Phytosociology of snowbed and exposed ridge vegetation of Svalbard

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Abstract Arctic vegetation still lacks a uniform system to classify its plant communities, the current arrangement of the phytosociological data being difficult to interpret. However, using modern methods, it has proved possible to organize the current data to create a suitable system based on numerical algorithms (detrended correspondence analysis and cluster analysis) and traditional methods for 135 phytosociological relevés from snowbed and exposed ridge habitats of Svalbard; 125 relevés were selected from twentieth and early twenty-first century publications, and ten relevés were collected by our group in 2012 from the Kaffiøyra Plain (Oscar II Land, NW Spitsbergen). Our analysis has shown there to be four associations and one community. Two associations and one community are distinguished within the Luzulion arcticae Gjærev. 1950: (1) the Pedicularietum hirsutae ass. nov., (2) the Deschampsietum alpinae (Nordh. 1943) Węgrzyn and Wietrzyk 2015 stat. nov., and (3) the Minuartia biflora community. Two syntaxa were assigned to the Luzulion arcuatae Elvebakk ex Węgrzyn and Wietrzyk 2015: (4) the Anthelietum juratzkanae Kobayashi ex Węgrzyn and Wietrzyk 2015 with a confirmed status and (5) the Gymnomitrietum coralloidis Hadac ex Węgrzyn and Wietrzyk 2015 stat. nov. was described by means of a new approach.

Keywords Arctic · Luzulion arcuatae · Luzulion arcticae · Numerical classification · Syntaxonomy

Introduction

Since the beginning of exploration of northern polar regions, researchers have paid special attention to the Arctic vegetation as being one of the most sensitive components of the polar terrestrial ecosystems. In the recent decades, rapid response of Arctic vegetation to the ongoing climate change has been observed (Stow et al. 2004; Jónsdóttir 2005; Węgrzyn et al. 2011; Olech et al. 2011). Observing these changes appears to be easy due to the simplicity of the species composition of plant communities, but despite the relatively small number of species forming the tundra, Arctic vegetation still lacks a complete, uniform, and transparent system that will classify all the communities in terms of the classical plant phytosociology (Braun-Blanquet 1964; Walker et al. 1994; Nilsen and Thannheiser 2013).

Considerable attention to phytosociological research has been paid regarding the Svalbard flora in comparison with other elements of the Arctic vegetation (Elvebakk and Prestrud 1996; Rønning 1996; Walker et al. 2005). Although botanical research of Svalbard has been undertaken since the eighteenth century, it has solely consisted of describing new species and documenting their location (Nilsen and Thannheiser 2013). The first description of the Svalbard plant habitats was by Elton and Summerhayes (1928), and the oldest phytosociological study of the Svalbard tundra was conducted by Hadač (1946). After 1950, the vegetation of the archipelago was mainly examined by Rønning (1965), Eurola (1968), Philippi (1973). In subsequent years, phytosociological studies were...
continued by Brattbakk (1980), Hartmann (1980), Dubiel and Olech (1990), Möller and Thannheiser (1997), Nilsen et al. (1999), and Möller (2000). The characteristics of the plant community habitats in Svalbard were studied by Elvebakk (1994, 2005), and in a broader sense, Walker et al. (1994) assigned the circumpolar vegetation communities to specific habitat types; however, several phytosociological problems emerged in these two mentioned papers, one of which is the assignment of Luzulion arcticae Elvebakk ex Węgrzyn and Wietzryk 2015 to various habitats. Elvebakk (1994) assigned it to snowbed and exposed ridge and Walker et al. (1994) to polar desert and scree vegetation. From the standpoint of environmental factors, scree vegetation can be considered as exposed ridge, but snowbed is a completely different type of habitat (Elvebakk 1994). The current arrangement of phytosociological data available in the literature is perplexing, and researchers have run into numerous problems when trying to employ it (Nilsen and Thannheiser 2013). Such problems result from (1) the usage of different phytosociological systems, (2) the usage of different size of area of the relevés, (3) the questioned representativeness of the results of phytosociological research for the whole area of Svalbard, (4) the omission of cryptogamic species (mainly lichens), and (5) not taking into account the cryptogamic species as character species of syntaxa, although they are the main element of tundra vegetation. Researchers who have recently attempted to order the phytosociological system of the Spitsbergen communities still show the large gaps existing in Arctic vegetation data (Nilsen and Thannheiser 2013).

Our studies, based on 10 of our own relevés and 125 relevés from the literature (Table 1), were analysed by phytosociological and numerical methods.

In July 2012, ten phytosociological relevés (each of 1 m² area) were taken in the Kaffiøyra plain. The location of each relevé was determined in accordance with the cardinal principle of selecting a uniform and homogenous plant community surface (Braun-Blanquet 1964). The list of species of vascular plants, bryophytes, lichens, and cyanobacteria was obtained for each relevé. Additionally, the degree of cover-abundance and the sociability for each species were defined (Braun-Blanquet 1964). Taxa which were difficult to identify and fragments of biological soil crusts were collected for further determination in the laboratory. All material has been deposited in the Herbarium of the Institute of Botany of the Jagiellonian University in Kraków (KRA).

The 125 relevés selected from publications referred to plant communities that Elvebakk (1994) assigned to two alliances: the Luzulion arcticae Gjærev. 1950 and the L. arcticae Elvebakk ex Węgrzyn and Wietzryk 2015 (Table 1). The analysed dataset also contained relevés of other plant communities that have a high degree of similarity in relation to those previously mentioned (Table 1). Selection was necessary because many citations, despite describing new syntaxa, did not contain the required phytosociological data (Elvebakk 1994; Weber et al. 2000); these refer to four of the communities listed in Table 1: the Salix polaris-Cetraria delisei com. Hadač 1989, the Saxifraga oppositifolia-Cetraria delisei com. Elvebakk 1985, the Cetraria delisei com. Mattick 1949 and the “rodsildre lavmark” com. Brattbakk 1979. A second problem encountered during the selection process resulted from omitting or grouping together epilithic and soil lichens by some authors for two communities: the Saxifraga oppositifolia com. Möller 2000 and the Cetrarietum delisei Möller 2000. Furthermore, only relevés having an area of 1–10 m² were employed for the analysis. Therefore, the relevés of the Cetraria delisei com. Brossard et al. 1984, the Cetraria delisei-Saxifraga oppositifolia com. Nimis 1985, and Saxifraga oppositifolia com. Dubiel and Olech 1990 with a plot area of only 0.01 m² were omitted, as were the relevés of “community C” com. Barkman 1987.
Table 1  The list of plant communities and associations associated with the snowbed and exposed ridge habitats

| Community | Authors, year | Localization | Number of relevés | Numbering of relevés in the data analyses |
|-----------|---------------|--------------|-------------------|------------------------------------------|
| Included in the statistical analyses | | | |
| “Community of Kaffiøyra Plain” | Own data, Jul. 2012 | 1 | 10 | 1–10 |
| “Polar barren desert” com. | Gjessing and Øvstedal (1975) | 2 | 5 | 11–15 |
| Cerastium arcticum-Anthelia juratzkana com. | Hadač (1989) | 9, 10 | 3 | 16–18 |
| Pedicularis hirsuta-Gymnomitrietum coralloidis | Hadač (1989) | 10, 11 | 3 | 19–21 |
| Luzulo confusae-Salicetum polaris | Hadač (1989) | 5, 6, 7, 8, 10 | 7 | 22–28 |
| Gymnomitrietum coralloidis prov. | Hadač (1946) | 4 | 1 | 29 |
| Solorino-Salicetum polaris prov. | Hadač (1946) | 4 | 1 | 30 |
| Saxifragetum caespitosae, subass. Oncohophorus wahlenbergii prov. | Kobayashi et al. (1990) | 3 | 3 | 31–33 |
| Cetraria delisei com. | Dubiel and Olech (1990) | 12, 13 | 15 | 34–48 |
| Saxifraga nivalis com. | Dubiel and Olech (1990) | 14 | 6 | 49–54 |
| Ranunculus gracilis com. | Dubiel and Olech (1990) | 15 | 2 | 55–56 |
| Saxifraga oppositifolia-Cetraria delisei norv.: “rødsildre lavhei” com. | Brattbakk (1986) | 2 | 4 | 57–60 |
| Saxifraga oppositifolia-Drepanocladius uncinatus com. | Hjelmstad (1981) | 16 | 5 | 61–65 |
| Saxifraga oppositifolia-Cetraria delisei norv.: “moserikt” com. (community in which bryophytes are dominant) | Hermansen (1979) | 2 | 10 | 66–75 |
| Saxifraga oppositifolia-Cetraria delisei norv.: “lavrikt” com. (community in which lichens are dominant) | Hermansen (1979) | 2 | 20 | 76–95 |
| Cetraria delisei-Saxifraga oppositifolia com. | Elvebakk (1979) | 2 | 40 | 96–135 |
| Not included in the statistical analyses | | | |
| Salix polaris-Cetraria delisei com. | Hadač (1989) | | No relevés |
| Saxifraga oppositifolia-Cetraria delisei com. | Elvebakk (1985) | | No relevés |
| Cetraria delisei com. | Mattick (1949) | | No relevés |
| “Rødsildre lavmark” com. (“rødsildre lavhei””) | Brattbakk (1979) | | No relevés |
| Saxifraga oppositifolia com. | Möller (2000) | | 6 | – |
| Cetrarietum delisei | Möller (2000) | | 10 | – |
| Cetraria delisei com. | Brossard et al. (1984) | | 8 | – |
| Cetraria delisei-Saxifraga oppositifolia com. | Nimis (1985) | | 69 | – |
| Saxifraga oppositifolia com. | Dubiel and Olech (1990) | | 3 | – |
| “Community C” com. | Barkman (1987) | | 3 | – |

Data are taken from existing literature. Additionally, data for the relevés from the Kaffiøyra Plain are given.

One relevé of *Luzulo confusae-Salicetum polaris* Hadač 1989, and two relevés of *Saxifraga nivalis* com. Dubiel and Olech 1990 since their areas were too large (12–100 m²). The localities of selected and analysed relevés are marked on the map of Svalbard (Fig. 1).

The species of vascular plants, bryophytes, and lichens, whose presence was highly questionable, were deleted from the dataset. Cyanobacteria species were not included in the analysis because the majority of other authors also did not take them into account.

In the case of phytosociological tables with a cover-abundance scale other than that of Braun-Blanquet (1964), the scale was changed to allow a compilation of relevés in phytosociological analyses using the numerical methods in...
Fig. 1 The localization of relevés used in the data analyses: 

- a — Kafføyra Plain, 
- b — Brøggerhalvøya, 
- c — Bohemanflya, 
- d — Arnıcadalen, 
- e — Verdeborgsletta, 
- f — Linnédalen, 
- g — Kongressdalen, 
- h — Minervaodden, 
- i — Bykollen, 
- j — Grønfljordfjellet, 
- k — Grøndalen, 
- l — Palffyodden, 
- m — Hornsundneset, 
- n — Sergeevjellet, 
- o — Breinesflya, 
- p — Frankenhalvøya.
Detrended correspondence analysis (DCA) was done in the CANOCO 4.5 (Lepš and Šmilauer 2003) in order to extract the groups of similar relevés (Hill and Gauch 1980). Cluster analysis was performed using the flexible UPGMA (flexible unweighted pair group method with arithmetic mean, \( \beta = 0.15 \)) in SYN-TAX 2000 (Podani 2001). The goal here was to show similarity between relevés (Sokal and Michener 1958). In order to perform the above-mentioned analyses, the cover-abundance scale proposed by van der Maarel (1979) was used.

For all the alliances and associations separated in the data analyses, a synthetic table containing the constancy and fidelity for each species was made using two programs: TURBOVEG 2000 (Hennekens 2012) and JUICE (Tichý and Holt 2006). Based on these results, the character and companion species were defined (Braun-Blanquet 1964). Nomenclature of syntaxa followed the “International Code of Phytosociological Nomenclature” (Weber et al. 2000).

The last stage of the analysis was to prepare the phytosociological table describing the vegetation occurring in the Kaffiøyra Plain. This was made on the basis of ten relevés using TURBOVEG 2000 (Hennekens 2012) and JUICE (Tichý and Holt 2006) software.

The nomenclature of vascular plants, bryophytes, lichens, and cyanobacteria is according to Elvebakk and Prestrud (1996), The Plant List (2013), MycoBank (2014).

**Results**

As a result of the DCA, the 135 relevés are divided into two groups, graphically presented in the ordination, both of which are correspond to revised alliances (Fig. 2). In the first group (\( L. \) arcticae Gjærev. 1950), 88 relevés represented by the following communities occur: the “community of the Kaffiøyra Plain”, the \( Saxifraga \) oppositifolia-Cetraria delisei “moserik” com. Hermansen 1979, the \( Saxifraga \) oppositifolia-Cetraria delisei com. “lavrikt” Hermansen 1979, the “polar barren desert” com. Gjessing and Øvstedal 1975, the Cetraria delisei-Saxifraga oppositifolia com. Elvebakk 1979, the \( Saxifraga \) oppositifolia-Cetraria delisei “rødsildre lavhei” com. Brattbakk 1986.

The second group (\( L. \) arcuatae Elvebakk ex Węgrzyn and Wietrzyk 2015) includes 47 relevés. They belong to other communities, namely the Cerastium arcticum-Anthelia juratzkana com. Hadač 1989, the Pedicularis hirsutae-Gymnomitrietum coralloidis Hadač 1989, the Luzulo confusae-Salicetum polaris Hadač 1989, the G. coralloidis Hadač.

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**Fig. 2** Detrended correspondence analysis (DCA) scatterplot of 135 relevés (numbers) along the first and second ordination axes. Two groups of relevés were distinguished: the \( L. \) arcticae Gjærev. 1950 and the \( L. \) arcuatae Elvebakk ex Węgrzyn and Wietrzyk 2015.
1946 prov., the Solorineto-Salicetum polaris Hadač 1946 prov., the Saxifragetum cespitosae, the subassociation of Oncophorus wahlenbergii Kobayashi 1988 prov. (Kobayashi et al. 1990), the Cetraria delisei com. Dubiel and Olech 1990, the Saxifraga oppositifolia-Drepanocladus uncinatus com. Hjelmstad 1981; one relevé (no. 122) belongs to the Cetraria delisei-Saxifraga oppositifolia com. Elvebakk 1979.

In order to confirm the above ordination (Fig. 2), a cluster analysis was performed, which results in a dendrogram that groups all relevés into clusters (Fig. 3). This analysis confirmed the division of the analysed relevés into two groups, equal to alliances; within these groups, five associations were distinguished (Fig. 3).

After grouping the syntaxa with numerical methods (Figs. 2, 3), they were analysed with a phytosociological method. Table 2 classifies all obtained syntaxa based on the degree of constancy and fidelity of species of vascular plants, bryophytes, and lichens. Relevés belonging to the L. arcticae Gjærev. 1950 were grouped into two associations and one community. The Minuartia biflora community and the Pedicularietum hirsutae ass. nov. are described for the first time (Tables 2 and 3; Fig. 3). The third one, Deschampsietum alpinae (Nordh. 1943) Węgrzyń and Wietrzyk 2015 stat. nov., has a new phytosociological status (Table 2; Fig. 3).

Two plant communities were classified into the M. biflora community: the “community of the Kafigøyra Plain” and the Saxifraga oppositifolia-Cetraria delisei “moserikt” com. Hermansen 1979. The similarity between these relevés resulted from the participation of such species as: Lecidea ramulosa Th. Fr., Juncus biglumis L., M. biflora (L.) Schinz & Thell., Dicranoweisia crispula (Hedw.) Milde, Saxifraga hieracifolia Waldst. & Kit. ex Willd. and Draba micropetala Hook.; the last four species were considered as differential species for the community (Table 2; Fig. 3.)

The relevés of the Cetraria delisei-Saxifraga oppositifolia com. Elvebakk 1979 (partially) and the Saxifraga oppositifolia-Cetraria delisei “lavrikt” com. Hermansen 1979 were grouped into one association, called P. hirsutae ass. nov. Within this association, relevé number 9 of the Saxifraga oppositifolia-Cetraria delisei “lavrikt” com. Hermansen 1979 was chosen as a nomenclatural type for this association. The distinguishing feature of these relevés is the presence of the subsequent character species: P. hirsuta L., Lecanora epibryon (Ach.) Ach., Minuartia rubella (Wahlenb.) Hiern, Carex misandra R.Br., Equisetum variegatum Schleih. ex F. Weber & D. Mohr, and Solorina bispora Nyl. (Table 2; Fig. 3). The first two species have the highest degree of fidelity (IV) and are the most frequent in the species composition of the association.

The next distinguished association, D. alpinae (Nordh. 1943) Węgrzyń and Wietrzyk 2015 stat. nov., is
Table 2 A synthetic table containing the species of vascular plants, bryophytes, and lichens

| Name of alliance | Luzulion arcticae Gjærev. 1950 | Luzulion arcuatae Elvebakk ex Węgrzyn & Wietrzyk 2015 | FIDELITY FOR EACH SYNTAXA MARKED BY GREY AREA |
|------------------|---------------------------------|--------------------------------------------------------|---------------------------------------------|
| Name of association/community | Minuartia biflora community | Deschampsietum alpinum (Nordh. 1943) Węgrzyn & Wietrzyk 2015 | Anthelietum juratzkanae KOBAYASHI ex Węgrzyn & Wietrzyk 2015 |
| Number of relevés | 20 | 33 | 36 | 14 | 32 |

| Character species for the alliances | Luzula nivalis | Lecidea ramulosa | Distichium hagenii | Blepharostoma trichophyllum | Distichium inclinatum | Hancus biglanus | Campylium polygonum | Orthothecium strictum | Pohlia crude | Collema ceraniscum | Pseudocalliergon turgescens | Ditrichium flexicaule | Luzula confusa | Distichium inclinatum | Juncus biglumis | Campylium polygonum | Gymnomitrietum coralloidis HADAC ex Węgrzyn & Wietrzyk 2015 |
|-----------------------------------|----------------|----------------|------------------|---------------------------|-------------------|-----------------|----------------|----------------|------------|----------------|----------------|----------------|-----------------|----------------|----------------|-----------------|
| Number of relevés | 20 | 33 | 36 | 14 | 32 |

| Character species for the associations/dominant species in the community | Saxifraga hieracifoila | Minuartia biflora | Dicranum elongatum | Stereocladon alpinum | Anthelietum turgidum | Pedicularis hirsuta | Carex misandra | Deschampsia flexicaule | Equisetum variegatum | Solorina bispora | Minuartia rubella | Pedicularis hirsuta | Carex misandra | Distichium flexicaule | Solorina bispora | Leucobryum fructicans | Gymnomitrietum coralloidis |
|------------------------------------------------|-------------------------|------------------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Number of relevés | 20 | 33 | 36 | 14 | 32 |

Common species: Vascular plant: Cerastium arcticum, Salix polaris, Saxifraga cernua, S. cespitosa, S. oppositifolia; Mosses: Brachythecium glacieale, Polytrichastrum alpinum; Lichens: Cetrariella delisei, Ochrolechia frigida, Cetraria islandica

The ordering is based on the degree of constancy and fidelity within each syntaxon. The characteristic species of alliances and associations are listed, and their constancy value is marked by grey area. Additionally, the common species within both habitats (snowbed and exposed ridge) are presented below the table. The letters (p, m, l) in the table mean the species identification: p—vascular plant; m—moss; l—lichen. The “constancy” represents the frequency of each species in all relevés of particular syntaxa. The “fidelity” means the species suitability as characteristic taxa for particular syntaxa, and it is based on the constancy level. The asterisk (*) marked the differential species in the Minuartia biflora community.
## Table 3 The Minuartia biflora community of the Kafføyna Plain

| Number of relevés | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Constancy |
|-------------------|---|---|---|---|---|---|---|---|---|----|-----------|
| Date              | Jul. 2012 | Jul. 2012 | Jul. 2012 | Jul. 2012 | Jul. 2012 | Jul. 2012 | Jul. 2012 | Jul. 2012 | Jul. 2012 | Jul. 2012 |           |
| Location (WGS84)  | 78°40’23.5” | 78°40’23.7” | 78°40’23.9” | 78°40’24.2” | 78°40’23.9” | 78°40’24.0” | 78°40’10.0” | 78°40’10.0” | 78°40’14.8” | 78°40’19.4” |           |
| Altitude (m)      | 4 | 4 | 4 | 5 | 5 | 17 | 17 | 17 | 19 | 15 |           |
| Area of relevés (m²) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |           |
| Saxifraga oppositifolia | p | 3.1 | 4.1 | 3.1 | 2.1 | 3.1 | 1.1 | 1.1 | 3.1 | 3.1 | V         |
| Cetrariella delisei | l | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 1.2 | 1.2 | 2.2 | 1.2 | V         |
| Ochrolechia frigida | l | +.2 | +.2 | +.2 | +.2 | +.2 | +.2 | +.2 | +.2 | +.2 | V         |
| Lecidea ramulosa | l | 2.2 | 2.2 | 2.2 | 1.2 | 3.2 | 3.2 | 1.2 | 1.2 | 1.2 | V         |
| Collema ceraniscum | l | +.2 | 1.2 | 2.2 | 1.2 | 2.2 | 1.2 | 3.2 | 3.2 | 2.1 | V         |
| Polyblastia cupularis | l | +.2 | +.2 | +.2 | +.2 | 1.1 | +.2 | – | – | +.2 | +.2 | IV        |
| Salix polaris | p | – | +.2 | – | – | – | 2.2 | 2.2 | +.2 | – | +.2 | III       |
| Saxifraga cespitosa | p | +.1 | – | – | – | – | +.1 | 1.1 | 1.1 | 1.1 | +.1 | III       |
| Minuartia biflora | p | – | – | +.1 | – | – | +.1 | – | +.1 | +.1 | +.1 | III       |
| Juncus biglumis | p | – | – | +.1 | – | – | +.1 | – | +.1 | 1.1 | +.1 | III       |
| Stereocaulon alpinum | l | – | +.2 | +.2 | +.2 | 1.1 | +.2 | – | +.2 | – | – | III       |
| Sanionia uncinata | m | – | – | +.2 | +.2 | – | 1.2 | 3.2 | 2.2 | 3.2 | III       |
| Pohlia nutans | m | – | +.2 | +.2 | 1.1 | – | 3.2 | 1.2 | 1.2 | +.2 | III       |
| Cerastium alpinum | p | +.2 | – | +.2 | +.2 | – | 1.2 | – | – | – | – | II        |
| Poa vivipara | p | – | – | – | – | +.1 | – | – | +.1 | 1.1 | II        |
| Sagina nivalis | p | – | +.2 | +.2 | +.2 | – | – | – | – | +.2 | II        |
| Saxifraga cernua | p | – | – | – | – | – | 1.1 | +.1 | +.1 | +1.1 | II        |
| Silene acaulis | p | – | – | – | – | – | 1.1 | 1.1 | 1.1 | +.1 | – | – | II        |
| Polyblastia theleodes | l | – | – | – | – | – | +.2 | +.2 | – | – | +.2 | II        |
| Dicranowisia crispula | m | – | – | – | 1.2 | – | – | – | – | – | 1.2 | II        |
| Pilidium ciliare | m | – | – | – | – | 3.2 | 2.2 | – | 3.2 | 3.2 | II        |
| Blepharostoma trichophyllum | m | – | – | – | +.2 | – | – | – | – | – | – | I         |
| Ditrichium flexicaule | m | – | – | – | – | – | 1.2 | – | 1.2 | – | I         |

The letters (p, m, l) in the table mean the species identification: p—vascular plant; m—moss; l—lichen. The letter D marks the differential species. The “constancy” represents the frequency of each species in all relevés of particular syntaxa.

Sporadic species: Vascular plants: Bistorta vivipara, Cardamine pratensis, Carex subspathacea, Cerasium arcticum, Draba lactea, Equisetum scirpoideae, Luzula confusa, Oxyria digyna, Papaver dahlianum, Saxifraga aizoides, S. nivalis, S. ternis, Silene uralensis; Mosses: Bryum pseudotriquetrum, Campylium chrysophyllum, Calliergon richardsonii, Dicranum spadiceum, Drepanocladus cossonii, D. revolvens, Polytrichastrum alpinum; Lichens: Bryonora castanea, Caloplaca cerina, Cetraria islandica, Cladonia borealis, C. macrocarpa, C. pyxidata, Flavocetraria nivalis, Lecanora epibryon, Lecidea caesiocinerea, L. lapicida, L. sanguineotria, Micarea incrustata, Ochrolechia androgyna, Protopannaria pezizoides, Psoroma hypnorum, Schaerophorus globosus, Polyblystra intermedia, Verrucaria aesthiohola, V. caerulea, V. margaerea, V. pinguiula; Cyanobacteria: Gloeocapsa alpina, G. kuetzingiana, G. minor, G. montana, G. punctata, G. rupestris, Mesotaenium chlamydosporum, Nostoc paludosum, N. microsceptum, Tolypotrix elenkenii
represented by the “polar barren desert” com. Gjessing and Øvstedal 1975, the Saxifraga oppositifolia-Cetraria delisei “rødildre lavhei” com. Brattbakk 1986, and the Cetraria delisei-Saxifraga oppositifolia com. Elvebakk 1979 (partially). In the relevés of this association, apart from common bryophytes such as Platydictya jungermannioides (Brid.) H.A. Crum (fidelity degree: IV), and Timmia austrica Hedw. (fidelity degree: III), the grass Deschampsia alpina (L.) Roem. & Schult. (one of the character species of the association) has the largest frequency (fidelity degree: V); other character species of the association are Draba corymbosa R.Br. ex DC., Cerastium regelii Ostenf., and Cochlearia officinalis L. (Table 2; Fig. 3).

Relevés within the L. arcuatae Elvebakk ex Węgrzyn and Wietrzyk 2015 were assigned to the Anthelietum juratzkanae Kobayashi ex Węgrzyn and Wietrzyk 2015 and to the G. coralloidis Hadać ex Węgrzyn and Wietrzyk 2015 stat. nov. After this study, the phytosociological status of A. juratzkanae stat. nov. remains uncertain. In the relevés of this association, apart from communities of Spitsbergen proposed by Nilsen and Nordhagen (1936); in the hierarchical classification of the plant communities of Spitsbergen proposed by Nilsen and Thannheiser (2013), the Luzulion nivalis Nordh. 1936 had a rank of suballiance (and belong to the alliances of the Saxifrago-Ranunculon nivalis Nordh. 1943 em. Dierßen 1984). However, the current work shows that this syntaxon should be raised again to the rank of alliance, due to its nature and distinctiveness of its species composition in comparison with the Saxifrago-Ranunculon nivalis Nordh. 1943 em. Dierßen 1984. It is worth noticing that the authorship of the description of this syntaxon is ambiguous: the publication of Nordhagen (1936) did not contain a description of the Luzulion nivalis Nordh. 1936;
1980, differed from \textit{L. arcuatae} the necessity of further research. Our studies showed the Spitsbergen plant communities \cite{NilsenThannheiser2015} from other listed syntaxa. The species composition, but not to the \textit{L. arcuatae} Elvebakk \cite{Weber2000} referred only to the alpine plant communities \cite{Braun-BlanquetJenny1926}. Originally, the \textit{Salicetea herbacea} \cite{Br.-Bl.2005} referred to the later successional stage with a higher proportion of lichens and vascular plants. This syntaxon occupies more humid, unregulated substrates, and it is dominated by bryophytes. This stage is dominant in the Kaffiøyra Plain, where the glacier rivers often erode the substrate. Despite our study, we decided not to give association rank to this community since it requires further investigation in the field. The association of \textit{P. hirsutae} ass. nov. corresponds to the later successional stage with a higher proportion of lichens and vascular plants. This syntaxon occupies more stable and drier substrates; so it can be assumed that as the habitat is stabilizing and drying the \textit{M. biflora} community is gradually replaced by the \textit{P. hirsutae} ass. nov.

Due to the similarity of alpine conditions to arctic ones, the alpine phytosociological classification was used to characterize the arctic vegetation \cite{Gjære1956,Dierßen1984}. Originally, the \textit{Salicetalia herbacea} \textit{Br.-Bl. et al. 1947} and the \textit{Thlaspietea rotundifoli} \textit{Br.-Bl. et al. 1947} represented snowbed vegetation, as proposed by Elvebakk \cite{Elvebakk1994}. Plant communities assigned by Elvebakk \cite{Elvebakk1994} to the \textit{L. arcticae} \textit{Gjære} 1950 are in our classification grouped into two associations and one community \cite{Table2}. Furthermore, several of these species indicated that both syntaxa belong to the same type of vegetation—\textit{(G1)} graminoid tundra \cite{Walker2005}.

Our syntaxonomic ordering is hierarchic and uses modern statistical analysis. In the existing phytosociology system \cite{Elvebakk1994} that characterizes the plant communities of snowbed and exposed ridge, there is a problem of synonymous associations and communities describing the same vegetation. Our classification is different from the one proposed by Elvebakk \cite{Elvebakk1994}. Plant communities assigned by Elvebakk \cite{Elvebakk1994} to the \textit{L. arcticae} \textit{Gjære} 1950 are in our classification grouped into two associations and one community \cite{Table2,Fig3}. Similarly, eight plant communities assigned by Elvebakk \cite{Elvebakk1994} to the \textit{L. arcuatae} Elvebakk ex Węgrzyn and Wietrzyk 2015 are grouped here into only two associations \cite{Table2,Fig3}.

In terms of habitat, the \textit{M. biflora} community and \textit{P. hirsutae} ass. nov. refer to two successional types of tundra, as noted by Elvebakk \cite{Elvebakk1979} and Hermansen \cite{Hermansen1979}, but have never been described as associations. The \textit{M. biflora} community is the earlier, initial stage, occurring on more humid, unregulated substrates, and it is dominated by bryophytes. This stage is dominant in the Kaffiøyra Plain, where the glacier rivers often erode the substrate. Despite our study, we decided not to give association rank to this community since it requires further investigation in the field. The association of \textit{P. hirsutae} ass. nov. corresponds to the later successional stage with a higher proportion of lichens and vascular plants. This syntaxon occupies more stable and drier substrates; so it can be assumed that as the habitat is stabilizing and drying the \textit{M. biflora} community is gradually replaced by the \textit{P. hirsutae} ass. nov.

The \textit{D. alpinae} \cite{Nordh1943} Węgrzyn and Wietrzyk 2015 stat. nov. \cite{Table2} were described for the first time

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by Samuelsson (1916) and later revised by Nordhagen (1943). In the hierarchical classification of Spitsbergen plant communities (Nilsen and Thannheiser 2013), this syntaxon was assigned to the Cerasio-Saxifragion cernuae Hartm. 1980 (alliance equal to the L. arcuatae Elvebakk ex Węgrzyn and Wietrzyk 2015). The results of the current analyses indicate the necessity of moving the D. alpinae (Nordh. 1943) Węgrzyn and Wietrzyk 2015 stat. nov. to the L. arcuatae Gjære. 1950, due to the presence of character species of this alliance in the species composition of the association (Table 2). Moreover, this syntaxon occurs on oligotrophic substrates, in this case acidic and wet soils.

The A. juratzkanae Kobayashi et al. 2000 (Nordh. 1943) Węgrzyn and Wietrzyk 2015 seems to be adequate to the Anthelia-Cesia-riche Luzula arcuata-Ass. Nordh. 1928. In the phytosociology classification of Nilsen and Thannheiser (2013), they refer to Nordhagen (1928), but published a different name of syntaxon: the Anthelo-Luzuletum arcuatae Nordh. 1928. However, Nordhagen (1928) did not contain information on the Anthelor-Luzuletum arcuatae, but included a description of Anthelia-Cesia-riche Luzula arcuata-Ass. Nordh. 1928. Despite the suggestions that the Anthelia-Cesia-riche Luzula arcuata-Ass. Nordh. 1928 and the Anthelio-Luzuletum arcuatae Nordh. 1928 are associations, they are insufficiently published according to the “International code of phytosociological nomenclature” (Weber et al. 2000). The A. juratzkanae Kobayashi 1988 prov. (Kobayashi et al. 1990) was a provisional name; according to our work, this name truly characterizes the described type of vegetation. In terms of habitat, the A. juratzkanae Kobayashi ex Węgrzyn and Wietrzyk 2015 covers scree areas with initial soils and because of that we assigned this association to the L. arcuatae Elvebakk ex Węgrzyn and Wietrzyk 2015.

The G. coralloidis Hadač ex Węgrzyn and Wietrzyk 2015 stat. nov. was not included in the classification of plant communities of Spitsbergen (Nilsen and Thannheiser 2013). Hadač (1946) assigned it to the order Salicetalia herbaceae Br.-Bl. ap. Br.-Bl. and Jenny 1926, but the current analyses show considerable similarity to the L. arcuatae Elvebakk ex Węgrzyn and Wietrzyk 2015 in terms of species composition and the presence of character species (Table 2). The substrate of this association is dry and composed of gravel and small pebbles (Dubiel and Olech 1990).

In these studies, we wished to draw attention to the possibility of using historical vegetation data to solve phytosociological problems faced by scientists who are trying to create a uniform system of plant community classification. To achieve this, modern numerical methods were used. In several cases, they confirmed the correctness of schemes proposed by cited authors, who described plant communities using traditional phytosociological methods. However, our analyses have also led to the proposal of a new hierarchical classification of snowbed and exposed ridge plant communities of Svalbard and may hopefully for the foundation for revisions of syntaxa of other habitats.

Further to the hierarchical classification of plant communities of Spitsbergen elaborated by Nilsen and Thannheiser (2013), we would like to present, on the basis of our studies, the new classification of examined syntax as follows:

**Habitat: Snowbed**

**Class:** Saliceta herbaceae Br.-Bl. et al. 1947

**Order:** Salicetalia herbaceae Br.-Bl. ap. Br.-Bl. and Jenny 1926

**Alliance:** Luzulion arcticae Gjære. 1950

**Association:** Tomenthypnum involuti Hadač 1946

**Association:** Deschampsietum alpinae (Nordh. 1943) Węgrzyn and Wietrzyk 2015 stat. nov.

**Association:** Pedicularietum hirsutae Węgrzyn and Wietrzyk 2015 ass. nov.

**Community:** Minuartia biflora com.

**Habitat: Exposed ridge**

**Class:** Thlaspietalia rotundifolii Br.-Bl. et al. 1947

**Order:** Androsaceta alpinae Br.-Bl. ap. Br.-Bl. and Jenny 1926

**Alliance:** Luzulion arcuatae Elvebakk ex Węgrzyn and Wietrzyk 2015

**Association:** Anthelietum juratzkanae Kobayashi ex Węgrzyn and Wietrzyk 2015

**Association:** Gymnomitrietum coralloidis Hadač ex Węgrzyn and Wietrzyk 2015

**Association:** Sphaerophoro-Racemietum lanuginose (Hadač 1946; Hofm. 1968)

**Association:** Oxyrio-Trisetum spicati (Hadač 1946) Hadač 1989

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