
Animal faeces	caribou, muskox
<u>Dry site</u>	
Position (GPS)	69°26.46'N, 114°43.50'W
Altitude	200 m
Frost patterns	weak stripes
Slope	direction S, 4°
Drainage	well
Permafrost depth	>100 cm
Plant cover	10 %
Dominant spec.	*Dryas integrifolia, Saxifraga oppositifolia*
Soil crust	no
Roots down to	35 cm
Soil animals	nematodes
Soil type	Psammorthel
Stone content	20, large rocks at > 90 cm
Animal faeces	muskox
Site No	**8**
Landing site	Paulatuk, Pierce Point, Albert Bay (Inuvaluit)
Position	69°N, 122°10'W
Date	July 26-27, 1999
Terr. ecozone*	Coronation Hills (Region 36), low arctic, tann -11, tsum 5, twin -26, pann 200, palaeozoic carbonates, continuous permafrost, glacial tills, fluvioglacial and marine deposits, cryosols.
Site remarks:	Landscape with large rocky outcrops and strongly weathered rocks. Plains and slight slopes well covered with grasses and mosses, higher levels mostly barren and gravels covered by lichens. Frost patterns not visible.
<u>Mesic site</u>	
Position (GPS)	69°45.85'N, 122°03.02'W
Altitude	80 m
Frost patterns	no
Slope	direction / dipping 0°
Drainage	no
Permafrost depth	105 cm
Plant cover	100 %
Dominant spec.	*Carex* spp., *Dryas integrifolia, Saxifraga oppositifolia, Silena acaulis, Hedysarum mackenzei*
Soil crust	no
Roots down to	25 cm
Soil animals	nematodes, oligochaetes
Soil type	Psammorthel

Stone content	30
Animal faeces	grizzly
<u>Dry site</u>	
Position (GPS)	69°45.84'N, 122°02.84'W
Altitude	110 m
Frost Patterns	no
Slope	direction W, 3°
Drainage	well
Permafrost depth	>100 cm
Plant cover	10 %
Dominant spec.	*Carex* spp.; *Dryas integrifolia, Saxifraga oppositifolia*
Soil crust	no
Roots down to	15 cm
Soil animals	nematodes, rotators
Soil type	Psammorthel
Stone content	>70 %
Animal faeces	no
Site No	**9**
Landing site	Banks Island South, Swan Lake (Inuvaluit)
Position	71°45' N, 123°30'W
Date	July 28-29, 1999
Terr. ecozone*	see Site 6
Site remarks	Landscape with large hills with fjells on top and vegetated areas at low slopes and in valleys. Large polygons close to lake and in river plains.
<u>Mesic site</u>	
Position (GPS)	71°42.96'N, 123°44.36'W
Altitude	250 m
Frost patterns	small hummocks
Slope	direction W, 2°
Drainage	well
Permafrost depth	55 cm
Plant cover	100 cm
Dominant spec.	*Carex* spp., *Dryas integrifolia, Salix arctica*
Soil crust	no
Roots down to	35 cm
Soil animals	n.d.
Soil type	Haplorthel
Stone contents	10 %
Animal faeces	muskox
<u>Dry site</u>	
Position (GPS)	71°43.01'N, 123°44.14'W
Altitude	290 m
Frost patterns	no
Slope	direction / dipping 0°
Drainage	well
Permafrost depth	>100 cm
Plant cover	30 %
Dominant spec.	*Dryas integrifolia, Draba cinerea, Artemisia borealis, Salix arctica*
Soil crust	no
Roots down to	40 cm
Soil animals	n.d.
Soil type	Psammorthel
Stone content	>70 %
Animal faeces	muskox

Tab. 2: Locations, sites and site descriptions TNW-99 (Leg 1). (* = data of Terrestrial Ecozones from <http://www.cciw.ca/eman-temp/ecozones/>). Abbreviations: tann = annual mean temperature in °C; tsum = summer mean temperature; twin = winter mean temperature; pann = mean annual precipitation in mm.

Tab. 2: Stationen und Standortbeschreibungen für den Abschnitt 1 der Expedition TNW99. (* Angaben zu den „Terrestrial Ecozones" von: <http://www.cciw.ca/eman-temp/ecozones/>). Abkürzungen: tann = mittlere Jahrestemperatur in °C; tsum = mittlere Sommertemperatur; twin = mittlere Wintertemperatur; pann = mittlerer Jahresniederschlag in mm.

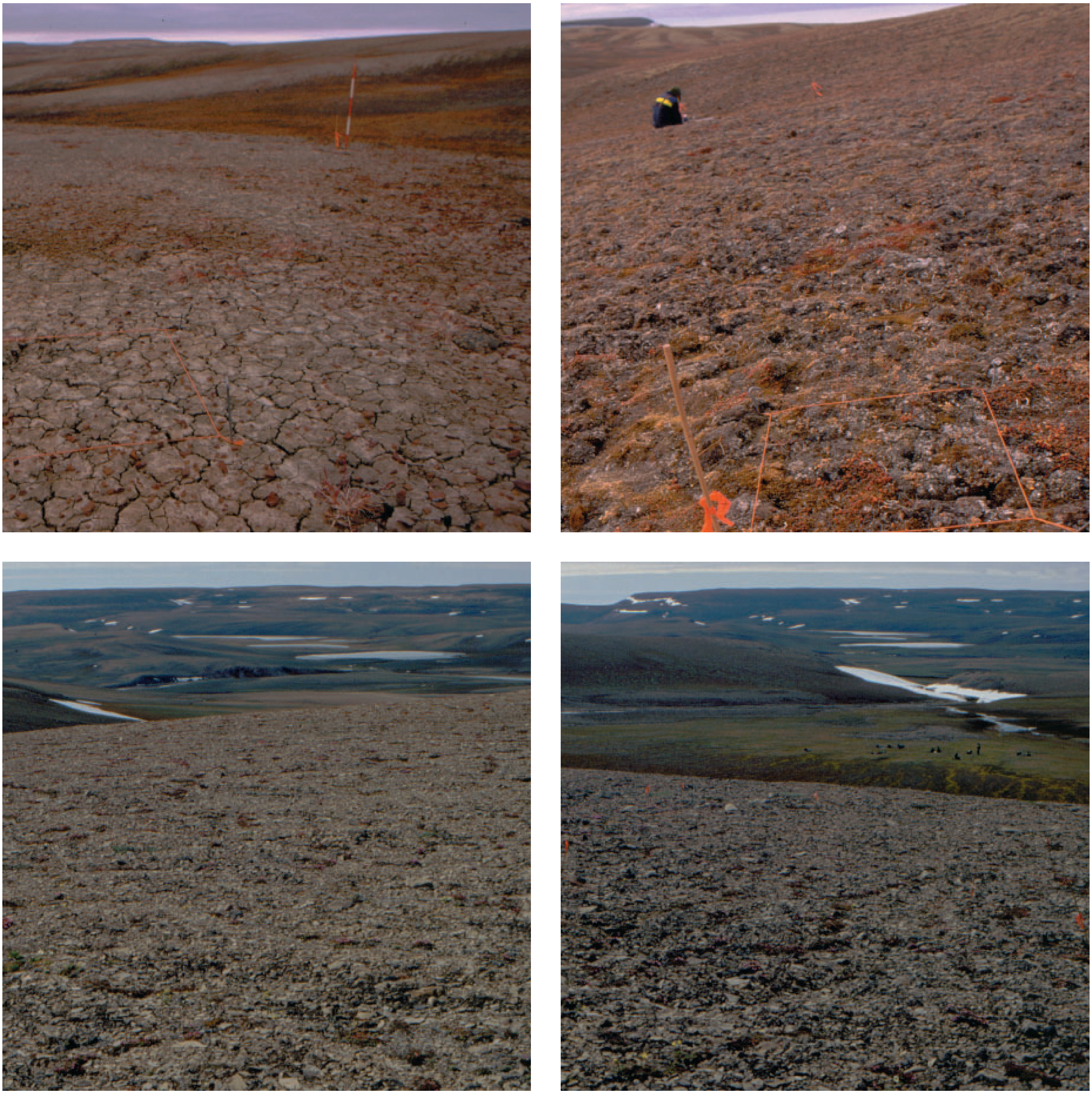

Fig. 2: Photographs from sampling sites representing landscapes of bioclimatic zones A and B (see Fig. 1 and Tab. 1). Top = Zone A, Site 14, Ellef Ringnes Island, dry left and mesic (right); photos by A. Dahlberg. Bottom = Zone B, Site 4, Bathurst Island (south), dry (left) and dry and mesic in the background (right); photos by M. Bölter.

Abb. 2: Fotos repräsentativer Probenorte für die bioklimatischen Zonen A und B (siehe Abb. 1 und Tab. 1). Oben: Zone A, Station 14, Ellef Ringnes Island, trockener Standort (links) und mesisch-feuchter Standort (rechts); Fotos: A. Dahlberg. Unten: Zone B, Station 4, Bathurst Island (south), trocken (links), trockener und mesisch-feuchter Standort im Hintergrund (rechts) (Fotos M. Bölter).

Sampling

Arriving at a site by helicopter, the area was surveyed from the air to find a suitable spot to use as campsite and, hence, also study site. The site was selected in a way that allowed all researchers within each theme to gain maximum information about the area. However, site selection was always a compromise. At each site, an area characterized as mesic and another characterized as dry were selected. These characterizations turned out to be more than trivial because of the huge difference in plant composition and hydrology from site to site. However, to be able to carry out longitudinal and latitudinal comparisons on a large scale in our biodiversity estimates, we had to find reasonably comparable communities at the different sites.

The mesic habitat would typically have 100 % plant cover, whereas the drier habitat had scattered plant cover. Examples of mesic as well as dry areas are shown in figures 2 to 4. Figures 5 to 9 show some typical soil profiles of dry and mesic

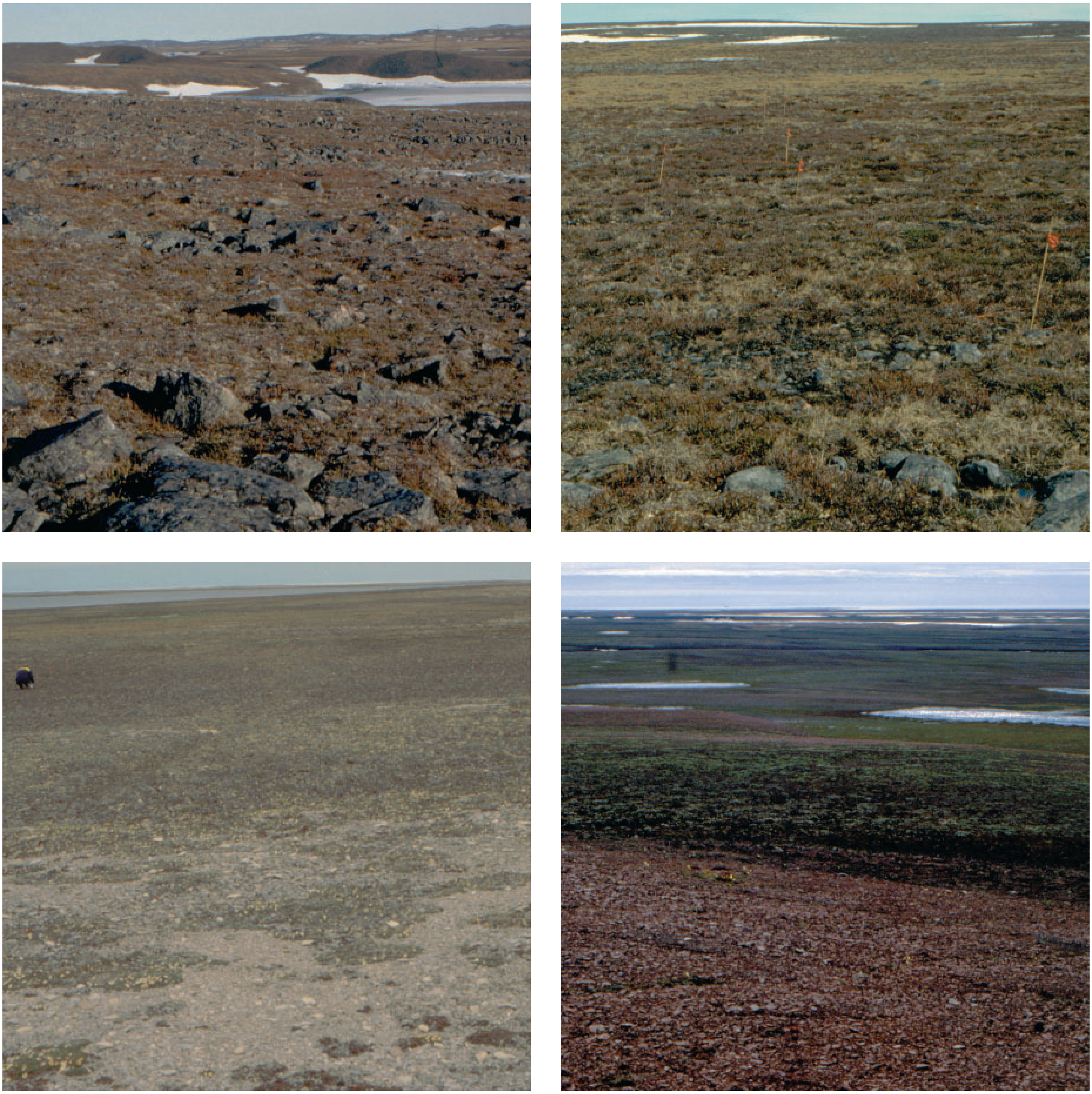

Fig. 3: Photographs from sampling sites representing landscapes of bioclimatic zone C (see Fig. 1 and Tab. 1). Top = Zone C, Site 2; Melville Peninsula, dry (left) and mesic (right). Bottom = Zone C, Site 6, King William Island (left) and Site 3, Sommerset Island (right) with the dry areas in the foreground and the mesic areas in the background (Photos M. Bölter).

Abb. 3: Fotos repräsentativer Probenorte für die bioklimatischen Zone C (siehe Abb. 1 und Tab. 1). Oben: Zone C, Station 2; Melville Peninsula, trocken (links) und mesic (rechts). Unten: Zone C, Station 6, King William Island (links) und Station 3, Sommerset Island (rechts) mit den trockenen Standorten im Vordergrund, den mesisch-feuchten im Hintergrund (Fotos M. Bölter).

sites. Important differences between sites and plots can be seen by the organic top layers and the root depth. Details of soils are given by Bölter et al. (2006). For the vegetation analysis we selected a 20 x 20 m plot in each plant community and studied 10 random quadrates (50 x 50 cm). Point frames with 25 points gave a measure of plant abundance and diversity. Experts on the different groups of organism participated in the determination of the material collected.

Following the common sampling of different plant species, seed banks were sampled within the same quadrates (10 per plant community). The topsoil (approx. 1 cm) and a deeper horizon (1-5 cm) of a 10 x 10 cm square were removed. The samples were stored in a -4 °C freezer on board the ship and later brought back to Sweden for germination tests. In five of the ten quadrates a second series of samples was collected in exactly the same way but adjacent to the first samples. These soil samples were dried on the ship and sent to Trois-Rivières, Canada, where they were sieved and sorted to quantify the total seed bank.

Fig. 4: Photographs from sampling sites representing landscapes of bioclimatic zones D and E (see Fig. 1 and Tab. 1). Top = Zone D, Site 9, Banks Island, dry (left) and mesic (right). Botttom = Zone E, Site 8, Paulatuk, dry (left) and mesic (right) (Photos M. Bölter).

Abb. 4: Fotos repräsentativer Probenorte für die bioklimatischen Zonen D und E (s. Abb. 1 und Tab. 1). Oben: Zone D, Station 9, Banks Island, trocken (links) und mesic (rechts); Unten: Zone E, Station 8, Paulatuk, trocken (links) und mesic (rechts) (Fotos M. Bölter).

Investigations on soils and soil microbes were carried out at landing sites of Leg 1 only (Tab. 2). Soil pits were dug down to 1 m depth or until the permafrost level was reached. Analyses of the below-ground aspects were carried out close to the common plots; the description is therefore relevant for comparison with the results of the vegetation analysis. Soils were described and sampled with the aim of evaluating their taxonomical properties (primarily according to the US. Soil Taxonomy). Often, soil frost patterns were observed as large stripes along hill slopes, e.g., on Somerset Island and on Bathurst Island. Different sub-samples were used to analyse the organic and inorganic matter and the soil micro-organisms. Soil surface samples from Leg 2 were collected by Dr. A. Dahlberg. All samples which could not be treated and analysed directly were adequately stored during the cruise for further analyses at home.

Different aspects of botany, such as seed banks, genetic variability, and plant community studies of herbs, mosses and lichens will follow later.

Fig. 5: Photographs of soil profiles from bioclimatic Zone B, Bathurst Island (south), Site 4, dry site (left) and mesic site (right) (Photos M. Bölter).

Abb. 5: Fotos von Bodenprofilen der bioklimatischen Zone B, Bathurst Island (süd), Station 4, trockener Standort (links) und mesisch-feucht (rechts) (Fotos M. Bölter).

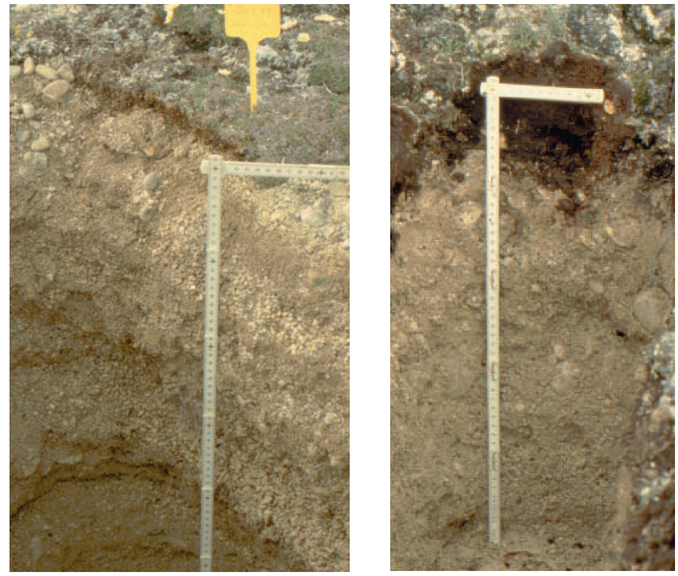

Fig. 7: Photographs of soil profiles from bioclimatic Zone C, King William Island, Site 6, dry site (left) and mesic site (right) (Photos M. Bölter).

Abb. 7: Fotos von Bodenprofilen der bioklimatischen Zone C, King William Island, Station 6, trockener Standort (links) und mesisch-feucht (rechts) (Fotos M. Bölter).

Fig. 9: Photographs of soil profiles from bioclimatic Zone E, Paulatuk, Site 8, dry site (left) and mesic site (right) (Photos M. Bölter).

Abb. 9: Fotos von Bodenprofilen der bioklimatischen Zone E, Paulatuk, Station 8, trockener Standdort (links) und mesisch-feucht (rechts) (Fotos M. Bölter).

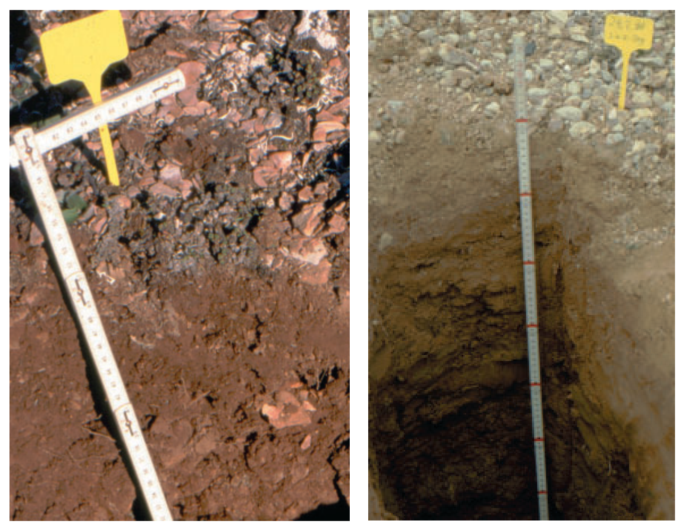

Fig. 8: Left = Photograph of soil profile from bioclimatic Zone C, Sommerset Island, Site 3, dry site. Right = Photograph of soil profile from bioclimatic Zone D, Wollaston Peninsula, Site 7, dry site (Photos M. Bölter).

Abb. 8: Links: Foto eines Bodenprofile der bioklimatischen Zone C, Sommerset Island, Station 3, trockener Standort. Links: Foto eines Bodenprofils der bioklimatischen Zone D, Wollaston Halbinsel, Station 7, trockener Standort (Fotos M. Bölter).

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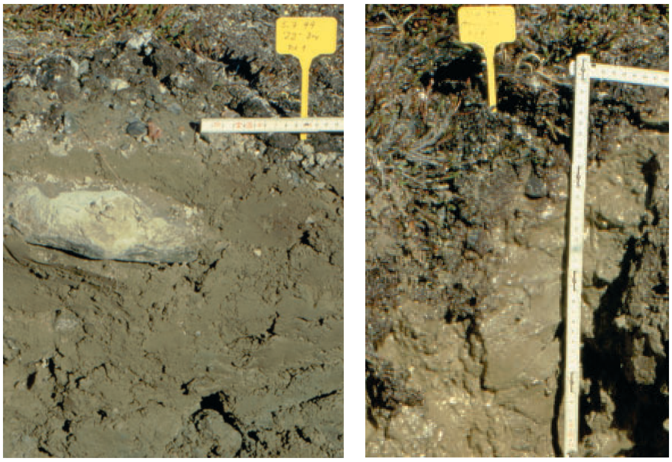

Fig. 6: Photographs of soil profiles from bioclimatic Zone C, Melville Peninsula, Site 2, dry site (left) and mesic site (right) (Photos M. Bölter).

Abb. 6: Fotos von Bodenprofilen der bioklimatischen Zone C, Melville Peninsula, Station 2, trockener Standort (links) und mesisch-feucht (rechts) (Fotos M. Bölter).

References

Abbott, R.J., Smith, L.C., Milne, R.I., Crawford, R.M.M., Wolff, K. & Balfour, J. (2000): Molecular analysis of plant migration and refugia in the Arctic.- Science 289: 1343-1346.

ACIA (2004): Impacts of a warming Arctic.- Cambridge University Press, Cambridge, 1–140.

Batten, D.S. & Svoboda, J. (1994): Plant communities on the uplands in the vicinity of the Alexandra Fiord Lowland.- In: J. Svoboda & B. Friedman (eds). Ecology of a polar oasis, Alexandra Fiord, Ellesmere Island, Captus University Press, Toronto, 97-110.

Bliss, L.C. (1981): North American and Scandinavian tundras and polar deserts.- In: L.C. Bliss, O.W. Heal & J.J. Moore (eds). Tundra ecosystems: A comparative analysis, Cambridge University Press, Cambridge, 8-24.

Bliss, L.C. (1997): Arctic ecosystems of North America.- In: F.E. Wielgo-laski (ed). Ecosystems of the world, Vol 3, Polar and alpine tundra, Elsevier, Amsterdam, 551-663.

Bliss, L.C. & Svoboda, J. (1984): Plant communities and plant production in the western Queen Elizabeth Islands.- Holarct. Ecol. 7: 325-344.

Bliss, L.C. & Gold, W.G. (1994): The patterning of plant communities and edaphic factors along a high arctic coastline: implications for succession.- Can. J. Bot. 72: 1095-1107.

Bliss, L.C., Heal, O.W. & Moore, J.J. (eds) (1981): Tundra ecosystems: a comparative analysis.- Cambridge University Press, Cambridge, pp. 813.

Bölter, M. (2006): Microbiological communities and properties of soils: results of the Tundra Northwest Expedition 1999 (Nunavut and Northwest Teritories, Canada).- Polarforschung 73: 89–101.

Bölter, M., Blume, H.-P. & Wetzel, H. (2006): Properties, formation, classify-cation and ecology of soils: Results if the Tundra Northwest Expedition 1999 (Nunavut and Northwest Territories, Canada).- Polarforschung 73: 103–110.

Brown, J., Miller, P.C., Tieszen, L.L. & Bunnell, F.L. (eds) (1980): An Arctic ecosystem. The coastal tundra at Barrow, Alaska.- Dowden, Hutchinson, Ross, Stroudsburg, pp. 571.

Chapin, F.S. III, Fetcher, N., Kielland, K., Everett, K.R. & Linkins, A.E. (1988): Productivity and nutrient cycling of Alaskan tundra: enhancement by flowing soil water.- Ecology 69: 693-702.

Cheng, W., Virginia, R.A., Oberbauer, S.F., Gillespie, C.T., Reynolds, J.F. & Tenhunen, J.D. (1998): Soil nitrogen, microbial biomass, and respiration along an arctic toposequence.- Soil Sci. Soc. Amer. J. 62: 654-664.

Clark, P.U., & Mix, A.C. (2002): Ice sheets and sea level of the last glacial maximum.- Quat. Sci. Rev. 21: 1-7.

Cockell, C.S., Lee, P., Schwerger. A.C., Hidalgo, L., Jones, J.A. & Stokes, M.D. (2001): Microbiology and vegetation of micro-oases and polar de-sert, Haughton Impact Crater, Devon Island, Nunavut, Canada.- Arct. Antarct. Alp. Res. 33: 306-318.

Dyke, A.S., Andrews, J.T., Clark, P.U., England, J.H., Miller, G.H., Shaw, J., & Veillette, J.J. (2002): The Laurentide and Innuitian ice sheets during the last glacial maximum.- Quat. Sci. Rev. 21: 9-31.

Edlund, S.A. (1983): Bioclimatic zonation in a high-arctic region: central Queen Elizabeth Islands.- Geol. Surv. Canada, Current Res. A, Paper 83-1A, Ottawa, 381-390.

Elliot, D. & Svoboda, J. (1994): Microecosystems around a large erratic boulder: a high-arctic study.- In: J. Svoboda & B. Freedman (eds). Ecology of a polar oasis, Captus University Publications, Toronto, 207-213.

Elvebakk, A, Elven, R. & Razzhivin, V.Yu. (1999): Delimitation, zonal and sectorial subdivision of the Arctic fort he Panarctic Flora Project.- In: I. Nordal & V.Y. Razzhivin, The Norwegian Academy of Science and Letters, Oslo. Ny Serie No. 38. 375-386.

England, J.H. (1999): Coalescent Greenland and Innuitian ice during the last glacial maximum: revising the Quaternary of the Canadian High Arctic.- Quat. Sci. Rev. 18: 421-456.

Everett, K.R,, Vassiljevskaya, V.D., Brown, J. & Walker, B.D. (1981): Tundra and analogous soils.- In: L.C. Bliss, O.W. Heal & J.J. Moore (eds). Tundra ecosystems: a comparative analysis, Cambridge University Press, Cambridge, 139-179.

French, H.M. & Slaymaker, O. (1993): Canada's cold land mass.- In: H.M. French & O. Slaymaker (eds). Canada's cold environments, McGill Quenn's University Press, Montreal, 3-27.

Gebauer, R. & Reynolds, J.F. & Tenhunen, J.D. (1995): Growth and alloca-tion of the arctic sedges Eriophorum angustifolium and E. vaginatum: effects of variable soil oxygen and nutrient availability.- Oecologia 104: 330-339

Gilmanov, T.G. & Oechel, W.C. (1995): New estimates of organic matter reserves and net primary productivity of the North American tundra eco-systems.- J. Biogeogr. 22: 723-741.

Grönlund, E. (ed) (1999): Polarforskningssekretariatet Arsbok 1999, Polar-forsknings-sekretariatet, Stockholm, 1–204.

Henry, G.H.R., Svoboda, J. & Friedman, B. (1990): Standing crop and net production of sedge meadows of an ungrazed polar desert oasis.- Can. J. Bot. 68: 2660-2667.

Hultén, E. (1937): Outline of Arctic and boreal biota during the Quaternary period, Cramer, New York.

Larsson, E.-L. & Lévesque, E. (2002): Germinable seed banks across the Canadian Arctic.- In: E.-L. Larsson, Seed banks and seed dispersal in subarctic and arctic environments, Dissert. (ISBN 91 88896 40 4), Göteborg University, Sweden.

McGraw, J.B., Vavreck, M.C. & Bennington, C.C. (1991): Ecological genetic variation in seed banks. I. establishment of a time transect.- J. Ecol. 79: 617-625.

Marshall, S.J., James, S.J., & Clarke, G.K.C. (2002): North American ice sheet reconstructions at the last glacial maximum.- Quat. Sci. Rev. 21: 175-192.

Maxwell, J.B. (1981): Climatic regions of the arctic islands.- Arctic 34: 225-240.

Michaelson, G.J., Ping, C.L. & Kimble, J.M. (1996): Carbon storage and distribution in tundra soils of Arctic Alaska, USA.- Arct. Alp. Res. 28: 414-424.

Miller, G.H., Wolfe, A.P., Steig, E.J., Sauer, P.E., Kaplan, M.R., & Briner, J.P. (2002): The Goldilocks dilemma: big ice, little ice, or "just-right" ice in the Eastern Canadian Arctic.- Quat. Sci. Rev. 21: 33-48.

Molau, U., Alerstam, T., Danell, K., Eriksen, B. & Granéli, W. (1999): Tundra Northwest 1999: A collaborative challenge in the Arctic.- Ambio 28: 287-291.

Pawlik, S. & Brewer, R. (1975): Micromorphological and analytical charac-teristics of some soils from Devon and King Christian Islands, N.W.T.- Can. J. Soil Sci. 55: 349-361.

Peterson, K.M. & Billings, W.D. (1980): Tundra vegetational patterns and succession in relation to microtopography near Atkasook, Alaska.- Arct. Alp. Res. 12: 473-483.

Post, W.M., Emanuel, W.R., Zinke, P.J. & Stangenberger, A.G. (1982): Soil carbon pools and world life zones.- Nature 298: 156-159.

Press, M.C., Potter, J.A., Burke, M.J.W., Callaghan, T.V. & Lee, J.A. (1998): Responses of a sub-Arctic dwarf shrub heath community to simulated en-vironmental change.- J. Ecol. 86: 315-327.

Rieger, S. (1974): Arctic soils.- In: J.D. Ives & R.G. Barry (eds). Arctic and Alpine environments, Methuen, London, 749-769.

Smith, C.A.S. & Veldhuis, H. (2004): Cryosols of the boreal, subarctic, and western cordillera regions of Canada.- In: J. Kimble (ed). Cryosols – permafrost-affected soils, Springer-Verlag, Berlin Heidelberg, 119-137.

Svoboda, J. & Freedman, B. (eds) (1994): Ecology of a polar desert, Alex-andra Fiord, Ellesmere Island.- Captus University Publ., Toronto.

Tarnocai, C. (2004): Cryosols of arctic Canada.- In: J. Kimble (ed). Cryosols – permafrost-affected soils, Springer-Verlag, Berlin Heidelberg, 95-117.

Webber, P.J. (1978): Spatial and temporal variation of the vegetation and its production, Barrow, Alaska.- In: L.L. Tieszen (ed). Vegetation and pro-duction ecology of an Alaskan Arctic tundra, Springer-Verlag, New York, 37-112.

Wielgolaski, F.E., Bliss, L.C., Svoboda, J. & Doyle, G. (1981): Primary production of tundra.- In: L.C. Bliss, O.W. Heal & J.J. Moore (eds). Tundra ecosystems: a comparative analysis, Cambridge University Press, Cambridge, 187-225.

Woodley, E.J. & Svoboda, J. (1994): Effects of habitat variations of phenolo-gy and nutrient concentration among four common plant species of the Alexandra Fiord Lowland.- In: J. Svoboda & B. Freedman (eds). Ecology of a polar desert, Alexandra Fiord, Ellesmere Island.- Captus University Publ., Toronto, 157-175.