POLISH POLAR RESEARCH
vol. 33, no. 4, pp. 383–394, 2012 doi: 10.2478/v10183-012-0026-z

Variability of contemporary vegetation around Petuniabukta, central Spitsbergen

Karel PRACH[1, 2], Jitka KLIMEŠOVÁ[2,1], Jiří KOŠNAR[1], Olexii REDČENKO[2] and Martin HAIS[1]

[1]*Faculty of Science, University of South Bohemia, Branišovská 31, CZ-37005 České Budějovice, Czech Republic <prach@prf.jcu.cz>*

[2]*Institute of Botany, Academy of Sciences of the Czech Republic, Dukelská 135, CZ-379 82 Třeboň, Czech Republic*

Abstract: Vegetation was described in various spatial scales in the area of 37.8 km^2 including distinguishing vegetation units, vegetation mapping, recording phytosociological relevés (53), and completing species lists of vascular plants (86), mosses (124) and lichens (40). Phytosociological relevés were elaborated using ordination methods DCA and CCA. The relevés formed clusters corresponding well to *a priori* assigned vegetation units. Slope and stoniness significantly influenced the vegetation pattern. Despite the high latitude (nearly 80° N), the vegetation is rather rich in species. Non-native species do not expand. The moss *Bryum dichotomum* is reported for the first time from Svalbard archipelago.

Key words: Arctic, Svalbard, bryophytes, lichens, ordination analysis, vascular plants, vegetation mapping.

Introduction

Vegetation changes in the High Arctic have recently been discussed especially in relationship to climate change (Parmesan 2006; Alsos *et al.* 2007; Thuiller *et al.* 2008; etc.). For any quantitative evaluation of such changes we need a solid description of vegetation patterns to which the changes could be related. There are not many studies which exploit repeated analyses of earlier described patterns (Moreau *et al.* 2009; Prach et al. 2010; Daniels *et al.* 2011). Thus, any present solid description of vegetation may enable repeated evaluations in the future and then potentially relate the revealed vegetation changes to climate change (Karlsen and Elvebakk 2003).

Vegetation description in various spatial scales may provide a useful framework to other studies. Vegetation is comparative easily perceived and not fluctuating so much in comparison with, for example, some animal populations. Moreover, methods are well developed and standardized (Kent and Coker 1992). Vegetation reflects environmental factors well, including human impact over various scales.

The vegetation map exists for the whole Svalbard archipelago (Elvebakk 2005) but its resolution is rather low. On the other hand, various vegetation studies have been conducted in rather small scales, from meters to hundreds of meters, matching various purposes (Hodkinson *et al.* 2003; Prach and Rachlewicz 2012 this issue). Several studies in Svalbard dealt with vegetation succession in front of retreating glaciers (Hodkinson *et al*. 2003; Moreau *et al*. 2003; Prach and Rachlewicz 2012 this issue). But there is virtually a lack of studies dealing with vegetation patterns over a landscape scale, encompassing various habitats across the landscape (but see Jónsdóttir 2005).

The aim of our study was to describe vegetation variability around the Petuniabukta in central Svalbard to provide (a) a framework to other studies conducted there, and (b) a solid basis for possible repeated analyses in the future. Our study consists of vegetation mapping, analyses of phytosociological relevés, and completing species lists.

Methods

The study was conducted around the Petuniabukta, the northernmost part of Billjefjorden, representing a branch of the main Svalbard fjord Isfjorden. The study area is delimited by 78°39’22” – 78°44’36” N latitude, 16°22’12” – 16°49’27” E longitude, and 78 (Avg.) – 736 (Max.) m a.s.l. of altitude. Average annual temperature is about -6.5°C, and average annual precipitation reaches *ca* 200 mm (Rachlewicz *et al.* 2007; Láska *et al.* 2012 this issue).

Field records were performed in the seasons of 2008–2010. Vegetation mapping and phytosociological relevés were recorded in 2008. Based on the initial extensive inspection of the whole area, vegetation units were delimited *ad hoc* regarding dominant and characteristic species (Mueller-Dombois and Ellenberg 1974). For the purpose of mapping, the units were pooled into 7 main units (see below) due to the scale of the map and frequent transitions or mozaic between the subunits. Field mapping was done into georeferenced aerial photographs (ASTER satellite scenes, ERSDAC, 2005)) in the total area of 37.8 km^2.

The vegetation units distinguished (numbers in parenthess denote the number of relevés) and their brief ecological characteristics are the following:

***Dryas octopetala* community** (19). — The widespread unit around the Petuniabukta bay. Several types can be distinguished depending on the species composition and environmental factors.

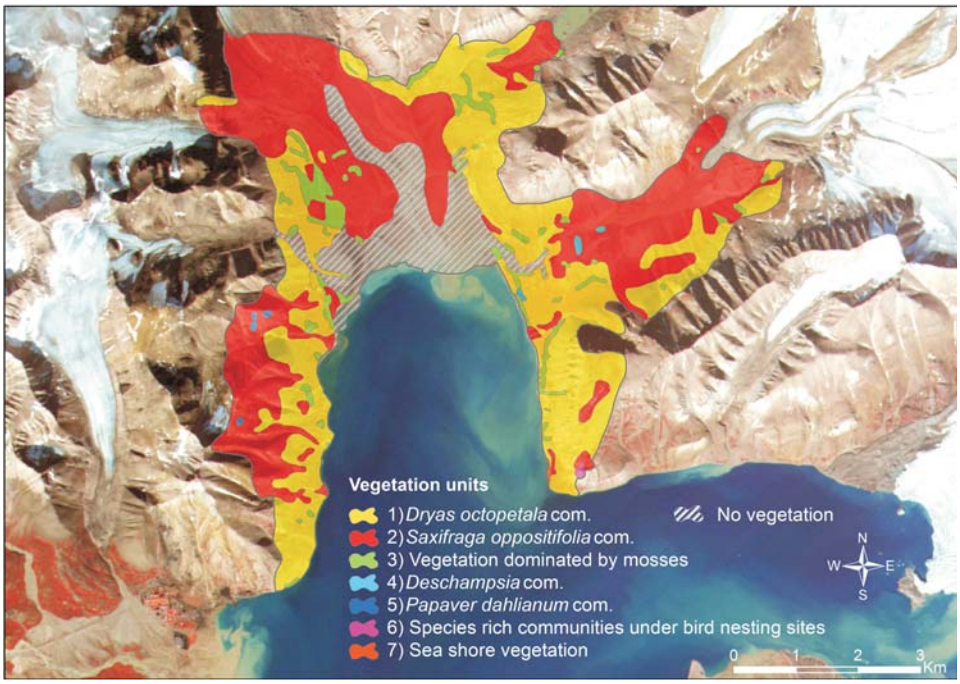


Fig. 1. A simplified vegetation map of the area around the Petuniabukta, central Svalbard, 2008.

– Species poor stands on extreme sites on crests and mountain summits probably with low or none snow cover in winter and very dry soil in summer. Cryogenic processes are often evident. Vegetation cover is low, less than 20%, usually about 10% with negligible cover of mosses tolerant to dry conditions (*Distichium* sp., *Ditrichum* sp.). *Saxifraga oppositifolia* is the most common accompanying species.
– Typical *Dryas* stands, with vegetation cover over 20%. Rather common type around the Petuniabukta, occurring on slightly exposed sites, especially on gravely substrates. A type with chionophobic *Carex nardina* is included into this unit.
– Stands with high participation of *Cassiope tetragona*. This type occurs on old and sufficienty wet but not very moist surfaces, not drying out too much in summer.
– With *Carex rupestris* as co-dominant. It occurs on old surfaces but drier then the previous one. The most common sub-unit around the Petuniabukta in average environmental situation.
– With *Carex misandra* as typical accompanying species. It occurs on relatively wet sites, often on comparably younger surfaces.
– With *Salix polaris* as a co-dominant. It often occurs on wet, both old and young surfaces. The higher soil moisture is probably conditioned by long lasting snow

cover (often around snow beds) or by high water tables in streams. Locally, *S. polaris* dominates and *Dryas* disappears, however, this vegetation type was not mapped separately due its small extent and transitions or mozaics, similar to sites with a high cover of otherwise widespread *Bistorta vivipara*.

***Saxifraga oppositifolia* community** (13). — It generally occurs on young, unstabilized surfaces deposited either by streams, glaciers, gravitation or the sea, *i.e.* on fluvial sediments, morains, screes or maritime terraces. *Saxifraga oppositifolia* seems to be frequently a first colonizer of various disturbed sites including those disturbed by humans (*e.g.*, mining roads unused for 10 years). It gradually increases in its cover but other species in the meantime may dominate, thus transitions to other mapping units are seen. *Saxifraga oppositifolia* exhibits also a broad ecological amplitude considering site moisture conditions: it accompanies *Dryas* on dry, exposed sites and on the other hand it occurs in moss carpets on seepage sites.
– Initial stages with very low vegetation cover (bellow 5%)
– More developed stages with higher vegetation cover

Vegetation dominated by mosses (12). — It usually ocurs in permanently wet patches in alluvial sites, snow beds or on seepages. In alluvial sites, cryogenic structures are often formed (humps) in successionally advanced vegetation. Dominant mosses are usually *Scorpidium* sp. and *Orthothecium chryseon*; also frequent are *Bryum pseudotriquetrum*, *Calliergon richardsonii*, *Catosopium nigritum*, *Meesia* sp. or *Cinclidium arcticum*.
– Well developed sites with humps, in wet depressions dominated by *Carex subspathacea*.
– With a high dominance of *Carex paralella* in somewhat drier sites, probably with more fluctuating water table.
– Initial stages without *Carex subspathacea* and *C. paralella*, typical humps are not yet formed.
– Seepage sites with usually low cover of vascular plants, totally dominated by mosses *Orthothecium chryseon* and *Philonotis tomentella*. This type occurs only in sites where seepage is intensive, otherwise mapped under other units (1, 2).
– Mosses dominated stands around snow beds. *Ranunculus pygmaeus* is the typical accompanying vascular plant.

***Deschampsia* community** (3). — This vegetation units occurs only very locally (i) in wet sites especially in aluvial sites where probably represents an initial stage to moss communities if not disturbed by a stream, and (ii) around settlements where some eutrophication is expected. *Deschampsia borealis* and *D. alpina* are typical of the former while *D. caespitosa* of the latter situation.

***Papaver dahlianum* community** (3). — It occurs on fine screes, especially in higher altitudes. Vegetation cover and species number is low.

Species rich communities under bird nesting sites (2). — These are typical of high vegetation cover and species richness, where the following species were especially noted: *Potentilla pulchella*, *Trisetum spicatum*, *Festuca baffinensis*, *Poa* cf. *hartzii*, *Saxifraga* spec. div. and *Draba* spec div. *Papaver dahlianum* is also present. They were recorded in only a few places in the area.

Sea shore vegetation (1). — It was noted in only one site in the study area and with very small extent in the SE margin of the Petuniabukta, where *Mertensia maritima* forms a narrow strip along the high tide zone. This vegetation is not more developed here probably due to brackish character of the water.

Phytosociological relevés (53), 5 × 5 m in size, were recorded in representative parts of vegetation patches, avoiding contact and transitional zones with other vegetation types. Cover of all vascular plants, mosses and lichens, together with cover of cyanophyte *Nostoc commune* as in important component of vegetation in wet sites, were visually estimated (Kent and Coker 1992). Cover of stones and slope were also recorded. Species lists of vascular plants, mosses and lichens were completed during the three seasons. The nomenclature is used according to Elvebakk and Prestrud (1996) for vascular plants and Øvstedal *et al.* (2009) for lichens. The nomenclature for bryophytes follows Frisvoll and Elvebakk (1996) and, for taxa not listed there, Hallingbäck *et al.* (2006, 2008) was used.

The field vegetation map was transformed into GIS using Arcview ArcGIS 9.3 program (www.esri.com). Phytosociological relevés were elaborated by multivariate ordination techniques of the Detrended Correspondence Analysis (DCA) and Cannonical Correspondence Analysis (CCA) using the Canoco program (Ter Braak and Šmilauer 2002). Because of the length of gradient (5.8 SD-units in DCA), the unimodal methods were used (Lepš and Šmilauer 2003). Species diversity was simply expressed as the number of species per relevé.

Results

The vegetation map. — The vegetation map of the area is presented in Fig. 1 and the percentage area of the particular vegetation units is presented in Table 1. In Table 1 average vegetation characteristics of the vegetation units is also listed. ANOVA revealed that the units significantly differed in the cover of E_1 and E_0, cover of stones and bare soil, and the number of vascular plants, while the numbers of mosses and lichens were only marginally significant. The highest cover of E_1 was attained in *Dryas octopetala* com., the lowest in *Papaver dahlianum* com. Cover of E_0 was, naturally, highest in vegetation dominated by mosses and there was the highest number of moss species. The lowest cover of vegetation and, correspondingly, the highest cover of stones and bare soil, was attained in the case of *Papaver dahlianum* com. The highest number of vascular plants was recorded in

Table 1

Percentage cover of the main vegetation units (see Fig. 1) of the total area of 37.8 km^2 subjected to mapping, and basic characteristics of the units. The characteristics in bold significantly differed among the vegetation units (ANOVA).

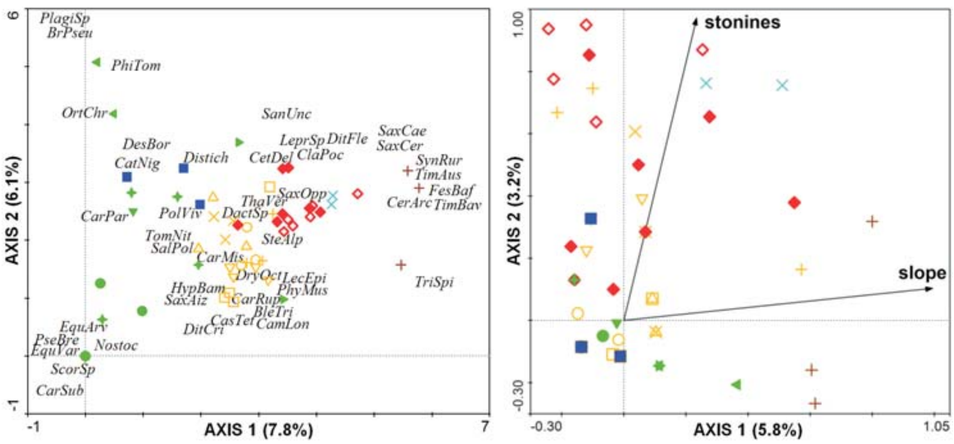
Vegetation units	Percentage of mapping area [%]	Cover E_1 [%]	Cover E_0 [%]	Stone and soil [%]	Slope [°]	No. of vasc. plants	No. of mosses	No. of lichens
Dryas octopetala com.	38.53	**41**	**24**	**42**	**7**	**10**	8	6
Saxifraga oppositifolia com.	43.65	**8**	**10**	**84**	**11**	**8**	6	4
Vegetation dominated by mosses	5.10	**30**	**68**	**16**	**4**	**13**	11	6
Deschampsia com.	0.18	**37**	**37**	**40**	**3**	**9**	10	3
Papaver dahlianum com.	0.14	**2**	**0**	**98**	**25**	**5**	6	5
Communities under bird nesting sites	0.08	**30**	**17**	**57**	**33**	**14**	6	7
Sea shore vegetation	0.06	?	?	?	?	?	?	?
No vegetation	12.26	–	–	–	–	–	–	–

the communities under bird nesting sites. The vegetation units did not differ too much in the number of lichens.

Ordination. — Results of the DCA analysis are presented in Fig. 2A. The relevés form clusters corresponding well to *a priori* assigned vegetation units but in a general view, the vegetation forms a continuum. The first axis explains 7.8% of the vegetation variability but it is difficult to interpret the axis by an environmental factor. The second axis (6.1% explained variability) seems to reflect site extremity from compact vegetation in bottom to low-cover vegetation on the top of the diagram.

In the CCA analysis we used two habitat characteristics which we were able to estimate easily in the field, *i.e.*, slope and stoniness (Fig. 2B). Both characteristics significantly influenced the vegetation pattern (p=0.002), but explained only 5.8% of vegetation variability in the case of slope, and 3.2% in the case of stones.

Species lists. — In total, 86 vascular plants, 124 mosses, and 40 lichens were recorded in the studied area (see Appendix 1). The moss *Bryum dichotomum* was found for the first time in Svalbard, growing in two small populations on bare soil in deglaciated area of Hørbyebreen glacier. The occurrence of *Didymodon icmadophilus* was confirmed for Svalbard. Most of the recorded bryophyte taxa belong to basiphilous bryophytes. Therefore, high diversity was found among *Bryum* taxa, together with high abundance of species such as *Ditrichum* sp. div., *Distichium* sp. div. or *Encalypta* sp. div. Another important factor influencing the distribution of bryophytes in Petuniabukta is the gradient of moisture. In lowland locations, locally abundant wetland habitats occur often with high bryophyte cover, with *Scorpidium* sp. div., *Catoscopium nigritum*, *Bryum pseudotriquetrum*, *B. cryophilum*, or *Campylium* sp. div. being dominant taxa. The opposite part of this gradient represent dry slopes in mountain altitudes, especially on exposed and un-



Symbols representing vegetation units: ***Dryas octopetala* com.**: + species poor stands, ○ typical stands, □ *Cassiope tetragona* stands, ▽ *Carex rupestris* co-dominant, △ *Carex misandra* accompanying, × *Salix polaris* co-dominant (1f); ***Saxifraga oppositifolia* com.**: ◇ initial stages, ◆ more developed stages; **vegetation dominated by mosses**: ● *Carex subspathacea* humps, ▼ *Carex paralella* dominant, ✚ initial stages, ◀ seepage sites, ▶ stands around snow beds; ■ ***Deschampsia* com.**; + ***Papaver dahlianum* com.**; × **Communities under bird nesting sites**

Fig. 2. Ordination analysis of phytosociological relevés. **A**. Detrended Correspondence Analysis (DCA). **B**. Cannonical Correspondence Analysis (CCA). Only the 1st and 2nd axis are shown. Percentages of variance explained by the axis are given in brackets. Abbreviations: *BleTri – Blepharostoma trichophyllum; BrPseu – Bryum pseudotriquetrum; CamLon – Campylium longicuspis; CarMis – Carex misandra; CarPar – Carex paralella; CarRup – Carex rupestris; CarSub – Carex subspathacea; CasTet – Cassiope tetragona; CatNig – Catoscopium nitritum; CerArc – Cerastium arcticum; CetDel – Cetraria delisei; ClaPoc – Cladonia pocillum; DactSp – Dactylina* sp.; *DesBor – Deschampsia borealis; Distich – Distichium inclinatum + D. capillaceum; DitCri – Ditrichum crispatissimum; DitFle – Ditrichum flexicaule; DryOct – Dryas octopetala; EquArv – Equisetum arvense; EquVar – Equisetum variegatum; FesBaf – Festuca baffinensis; HypBam – Hypnum bambergeri; LecEpi – Lecanora epibryon; LeprSp – Lepraria sp.; Nostoc – Nostoc sp.; OrtChr – Orthothecium chryseon; PhiTom – Philonotis tomentella; PhyMus – Physconia muscigena; PlagiSp – Plagiomnium sp.; PolViv – Polygonum viviparum; PseBre – Pseudocalliergon brevifolium; TimBav – Timmia bavarica; SalPol – Salix polaris; SanUnc – Sanionia uncinata; SaxAiz – Saxifraga aizoides; SaxCae – Saxifraga caespitosa; SaxCer – Saxifraga cernua; SaxOpp – Saxifraga oppositifolia; ScorSp – Scorpidium cossoni + S. revolvens; SteAlp – Stereocaulon alpinum; SynRur – Syntrichia ruralis; ThaVer – Thamnolia vermicularis; TimAus – Timmia austriaca; TomNit – Tomentypnum nitens; TriSpi – Trisetum spicatum.*

stable habitats. Such sites have often only sparse bryophyte cover, consisting of a few *Encalypta*, *Ditrichum* or *Distichium* taxa. Under mesic conditions the prevailing species with broader amplitude include *Orthothecium chryseon* and *Tomentypnum nitens,* for example. From a bryological point of view the bird cliffs were also interesting, among others with locally abundant cover of typical epilithic species such as *Didymodon johansenii* or *Grimmia anodon*, both being rather rare on Svalbard. Another peculiar habitat represent deglaciated areas with species of bare soil, namely *Aloina brevirostris*, *Bryum* sp. div., *Henediella heimii, Funaria arctica* or *Tortula* sp. div. Among 40 recorded lichens, 12 species play an important role in vegetation (see Appendix). The most common are *Collema* sp. (cyanolichen, Collemataceae) and *Fulgensia bracteata* (Teloschistaceae). Some remarks on the occurrence are given in Appendix 1.

Discussion

The map of potential vegetation of Europe (Bohn and Neuhäusl 2000) reports for Svalbard three vegetation units: Mountain arctic polar deserts (A1); Northern Arctic tundra (B1) and Middle Arctic tundra (B3). The same classification was adopted by Elvebakk (2005). In our classification of vegetation, *Papaver dahlianum* community represents Arctic polar desert. *Dryas octopetala* and *Saxifraga oppositifolia* communities can be seen as a core of Northern Arctic tundra (B1), except that with sub-type with *Cassiope tetragona* which would fall into Middle Arctic tundra (B3). Our other units represent azonal vegetation of special habitats, like wetlands and fertilized places under bird cliffs, which were not mapped in the above-mentioned sources (Bohn and Neuhäusl 2003; Elvebakk 2005).

Since it is a calcifobe species *Cassiope tetragona* inhabits special places in the studied area where sufficient layers of organic material accumulated (Acock 1940; Rønning 1996) which probably must wait until a sufficient layer of organic sediment accumulates over basic rock, which prevails in the studied area (Elvevold *et al.* 2007). We suppose that the tundra with *Cassiope tetragona*, as the plant community with the oldest vegetation history (Rozema *et al.* 2006), represents a climax here.

A large area around the Petuniabukta is without vegetation, being subjected to permanent erosion, mostly by streams (especially above the northernmost end of the bay), climatic extremes on the exposed tops and crests (Körner 2003), gravitation on steep slopes, or are not yet colonized by plants in recently deglaciated sites in the glacial forelands (Prach and Rachlewicz 2012 this issue). Vegetation is very sparse or missing on the exposed summits and crests due to climate extremity. *Papaver dahlianum* seems to be the vascular plant which is able to survive climatically most extreme environment and unstabilized substratum (Rønning 1996). The latter is reflected in the results of ordination (CCA, Fig. 2B) where the samples with *P. dahlianum* occur on the rightmost position along the X-axis correlated with slope. On the opposite end of an extremity gradient, *i.e.*, on flat and stoneless terrain, communities with *Deschampsia borealis, Carex subspathacea* and *Cassiope tetragona* occur. A similar gradient of extremity is seen in the DCA ordination which indicates that the two environmental factors, cover of stones and slope, are important environmental gradients for the vegetation variability. They can be rather easily evaluated in the field. Other relevant ecological factors, but not easily measurable, such as site moisture and nutrients, are largely determined by the two above-mentioned factors (see also Hodkinson *et al.* 2003 and Jónsdóttir 2005). Consequently, the first axis in the indirect DCA ordination seems to represent a complex gradient of increasing site extremity.

In the studied area of 37.8 km^2 we recorded 52% of the total Svalbard flora of vascular plants (Rønning 1996). There are missing some species typical of acidic substratum and, naturally, those which occur only in the western, oceanic part of Svalbard. We recorded two non-indigenous species, namely *Barbarea vulgaris* and *Stellaria graminea*, both occurring in the abandoned settlement of Pyramiden in the close vicinity of the studied area but in very limited number of individuals comparable to those recorded in 1987 by Liška and Soldán (2004). Moreover, two other non-native species, *Poa pratensis* s.l. and *Festuca rubra* s.l., were recorded there in sown swards having persisted since the time when the town was inhabited. Among bryophytes, *ca* 39% of the taxa presently known to occur on Svalbard (Frisvoll and Elvebakk 1996) was found in the studied area. A list of lichen species recorded in the studied area was already published by Redchenko *et al.* (2010) thus only those playing an important role in vegetation are listed in Appendix 1.

We can conclude that, despite the high latitude (nearly 80° N), the flora is rather rich. Non-native species are confined only to one abandoned settlement (Liška and Soldán 2004) and still not expanding despite the ongoing climate warming (Karlén 2005; Rachlewicz *et al.* 2007). Vegetation patterns still seem to be rather persistent to climate change (Prach *et al.* 2010). Evident successional changes can be seen only after retreating glaciers (Prach and Rachlewicz 2012 this issue). Since the position of each phytosociological relevé was recorded in coordinates by GPS, they can be repeatedly analyzed in the future. Repeated mapping may also reveal some possible future changes in vegetation pattern over the landscape scale.

Acknowledgements. — The research was supported by the following grants of the Ministry of Education of Czech Republic – INGO-LA341, LM2010009 Projekt CzechPolar, MSM 6007665801 and AVOZ60050516. We thank Alena Bartošová and Saša Bernardová for their support in the field work, Mark Gilquist for English revision and anonymous reviewers for their helpful comments.

References

ACOCK A.M. 1940. Vegetation of a calcareous inner fjord region in Spitsbergen. *Journal of Ecology* 28: 81–106.

ALSOS I.G., EIDESEN P.B., EHRICH D., SKREDE I., WESTERGAARD K., JACOBSEN G.H., LANDVIK J.Y., TABERLET P. and BROCHMANN C. 2007. Frequent long-distance plant colonization in the changing Arctic. *Science* 316: 1606–1609.

BOHN U. and NEUHÄUSL R. 2000. *Karte der natürlichen Vegetation Europas*. Bundesamt für Naturschutz, Bonn: 285 pp.

CANNONE N., GUGLIELMIN M. and GERDOL R. 2004. Relationships between vegetation patterns and periglacial landforms in northwestern Svalbard. *Polar Biology* 27: 562–571.

DANIELS F.J.A., de MOLENAAR J.G., CHYTRÝ M. and TICHÝ L. 2011. Vegetation changes in Southeast Greenland? Tasiilaq revisited after 40 years. *Applied Vegetation Science* 14: 230–241.

ELVEBAKK A. 2005. A vegetation map of Svalbard on the scale 1:3.5 mill. *Phytocenologia* 35: 951–967.

ELVEBAKK A. and PRESTRUD P. (eds) 1996. *A catalogue of Svalbard plants, fungi, algae and cyanobacteria*. Norwegian Polar Institute, Oslo: 395 pp.

ELVEVOLD S., DALLMANN W. and BLOMEIER D. 2007. *Geology of Svalbard*. Norwegian Polar Institute, Tromsø: 36 pp.

ERSDAC 2005. ASTER Users Guide, Part 1 General, Version 4. http://www.science.aster.ersdac.or.jp/en/documnts/users_guide/part1/pdf/Part1_4E.pdf (accessed 13.04.11).

FRISVOLL A.A., ELVEBAKK A. 1996. Part 2. Bryophytes. *In*: A. Elvebakk and P. Prestrud (eds) A catalogue of Svalbard plants, fungi, algae and cyanobacteria. *Norsk Polarinstitutt Skrifter* 198: 57–172.

HALLINGBÄCK T., LÖNNELL N., WEIBULL H., HEDENÄS L. and VON KNORRING P. 2006. *Nationalnyckeln till Sveriges flora och fauna. Bladmossor: Sköldmossor – blåmossor. Bryophyta: Buxbaumia – Leucobryum.* ArtDatabanken, SLU, Uppsala: 416 pp.

HALLINGBÄCK T., LÖNNELL N., WEIBULL H., von KNORRING P., KOROTYNSKA M., REISBORG C. and BIRGERSSON M. 2008. *Nationalnyckeln till Sveriges flora och fauna. Bladmossor: Kompaktmossor – kapmossor. Bryophyta: Anoectangium – Orthodontiumm*. ArtDatabanken, SLU, Uppsala: 504 pp.

HODKINSON I.D., COULSON S.J. and WEBB N.R. 2003. Community assembly along proglacial chronosequences in the high Arctic: vegetation and soil development in north-west Svalbard. *Journal of Ecology* 91: 651–663

JÓNSDÓTTIR I.S. 2005. Terrestrial ecosystems on Svalbard: heterogeneity, complexity and fragility from an Arctic island perspective. *Biological Environment: Proceedings of the Royal Irish Academy* 105B: 155–165.

KARLÉN W. 2005. Recent global warming: An artefact of a too-short temperature record? *Ambio* 34: 263–264.

KARLSEN S.R. and ELVEBAKK A. 2003. A method using indicator plants to map local climatic variation in the Kangerlussuaq/Scoresby Sund area, East Greenland. *Journal of Biogeography* 30: 1469–1491.

KENT M. and COKER P. 1992. *Vegetation description and analysis*. Belhaven Press, London: 225 pp.

KÖRNER Ch. 2003. *Alpine plant life. A functional plant ecology of high mountain ecosystems*. Springer, Berlin: 344 pp.

LÁSKA K., WITOSZOVÁ D. and PROŠEK P. 2012. Weather patterns of the coastal zone of Petuniabukta, central Spitsbergen in the period 2008–2010. *Polish Polar Research* 33 (4): 297–318.

LEPŠ J. and ŠMILAUER P. 2003. *Multivariate Analysis of Ecological Data using CANOCO*. Cambridge University Press, Cambridge: 284 pp.

LIŠKA J. and SOLDÁN Z. 2004. Alien vascular plants recorded from the Barentsburg and Pyramiden settlements, Svalbard. *Preslia* 76: 279–290.

MOREAU M., LAFFY D. and BOSSARD T. 2009. Recent spatial development of Svalbard strandflat vegetation over a period of 31 years. *Polish Polar Research* 28: 364–375.

MUELLER-DOMBOIS D. and ELLENBERG H. 1974. *Aims and methods of vegetation ecology*. J. Wiley, Chichester: 547 pp.

ØVSTEDAL D.O., TØNSBERG T. and ELVEBAKK A. 2009. *The Lichen Flora of Svalbard. Sommerfeltia, Oslo*. Natural History Museum, University of Oslo: 393 pp.

PARMESAN C. 2006. Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution and Systematics* 37: 637–669.

PRACH K., KOŠNAR J., KLIMEŠOVÁ J. and HAIS M. 2010. High Arctic vegetation after 70 years: a repeated analysis from Svalbard. *Polar Biology* 33: 635–639.

PRACH K. and RACHLEWICZ G. 2012. Succession of vascular plants in front of retreating glaciers in central Spitsbergen. *Polish Polar Research* 33 (4): 319–328.

RACHLEWICZ G., SZCZUCIŃSKI W. and EWERTOWSKI M. 2007. Post-"Little Ice Age" retreat rates of glaciers around Billefjorden in central Spitsbergen, Svalbard. *Polish Polar Research* 28: 159–186.

REDCHENKO O., KOŠNAR J. and GLOSER J. 2010. A contribution to lichen biota of the central part of Spitsbergen, Svalbard Archipelago. *Polish Polar Research* 31: 159–168.

RØNNING O.I. 1996. *The flora of Svalbard*. Norsk Polarinstitut, Oslo: 184 pp.

ROZEMA J., BOELEN P., DOORENBOSCH M., BOHNCKE S., BLOKKER P., BOEKEL C., BROEKMAN R.A. and KONERT M. 2006. A vegetation, climate and environment reconstruction based on palynological analyses of high arctic tundra peat cores (5000–6000 years BP) from Svalbard. *Plant Ecology* 182: 155–173.

TER BRAAK C.J.F. and ŠMILAUER P. 2002. *CANOCO Reference Manual and CanoDraw for Windows User's Guids: Software for Canonical Community Ordination (version 4.52)*. Microcomputer Power, Ithaca, New York: 500 pp.

THUILLER W., ALBERT C., ARAÚJO M.B., BERRY P.M,. CABEZA M., GUISAN A., HICKER T., MIDGLEY G.F., PATERSON J., SCHURR F.M., SYKES M.T. and ZIMMERMANN N.E. 2008. Predicting global change impacts on plant species' distributions: future challenges. *Perspectives in Plant Ecology, Evolution and Systematics* 9: 137–152.

WALTON J. 1922. A Spitsbergen salt marsh: with observations on the ecological phenomena attendant on the emergence of land from the sea. *Journal of Ecology* 10: 109–121.

Received 23 June 2011
Accepted 2 May 2012

Appendix 1

List of species recorded during 2008–2010 in the studied area

Vascular plants. — *Alopecurus borealis, Arenaria pseudofrigida, Bistorta vivipara, Braya purpurascens, Cardamine bellidifolia, Cardamine pratensis* subsp. *polemonioides, Carex misandra, Carex nardina, Carex parallela, Carex rupestris, Carex subspathacea, Cassiope tetragona, Cerastium alpinum, Cerastium arcticum, Cerastium cerastoides, Cerastium regelii, Cochlearia groenlandica, Cystopteris fragilis* var. *dickieana, Deschampsia alpina, Deschampsia borealis, Draba alpina, Draba* cf. *arctica, Draba corymbosa, Draba daurica, Draba* cf. *fladnizensis, Draba lactea, Draba oxycarpa, Draba subcapitata, Dryas octopetala, Dupontia psilosantha, Equisetum arvense, Equisetum scirpoides, Equisetum variegatum, Eriophorum angustifolium, Eriophorum scheuzeri, Eutrema edwardsii, Festuca baffinensis, Festuca vivipara, Huperzia selago, Juncus arcticus, Juncus triglumis* subsp. *albescens, Juncus biglumis, Koenigia islandica, Luzula arctica, Luzula arcuata* subsp. *confusa, Mertensia maritima, Minuartia biflora, Minuartia rossii, Minuartia rubella, Oxyria digyna, Papaver dahlianum, Pedicularis hirsuta, Pedicularis lanata* subsp. *dasyantha, Phippsia concinna, Poa abbreviata, Poa alpigena* var. *vivipara, Poa alpina, Poa arctica, Poa hartzii, Potentilla* cf. *chamissonis, Potentilla hyparctica, Potentilla pulchella, Potentilla* x *insularis, Puccinellia phryganodes, Puccinellia vahliana, Ranunculus pygmaeus, Ranunculus hyperboreus, Ranunculus sulphureus, Sagina nivalis, Salix polaris, Salix reticulata, Saxifraga aizoides, Saxifraga cernua, Saxifraga cespitosa, Saxifraga hieracifolia, Saxifraga hirculus, Saxifraga nivalis, Saxifraga oppositifolia, Silene acaulis, Silene furcata, Silene uralensis, Stellaria longipes, Stellaria humifusa, Taraxacum arcticum, Tofieldia pusilla, Trisetum spicatum.*

Bryophytes. — *Abietinella abietina, Aloina brevirostris, Amblystegium serpens, Aneura pinguis, Aongstroemia longipes, Aplodon wormskioldii, Arctoa fulvella, Aulacomnium palustre, Aulacomnium turgidum, Barbilophozia quadriloba, Blepharostoma trichophyllum, Blindia acuta, Brachythecium glaciale, Brachythecium* cf. *trachypodium, Brachythecium turgidum, Bryoerythrophyllum recurvirostrum, Bryum algovicum, Bryum amblyodon, Bryum arcticum, Bryum argenteum, Bryum calophyllum, Bryum cryophilum, Bryum dichotomum, Bryum knowltonii, Bryum nitidulum, Bryum pallescens, Bryum pseudotriquetrum, Bryum wrightii, Calliergon richardsonii, Campylium arcticum, Campylium longicuspis, Campylium stellatum, Catoscopium nigritum, Cephaloziella arctica, Cinclidium arcticum, Cirriphyllum cirrosum, Cratoneuron filicinum, Cyrtomnium hymenophylloides, Cyrtomnium hymenophyllum, Dicranum elongatum, Dicranum majus, Didymodon asperifolius, Didymodon icmadophilus, Didymodon johansenii, Distichium capillaceum, Distichium inclinatum, Ditrichum crispatissimum, Ditrichum cylindricum, Ditrichum flexicaule, Drepanocladus aduncus, Encalypta alpina, Encalypta longicollis, Encalypta procera, Encalypta rhaptocarpa, Fissidens osmundoides, Funaria arctica, Grimmia anodon, Grimmia torquata, Hennediella heimii, Hylocomium splendens, Hymenostylium recurvirostre, Hypnum bambergeri, Hypnum revolutum, Hypnum vaucheri, Jungermannia polaris, Leptobryum pyriforme, Lophozia badensis, Lophozia* cf. *heterocolpos, Lophozia* cf. *polaris, Lophozia gillmanii, Lophozia grandiretis, Lophozia pellucida, Lophozia perssonii, Meesia triquetra, Meesia uliginosa, Mnium thomsonii, Myurella julacea, Myurella tenerrima, Oncophorus virens, Oncophorus wahlenbergii, Orthothecium chryseon, Orthothecium strictum, Orthotrichum pylaisii, Philonotis tomentella, Plagiomnium* sp., *Plagiopus oederiana, Pohlia cruda, Polytrichastrum alpinum, Polytrichastrum sexangulare, Preissia quadrata, Pseudocalliergon brevifolium, Pseudocalliergon trifarium, Pseudocalliergon turgescens, Pseudoleskeella tectorum, Ptilidium ciliare, Racomitrium ericoides, Sanionia uncinnata, Sauteria alpina, Scapania cuspiduligera, Scapania gymnostomophila, Scorpidium cossonii, Scorpidium revolvens, Scorpidium scorpioides, Schistidium frigidum, Schistidium frisvollianum, Schistidium platyphyllum* subsp. *abrupticostatum, Schistidium rivulare, Schistidium tenerum, Splachnum vasculosum, Syntrichia ruralis, Tetraplodon blyttii, Tetraplodon mnioides, Timmia austriaca, Timmia bavarica, Timmia norvegica, Tomentypnum nitens, Tortella fragilis, Tortula leucostoma, Tortula mucronifolia, Trichostomum arcticum, Tritomaria quinquedentata, Tritomaria scitula, Voitia hyperborea, Warnstorfia pseudostraminea.*

Lichens (only the most common species are listed, for the complet list see Redchenko *et al.* 2010).— *Collema* sp. – in shaded sites; *Cetrariella delisei* – indicator of stabilized sites; *Flavocetraria nivalis* – grows mostly in open habitats; *Cladonia pocillum*; *Fulgensia bracteata* – this and previous species are commonly found on bare soil; *Lepraria* cf. *neglecta* – on soil in shaded sites; *Lepraria vouauxii* and *Peltigera venosa* – these two species were found on soil in sunny sites; *Pertusaria oculata* – on twigs, mosses and soil; *Physconia muscigena* – mainly on mosses but also on soil surface; *Stereocaulon alpinum* – on soil in stable sites; *Thamnolia vermicularis* – on soil between mosses and vascular plants.