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Circumpolar Arctic Vegetation Classification

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Abstract

Aims: An Arctic Vegetation Classification (AVC) is needed to address issues related to rapid Arctic-wide changes to climate, land-use, and biodiversity. **Location:** The 7.1 million km² Arctic tundra biome. **Approach and conclusions:** The purpose, scope and conceptual framework for an Arctic Vegetation Archive (AVA) and Classification (AVC) were developed during numerous workshops starting in 1992. The AVA and AVC are modeled after the European vegetation archive (EVA) and classification (EVC). The AVA will use Turboveg for data management. The AVC will use a Braun-Blanquet (Br.-Bl.) classification approach. There are approximately 31,000 Arctic plots that could be included in the AVA. An Alaska AVA (AVA-AK, 24 datasets, 3026 plots) is a prototype for archives in other parts of the Arctic. The plan is to eventually merge data from other regions of the Arctic into a single Turboveg v3 database. We present the pros and cons of using the Br.-Bl. classification approach compared to the EcoVeg (US) and Biogeoclimatic Ecological Classification (Canada) approaches. The main advantages are that the Br.-Bl. approach already has been widely used in all regions of the Arctic, and many described, well-accepted vegetation classes have a pan-Arctic distribution. A crosswalk comparison of *Dryas octopetala* communities described according to the EcoVeg and the Braun-Blanquet approaches indicates that the non-parallel hierarchies of the two approaches make crosswalks difficult above the plant-community level. A preliminary Arctic prodromus contains a list of typical Arctic habitat types with associated described syntaxa from Europe, Greenland, western North America, and Alaska. Numerical clustering methods are used to provide an overview of the variability of habitat types across the range of datasets and to determine their relationship to previously described Braun-Blanquet syntaxa. We emphasize the need for continued maintenance of the Pan-Arctic Species List, and additional plot data to fully sample the variability across bioclimatic subzones, phytogeographic regions, and habitats in the Arctic. This will require standardized methods of plot-data collection, inclusion of physiogonomic information in the numeric analysis approaches to create formal definitions for vegetation units, and new methods of data sharing between the AVA and national vegetation-plot databases.

Keywords: Alaska; bioclimate gradient; Braun-Blanquet approach; habitat type; plant growth form; plot database; syntaxon; vegetation mapping; tundra.

Abbreviations: AVA = Arctic Vegetation Archive; AVC = Arctic Vegetation Classification; BEC = Biogeoclimatic Ecological Classification; Br.-Bl. = Braun-Blanquet; CAFF = Conservation of Arctic Flora and Fauna; CAVM = Circumpolar Arctic Vegetation Map; CNVC = Canadian National Vegetation Classification; EUNIS = European Nature Information System; EVC = European Vegetation Classification; GIVD = Global Index of Vegetation-plot Databases; IASC = International Arctic Science Committee; ICPN = International Code of Phytosociological Nomenclature; PAF = Pan-Arctic Flora (for nomenclature of vascular plants); PASL = Pan-Arctic Species List (includes circumpolar checklist of vascular plants, mosses, liverworts, and lichens); USNVC = United States National Vegetation Classification.

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Introduction

Purpose

A unified consistent Arctic Vegetation Classification (AVC) is needed for a wide variety of reasons related to the importance of understanding the Arctic as a single global geo-ecosystem (Walker et al. 1994a; Walker & Raynolds 2011). A common language is needed to provide a framework for analyzing and modeling vegetation diversity across the Arctic as it responds to climatic and anthropogenic changes at multiple scales.

Scope

The geographic scope of the AVC includes the Arctic tundra biome as portrayed by the Circumpolar Arctic Vegetation Map (CAVM Team 2003). We also include the boreal maritime tundra areas (e.g., Aleutian Islands, Iceland, Faroe Islands, and Commodore Islands, and northern Kola Peninsula) because of the similar structure of the vegetation, which consists mainly of various combinations of herbaceous plants, dwarf shrubs (< 40 cm tall), low shrubs (40–200 cm tall), bryophytes and lichens.

History

The High Latitude Ecosystem Division of the US Man and the Biosphere Program sponsored a workshop in Boulder, Colorado, in March, 1992, to begin the process of making an Arctic vegetation classification. Several papers that reviewed the status of phytosociological research in the Arctic were published in the *Journal of Vegetation Science* (Walker et al. 1994a). The workshop participants resolved to create the following products: (1) an archive of vegetation plot data, (2) a *prodromus* (preliminary checklist) of existing arctic vegetation units; (3) a syntaxonomical classification for the circumpolar region; and (4) an arctic circumpolar vegetation map.

The Circumpolar Arctic Vegetation Map was the first concrete product resulting from the Boulder workshop. The map depicts the distribution of physiognomic categories of arctic vegetation north of Arctic tree line at a scale of 1:7,500,000 (CAVM Team 2003; Walker et al. 2005). An accompanying map to the CAVM depicts the Arctic bioclimate subzones (Elvebakk et al. 1999), which also provide the bioclimate subzonal framework for the AVC (Fig. 1). Additional Arctic vegetation mapping and classification papers are in a special issue of *Phytocoenologia* (Daniëls et al. 2005).

The basic conceptual framework for an Arctic vegetation plot database was laid out in the CAFF Strategy Series No. 5 (Walker & Raynolds 2011). In 2011, two workshops in Roskilde, Denmark, sponsored by the Nordic Network on Climate and Biodiversity (CBIO-NET), helped to lay the foundation for the Arctic Vegetation Archive (AVA), highlighting its application for modeling and predicting biodiversity (Walker et al. 2013a). The first international AVA Workshop occurred 14–16 April 2013 in Krakow, Poland (Walker et al. 2013b), and the second occurred 30–31 March 2017 in Prague, Czech Republic.

The Arctic Vegetation Archive

The first step for developing the AVC is the Arctic Vegetation Archive (AVA), which stores and manages Arctic vegetation plot data. There are approximately 31,000 available Arctic vegetation plots that conceivably could be included in the archive. The plots are well distributed across most of the 22 floristic sectors of the Arctic (Elvebakk et al. 1999) (Fig. 2), but most of the data predate modern analytical methods and were gathered using a variety of approaches and are not in digital formats. Hence they require considerable preparatory work before they can be used for analyses, which has been done for the Alaska portion of the Archive.

The Alaska Arctic Vegetation Archive (AVA-AK) is a prototype plot archive for the Arctic (Walker et al. 2014). The AVA-AK was developed for the US National Aeronautics and Space Administration (NASA) Arctic-Boreal Vulnerability Experiment (ABoVE) (ABoVE Science Definition Team 2014). The archive follows the lead of the European Vegetation Archive (EVA; Chytrý et al. 2015) and uses the Turboveg database approach (Hennekens & Schaminée 2001). An important aspect of the AVA-AK is its web-based publically accessible portal, the Alaska Arctic Geoecological Atlas, which is housed at the University of Alaska Geographic Information Network of Alaska (GINA) (http://alaskaaga.gina.alaska.edu). The portal provides a metadata catalog record and access to the available data for each AVA-AK dataset. The catalog record describes the associated research project, purpose and methods of data collection, links to the Turboveg v2 database (Hennekens & Schaminée 2001), and related ancillary data (Breen et al. 2014). Much of the existing data in the archive (24 datasets with 3026 plots) were collected during large multidisciplinary research programs such as the International Biological Program's Tundra Biome studies at Barrow, AK (Webber 1978), and the Biocomplexity of Patterned Ground studies along the northern Alaska bioclimate gradient (e.g., Kade et al. 2005; Epstein et al. 2008). The first version of the AVA-AK, was published in *Phytocoenologia* (GIVD ID NA-US-014, Walker et al. 2016a). A preliminary cluster analysis of the first 16 AVA-AK datasets (1565 plots) used a dendrogram approach to assess the relationship of numerically defined clusters to currently described Br.-

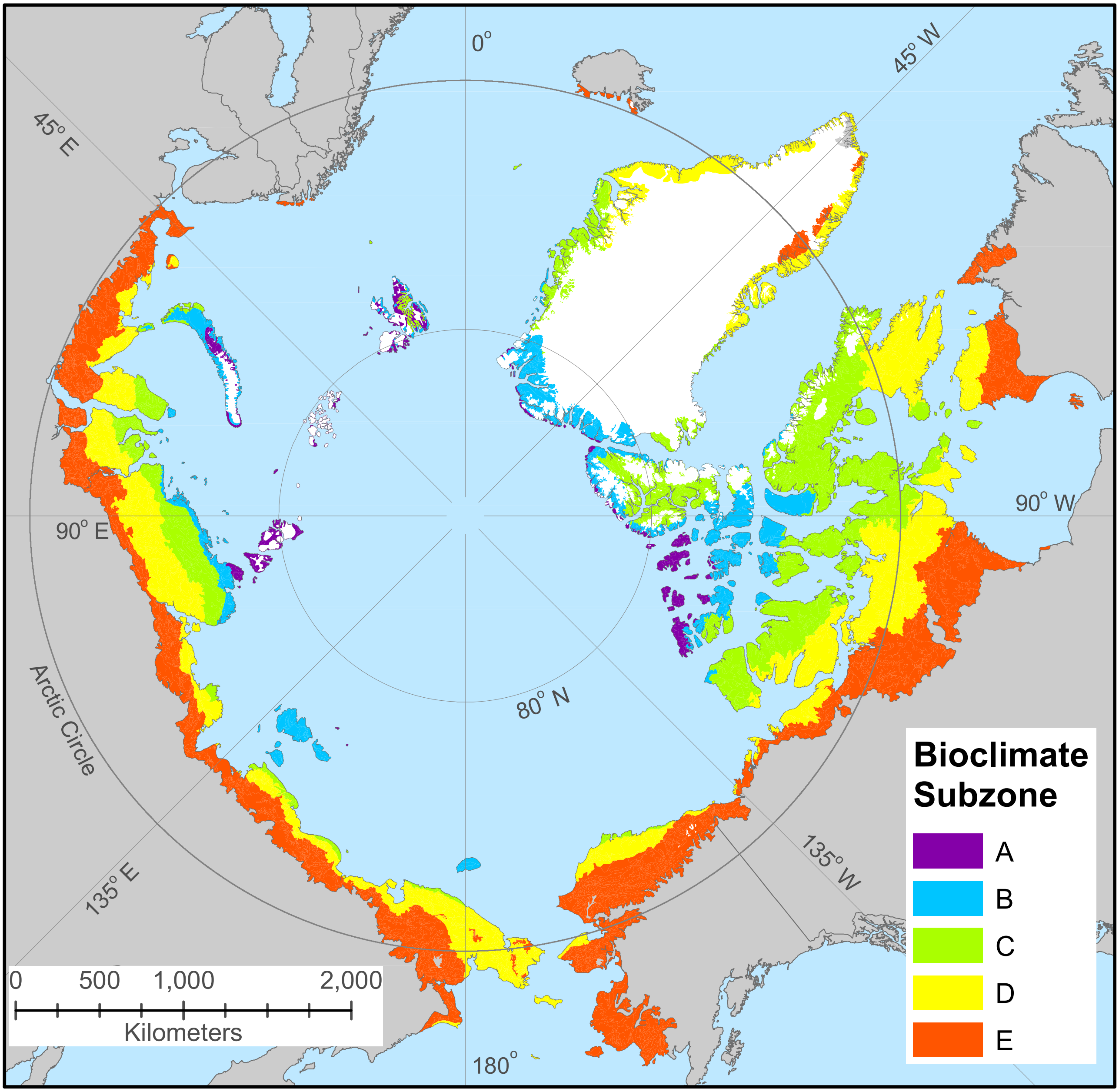

Fig. 1. Polar view of the Arctic bioclimate subzones (CAVM Team 2003). **Subzone A:** mean July temperature (MJT) = 1–3 °C**;** mostly barren. In favorable microsites, 1 lichen or moss layer < 2 cm tall, very scattered vascular plants hardly exceeding the moss layer. **Subzone B:** MJT = 4–5 °C; 2 vegetative layers, moss layer 1–3 cm thick and herbaceous layer, 5–10 cm tall, prostrate dwarf shrubs < 5 cm tall. **Subzone C:** MJT = 6–7 °C; 2 layers, moss layer 3–5 cm thick and herbaceous layer 5–10 cm tall, prostrate and hemi-prostrate dwarf shrubs < 15 cm tall (*Cassiope tetragona* is important in shallow snowbeds and some zonal sites). **Subzone D:** MJT = 6–7 °C; 2 layers, moss layer 5–10 cm thick and herbaceous and erect dwarf-shrub layer 10–40 cm tall. **Subzone E:** MJT = 10–12 °C; 2-3 layers, moss layer 5–10 cm thick, herbaceous/ erect dwarf-shrub layer 20–50 cm tall, sometimes with low-shrub layer to 80 cm.

Bl. syntaxa and to identify major data gaps (Fig. 3). The crispness of classification method (Botta-Dukát et al. 2005) within the JUICE program (Tichý et al. 2011) was used to determine the optimal number of clusters required to separate the dataset into distinct vegetation units. Maximum separation between clusters was achieved with four clusters which showed a general gradient in the data from a mix of wet to moist azonal primarily acidic plant communities on one side of the dendrogram to primarily moist to dry nonacidic, and zonal plant communities on the other side of the diagram. The next highest level of separation was achieved with 17 sub-

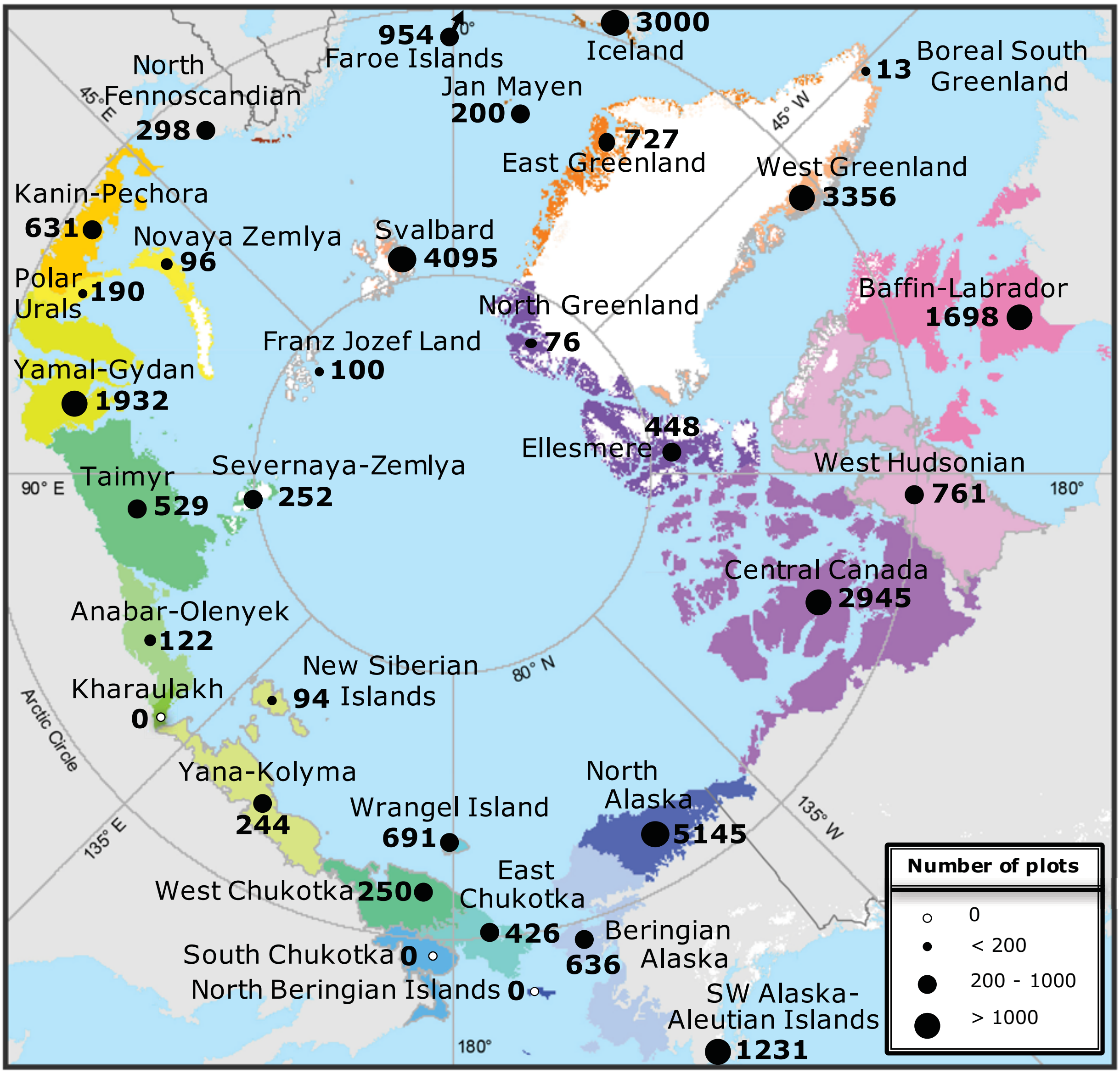

Fig. 2. Circumpolar distribution of the known 30,980 Arctic vegetation plots within the Arctic floristic sectoral subdivisions of Elvebakk et al. (1999), which are a modification of Yurtsev's (1994) floristic subprovinces. A few of the original 22 sectors have been subdivided where there are clear geographical separation and corresponding datasets: The Svalbard-Franz Josef Land sector is subdivided into Svalbard and Franz Jozef Land; Polar Urals-Novaya Zemlya sector subdivided into Polar Urals and Novaya Zemlya; Taimyr sector subdivided into Taimyr and Severnaya Zemlya; Yana-Kolyma sector subdivided in the Yana-Kolyma and New Siberian Islands; West Chukotka sector subdivided into West Chukotka and Wrangel Island; Ellesmere-North Greenland sector subdivided into Ellesmere and North Greenland; West Greenland sector subdivided into West Greenland and boreal south Greenland; North Iceland-Jan Mayen sector subdivided into Iceland and Jan Mayan. A few maritime boreal tundra areas are included: Faroe Islands, boreal portions of Iceland, and SW Alaska-Aleutian Islands, and Boreal South Greenland.

clusters that generally corresponded to geographical or ecological affiliation of groups of plant communities. Details of the analysis are in Supplement S3 of Walker et al. (2016a). The exercise demonstrated numerical methods were effective for separating large Arctic datasets into meaningful clusters that corresponded to groups of high-level Br.-Bl. syntaxa.

Overall, the AVA-AK is a major step toward consolidating existing plot data from Arctic Alaska into a single database with consistent species names that can be used for future classification and analysis of Arctic vegetation. There are, however, some artifacts/errors of spatial autocorrelation in our analysis where some plots from small regions representing different communities seem to be more similar than the same units from remote areas. For example, six of the 17 subclusters in Fig. 3 were nearly entirely composed of plots from two large datasets that contained unique vegetation of alpine areas of the Arrigetch Peaks in the Brooks Range (Cooper 1986) and pingos on the Arctic Coastal Plain (Walker 1990). These two datasets sampled much of the total habitat diversity at the drier end of the ecological gradients. Some of the spatial autocorrelation undoubtedly resulted from the same level of taxonomic expertise used in creating these datasets. Walker et al. (2016b) discuss other weaknesses and inconsistencies in the datasets and problems that were encountered during gathering and standardizing the data. These could largely be corrected by standardization of the plot-data survey methods in future vegetation surveys (discussed later in this article).

Rationale for using the Braun-Blanquet approach for the AVC

The international scope of the AVA involves countries with a diversity of national-classification approaches. This special issue of *Phytocoenologia* reviews some of the most common classification approaches currently used around the world. Three of these potentially have broad application in the Arctic: The Br.-Bl. approach, which was developed in Europe (Braun-Blanquet 1932, 1964; Guarino et al. this volume); the EcoVeg approach, which was initially developed for the U.S. National Vegetation Classification (USNVC) (Jennings et al. 2009; Faber-Langendoen et al. 2014 and this volume) and then expanded for broad international application; and the Biogeoclimatic Ecosystem Classification approach used in British Columbia, Canada (BEC: Pojar et al. 1987; MacKenzie & Meidinger this volume).

The participants at the 1992 Boulder workshop generally agreed that the best classification method for the Arctic is the Br.-Bl. approach because it was already widely used across the full Arctic. Emil Hadač used the approach to describe the vegetation of a diversity of Arctic habitats in Iceland and Svalbard (Hadač 1944, 1946, 1967, 1971a, b). The method has since been widely applied in northern areas of Europe (Dierßen 1996), Svalbard (Elvebakk 1994; Nilsen & Thannheiser 2013), and especially in Greenland (Böcher 1954, 1963; Daniëls 1975, 1982, 1994; de Molenaar 1974, 1976; Lünterbusch et al., 1997; Lünterbusch & Daniëls 2004; Lepping & Daniëls 2007; Bültmann & Daniëls 2013; Daniëls et al. 2016), including Greenland's arctic-alpine elevation belts (Sieg et al. 2006; Drees & Daniëls 2009). The Br.-Bl. method has also been used, but less extensively, in Arctic Russia (Matveyeva 1994, 1998, 2002, 2006; Kholod 2007; Koroleva 1994, 2006, 2015; Kucherov & Daniëls 2005; Matveyeva & Lavrinenko 2011; Lavrinenko et al. 2012, 2014, 2016; Ermokhina 2013; Matveyeva et al. 2013a, b; Lavrinenko & Lavrinenko 2015), Canada (Lambert 1968; Barrett 1972; Thannheiser 1976, 1987; Thannheiser & Willers 1988; Vonlanthen et al. 2008), and Alaska (Komárková & Webber 1980; Cooper 1986; Komárková & McKendrick 1988; Walker et al. 1994b; Schickhoff et al. 2002; Daniëls et al. 2004; Kade et al. 2005; Talbot et al. 2005, 2010; Talbot & Talbot 2008; Breen 2014).

Three other factors also argue for the application of the Br.-Bl. approach for the AVC. First, the Arctic has a relatively small and well known flora compared to other biomes (Daniëls et al. 2013; Daniëls 2013; Dahlberg & Bültmann 2013). It is the only biome with a standardized species list that can be used to easily compare accepted names and synonyms across the full extent of the biome. Checklists of Arctic vascular plants (Elven et al. 2011), lichens, (Kristinsson et al. 2010), mosses (Belland 2012 pers. comm.), and liverworts (Konstantinova et al. 2009) were combined into a single Pan-Arctic Species List (Raynolds et al. 2013).

Second, the Arctic is already well represented in the European Vegetation Classification (Mucina et al. 2016), which uses the Br.-Bl. approach. The first vegetation surveys using the Br.-Bl. approach focused on European mountains where environmental conditions and many plant communities are similar to those in the Arctic (e.g., Braun-Blanquet 1926, 1948; Braun-Blanquet & Jenny 1926; Domin 1928, 1933; Krajina 1933a, b). Many Br.-Bl. syntaxa described from Europe are common in the Arctic (Bültmann & Daniëls 2013). (See further discussion of this point below under discussion of the Arctic Vegetation Prodromus).

Finally, the recent summary of the EVC follows a conceptual framework of vegetation zonality (Walter 1973; Mucina et al. 2016) that fits well with the conceptual zonal mapping approach of the CAVM, thereby providing a unity between the classification and the existing map of the Arctic (CAVM Team 2003; Walker et al. 2005).

Although there are advantages in using the Br.-Bl. approach for the circumpolar Arctic, the method of naming plant communities using the International Code of Phytosociological Nomenclature (ICPN: Weber et al. 2000) is not likely to gain wide acceptance in the North American Arctic, partly due to the low amount of North America experience in using the complex rules of the ICPN. In the US, the EcoVeg approach (Faber-Langendoen et al. 2014; Faber-Langendoen this volume) has been adopted by land-management agencies as the vegetation standard for the US National Vegetation Classification (USNVC). The EcoVeg approach has also gained momentum in Arctic Alaska through the Alaska Natural Heritage Program (AKNHP) (Boggs et al. 2014; Boucher et al. 2016).

In Arctic Canada, the Canadian High Arctic Research Station (CHARS) is using the BEC approach (Pojar et al. 1987; MacKenzie & Meidinger this volume). Prof. V. J. Krajina, who developed the BEC approach, was from

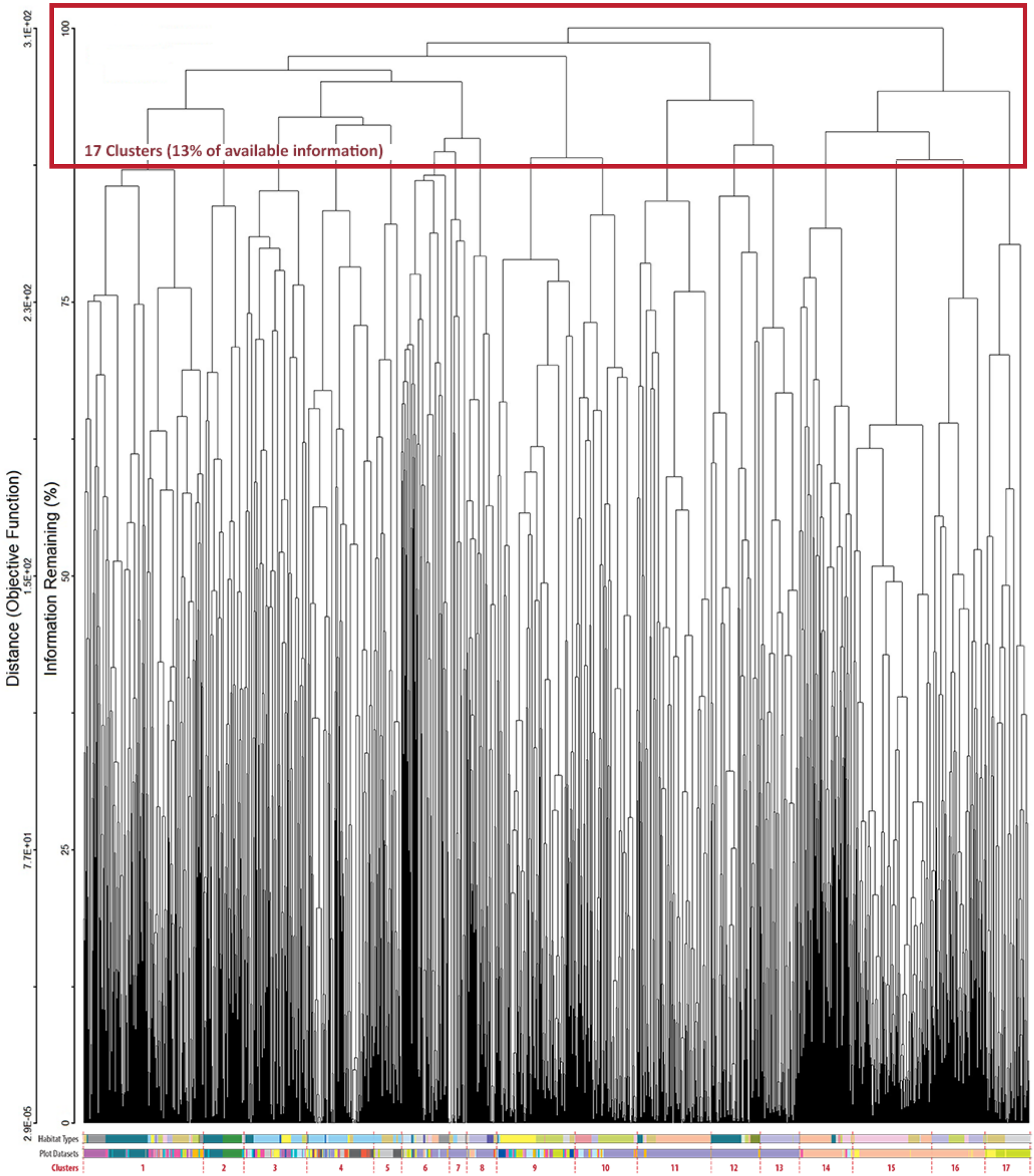

Fig. 3. Dendrogram of the first 16 datasets entered into the AVA-AK plot archive. The full dendrogram (left) shows the distribution of 1,565 plots in the archive. The upper portion of the dendrogram portrays the optimal number of clusters required to separate the dataset into distinct vegetation units as determined by the crispness of classification method (Botta-Dukát et al. 2005) within the JUICE program (Tichý et al. 2011). The maximum separation between clusters was achieved with four clusters; the next highest level of separation was achieved with 17 subclusters. A color-coded version of this upper portion of the dendrogram (right) reveals the general habitat trends across the diagram, which generally corresponds to geographical or ecological affiliation of groups of plant communities (see text for further discussion). Details of the habitat types and datasets in each cluster are shown in the color bars at the bottom of both diagrams. Diagnostic constant, and dominant species in each subcluster are in Supplement S3 of Walker et al. *(*2016a). (Modified from Walker et al. 2016a.)

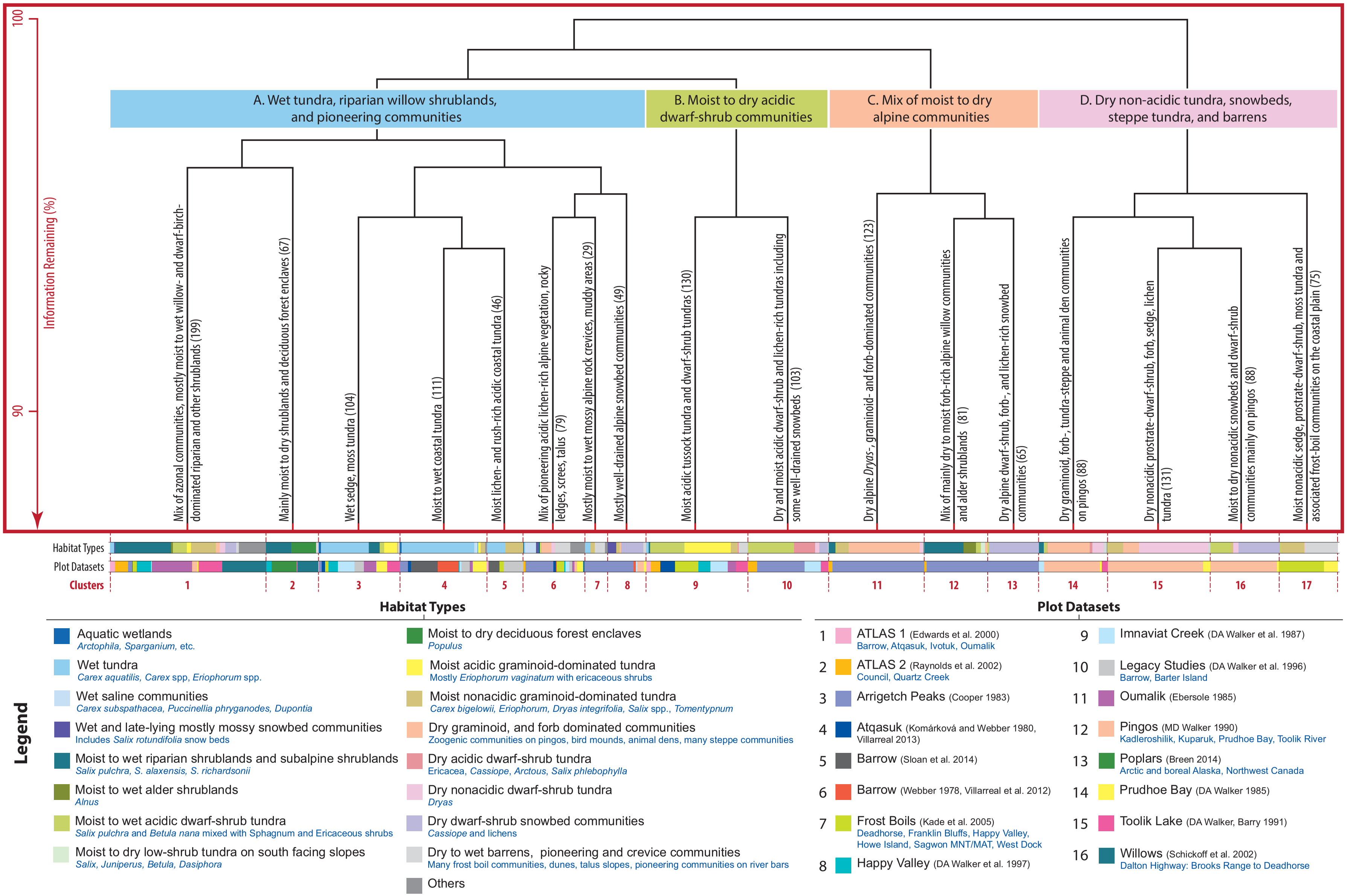
100
90
Information Remaining (%)
A. Wet tundra, riparian willow shrublands, and pioneering communities
B. Moist to dry acidic dwarf-shrub communities
C. Mix of moist to dry alpine communities
D. Dry non-acidic tundra, snowbeds, steppe tundra, and barrens
Mix of azonal communities, mostly moist to wet willow- and dwarf-birch-dominated riparian and other shrublands (199)
Mainly moist to dry shrublands and deciduous forest enclaves (67)
Wet sedge, moss tundra (104)
Moist to wet coastal tundra (111)
Moist lichen- and rush-rich acidic coastal tundra (46)
Mix of pioneering acidic lichen-rich alpine vegetation, rocky ledges, screes, talus (79)
Mostly moist to wet mossy alpine rock crevices, muddy areas (29)
Mostly well-drained alpine snowbed communities (49)
Moist acidic tussock tundra and dwarf-shrub tundras (130)
Dry and moist acidic dwarf-shrub and lichen-rich tundras including some well-drained snowbeds (103)
Dry alpine Dryas-, graminoid- and forb-dominated communities (123)
Mix of mainly dry to moist forb-rich alpine willow communities and alder shrublands (81)
Dry alpine dwarf-shrub, forb-, and lichen-rich snowbed communities (65)
Dry graminoid, forb-, tundra-steppe and animal den communities on pingos (88)
Dry nonacidic prostrate-dwarf-shrub, forb, sedge, lichen tundra (131)
Moist to dry nonacidic snowbeds and dwarf-shrub communities mainly on pingos (88)
Moist nonacidic sedge, prostrate-dwarf-shrub, moss tundra and associated frost-boil communities on the coastal plain (75)
Habitat Types
Plot Datasets
Clusters
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Legend
Habitat Types
Aquatic wetlands
Arctophila, Sparganium, etc.
Wet tundra
Carex aquatilis, Carex spp, Eriophorum spp.
Wet saline communities
Carex subspathacea, Puccinellia phryganodes, Dupontia
Wet and late-lying mostly mossy snowbed communities
Includes Salix rotundifolia snow beds
Moist to wet riparian shrublands and subalpine shrublands
Salix pulchra, S. alaxensis, S. richardsonii
Moist to wet alder shrublands
Alnus
Moist to wet acidic dwarf-shrub tundra
Salix pulchra and Betula nana mixed with Sphagnum and Ericaceous shrubs
Moist to dry low-shrub tundra on south facing slopes
Salix, Juniperus, Betula, Dasiphora
Moist to dry deciduous forest enclaves
Populus
Moist acidic graminoid-dominated tundra
Mostly Eriophorum vaginatum with ericaceous shrubs
Moist nonacidic graminoid-dominated tundra
Carex bigelowii, Eriophorum, Dryas integrifolia, Salix spp., Tomentypnum
Dry graminoid, and forb dominated communities
Zoogenic communities on pingos, bird mounds, animal dens, many steppe communities
Dry acidic dwarf-shrub tundra
Ericacea, Cassiope, Arctous, Salix phlebophylla
Dry nonacidic dwarf-shrub tundra
Dryas
Dry dwarf-shrub snowbed communities
Cassiope and lichens
Dry to wet barrens, pioneering and crevice communities
Many frost boil communities, dunes, talus slopes, pioneering communities on river bars
Others
Plot Datasets
1 ATLAS 1 (Edwards et al. 2000)
Barrow, Atqasuk, Ivotuk, Oumalik
2 ATLAS 2 (Raynolds et al. 2002)
Council, Quartz Creek
3 Arrigetch Peaks (Cooper 1983)
4 Atqasuk (Komárková and Webber 1980, Villarreal 2013)
5 Barrow (Sloan et al. 2014)
6 Barrow (Webber 1978, Villarreal et al. 2012)
7 Frost Boils (Kade et al. 2005)
Deadhorse, Franklin Bluffs, Happy Valley, Howe Island, Sagwon MNT/MAT, West Dock
8 Happy Valley (DA Walker et al. 1997)
9 Imnaviat Creek (DA Walker et al. 1987)
10 Legacy Studies (DA Walker et al. 1996)
Barrow, Barter Island
11 Oumalik (Ebersole 1985)
12 Pingos (MD Walker 1990)
Kadleroshilik, Kuparuk, Prudhoe Bay, Toolik River
13 Poplars (Breen 2014)
Arctic and boreal Alaska, Northwest Canada
14 Prudhoe Bay (DA Walker 1985)
15 Toolik Lake (DA Walker, Barry 1991)
16 Willows (Schickoff et al. 2002)
Dalton Highway: Brooks Range to Deadhorse

Fig. 3. cont.

Czechoslovakia and was well trained in the Br.-Bl. methods. The root units of the BEC method are defined by plot data that are compatible with the Br.-Bl. sampling approach and the current zonal and habitat-type structure of the European Vegetation Classification (Mucina et al. 2016). The BEC units can also be arranged hierarchically along the lines of the EcoVeg approach.

We currently plan to use the Br.-Bl. approach for the AVC, but independent EcoVeg and BEC classifications using the same AVA database would help to evaluate, compare, and improve all three methods for applications in the Arctic. (See below for an example of a crosswalk between equivalent units defined by the EcoVeg and Br.-Bl. methods.)

An Arctic vegetation prodromus

Although the Arctic is vastly under sampled – approximately 31,000 valid vegetation plots within an area of 7 million km^2 – there are enough data to start making an Arctic syntaxonomic checklist, or *prodromus*, as a precursor to a more comprehensive Arctic Vegetation Classification. The participants at the Krakow and Prague AVA meetings agreed that the hierarchical Br.-Bl. floristic structure of the European Vegetation Classification (Mucina et al. 2016) can be used as an example of what can be achieved for the Arctic. A preliminary list of common habitat-types and associated Br.-Bl. syntaxa (Table 1) includes information from the European vegetation checklist (Mucina et al. 2016), Greenland (Bültmann & Daniëls 2013), western North America (Peinado et al. 2005), and Alaska (Walker et al. 2016a). The recent revision of the EVC aligns higher-level Br.-Bl. syntaxa (classes, orders and alliances) with the habitat types of the European Nature Information System (EUNIS: European Environment Agency 2015; Rodwell et al. 2002). This Arctic list of habitat-types (Table 1) is now used to code new plots added to the AVA-AK.

The Arctic is already well represented in the European survey, which includes portions of the Arctic that are under the political rule of member nations of the European Union. Many already-described, well-accepted vegetation classes have a pan-Arctic distribution. Examples include, the non-acidic sedge and dwarf-shrub class – *Carici rupestris-Kobresietea bellardii* Ohba 1974, the acidic dwarf-shrub heath class – *Loiseleurio-Vaccinietea* Eggler ex Schubert 1960, and the cryptogam-rich herb class of polar deserts – *Drabo corymbosae-Papaveretea dahliani* Daniëls et al. 2016). There is also a group of other vegetation classes, where occurrence in Arctic regions is less certain but is anticipated. Proper evaluation and comparison with similar areas in Arctic North America may result in description of vicariant units of existing classes (e.g. deep snowbed vegetation – *Salicetea herbaceae* Br.-Bl. 1948, tall forb vegetation on mesic-moist soil – *Mulgedio-Aconitetea* Hadač et Klika in Klika et Hadač 1944, and alder and willow deciduous scrub and krummholz communities – *Betulo carpaticae-Alnetea viridis* Rejmánek ex Boeuf et al. 2014).

Next steps

Maximizing the value of Arctic vegetation plot surveys

Adding high-quality plot data to the AVA will be key to a successful classification. Additional data need to be collected across the full range of habitat types encountered along both the north-south bioclimate gradient (Fig. 1) and the east-west floristic gradients (Fig. 2). We recommend that future Arctic vegetation surveys adopt standardized sampling methods that are compatible with the Br.-Bl. and North American approaches and also provide standardized data that are useful for global biodiversity, remote-sensing, and ecosystem-modeling efforts (Walker et al. 2016b). The following outline of suggested protocols is a start, but should be formalized with more detail, and further suggestions by a wider group of Arctic vegetation scientists into a field manual specific for sampling Arctic plot data.

Reconnaissance: Adequate time should be allowed for reconnaissance and literature review prior to the formal surveys. Knowledge about the local geology, soils, and historical influences on the vegetation are critical for identifying the range of habitat types to sample. Every effort should be made to identify and sample the local zonal vegetation first and then prioritize other habitats according to their importance and area covered in the local landscape. In general finer-scale mapping efforts require more attention to habitat types and plant communities that cover small areas.

Site selection, permanent plots, and marking: The objective of a Br.-Bl. classification is often to characterize vegetation in certain habitat types (e.g., see Table 1). One requirement of the Br.-Bl. approach is the selection of sites with homogenous site conditions and vegetative cover (Westhoff & Van der Maarel 1978). Random sampling approaches are rarely effective for this unless the habitat type is relatively homogenous over large areas. The plots should be large enough to satisfy minimum-area requirements (Chytrý & Otýpková 2003), and replicate samples should be collected from several areas representative of each sampled plant-community type. All four corners of plots should be permanently marked with stakes and identification tags.

Site descriptions: A standardized description of the site should include the geographic coordinates of the plot, photo-id numbers (with the plot number in the photo of the local landscape, the plant community, and soil), a brief description of the vegetation, and a standardized set

Table 1. List of habitat types with closest equivalent Br.-Bl. units for the Arctic based on information from Greenland (Bültmann & Daniëls 2013), Europe (Mucina et al. 2016), Western North America (Peinado et al. 2005), and Alaska (Walker et al. 2016a) with organization following the Br.-Bl. classes and habitat types of Europe (Mucina et al. 2016).

Habitat type code	Habitat description	Closest equivalent Br.-Bl. unit
1	**ARCTIC ZONAL TUNDRA**	
1.01	**Polar desert vegetation, subzone A**	**PAP: *Drabo corymbosae-Papaveretea dahliani* Daniëls, Elvebakk et Matveyeva in Daniëls et al. 2016**
		PAP-01: *Saxifrago oppositifoliae-Papaveretalia dahliani* Daniëls, Elvebakk et Matveyeva in Daniëls et al. 2016
1.01.1	Polar deserts of the Arctic zone of the Arctic Ocean archipelagos – North America	PAP-01A: *Papaverion dahliani* Hofmann ex Daniëls, Elvebakk et Matveyeva in Daniëls et al. 2016
1.02	**Dry and mesic dwarf-shrub and graminoid zonal vegetation on non-acidic base-rich soils**	**KOB: *Carici rupestris-Kobresietea bellardii* Ohba 1974**
		KOB-01: *Thymo arcticae-Kobresietalia bellardii* Ohba 1974
1.02.1	Dry zonal habitats of graminoid tundra and dwarf-shrub heath vegetation of Scotland, Scandinavia, Iceland and the Arctic Ocean islands on base-rich soils, subzones B and C	KOB-01A: *Kobresio-Dryadio*n Nordhagen 1943
1.02.2	Mesic zonal habitats of graminoid tundra and dwarf-shrub heath vegetation of Arctic Western Russia and Siberia on base-rich soils, subzone B, C & D	KOB-01B: *Dryado octopetalae-Caricion arctisibiricae* Koroleva et Kulyugina in Chytrý et al. 2015
1.02.3	Graminoid tundra and dwarf-shrub heath vegetation of Greenland and the Arctic North America, subzones B, C & D, (includes for now early-melting base-rich *Cassiope-Tomentypnum* snowbeds)	KOB-01C: *Dryadion integrifoliae* Ohba ex Daniëls 1982
1.03	**Dry to mesic dwarf-shrub heath on acidic substrates, subzones D and E**	**LOI: *Loiseleurio procumbentis-Vaccinietea* Eggler ex Schubert 1960**
		LOI-03: *Deschampsio flexuosae-Vaccinietalia myrtilli* Dahl 1957
1.03.1	Wind-swept dry habitats with prostrate-dwarf-shrub tundra acidic soils, subzone D and E	LOI-03A: *Loiseleurio-Arctostaphylion* Kalliola ex Nordhagen 1943
1.03.2	Zonal habitats with erect-dwarf-shrub tundra acidic soils, subzones D and E (includes for now early-melting acidic *Cassiope-Hylocomium* snowbeds)	LOI-03B: *Phyllodoco-Vaccinion myrtilli* Nordhagen 1943
1.03.3	Low-shrub tundra, acidic soils, warmest parts of subzone E	
		LOI-04: *Vaccinio mini-Betuletalia exilis* Peinado et al. 2005
1.03.4	Amphiberingian chionophytic heath communities	LOI-04A: *Polygono plumosi-Cassiopion tetragonae* Peinado et al. 2005
1.03.5	Achionophytic heath communities (a vicariant alliance to the *Loiseleurio-Arctostaphyllion* that occurs in Northern Europe, Greenland as well as Eastern part of North America)	LOI-04B: *Hierochloo alpinae-Dryadion octopetalae* Peinado et al. in prep

Table 1. cont.

Habitat type code	Habitat description	Closest equivalent Br.-Bl. unit
2	**BOREAL MARITIME TUNDRA**	
2.01	**Mesic tall-herb vegetation, boreal maritime tundra**	***Mulgedio-Aconitetea* Hadač et Klika in Klika et Hadač 1944**
		MUL-05: *Epilobio lactiflori-Geranietalia sylvatici* Michl et al. 2010
2.01.1	Mesic tall-herb vegetation, boreal maritime tundra	MUL-05A: *Mulgedion alpini* Nordhagen 1943
3	**INTRAZONAL VEGETATION OF THE ARCTIC ZONE**	
3.01	**Cryo-xerophytic steppe and associated shrub on base-rich and (sub)saline substrates in continental Greenland and North America**	**SAX: *Saxifrago tricupidatae-Calamagrostietea purpurascentis* Drees et Daniëls 2009**
		SAX-01: *Saxifrago tricuspidatae-Calamagrostietalia purpurascentis* Drees et Daniëls 2009
3.01.1	Cryo-xerophytic steppe and associated shrub on base-rich soils	SAX-01A: *Saxifrago tricuspidatae-Calamagrostion purpurascentis* Cooper ex Drees et Daniëls 2009
3.01.2	Mesic forb-rich, turfy low Arctic (sub)saline steppe vegetation on base-rich soils	SAX-01B: *Puccinellion nuttallianae* Daniëls in Chytrý et al. 2015
3.02	**Arctic rush swards on acidic substrates in arctic region**	**TRI: *Juncetea trifidi* Hadač in Klika et Hadač 1944**
		TRI-01: *Juncetalia trifidi* Daniëls 1994
3.02.1	Wind-swept, chionophobous habitats on acidic soils dominated by rushes	TRI-01A: *Carici-Juncion trifidi Nordhagen* 1943
3.03	**Grass- & rush-rich, zoogenic habitats, subzones A, B & C**	**COC: *Saxifrago cernuae-Cochlearietea groenlandicae* Mucina et Daniëls in Mucina et al. 2016**
		COC-01: *Phippsio-Cochleariopsietalia groenlandicae* Hadač 1989
3.03.1	Zoogenic, disturbed habitats, subzones, all subzones	COC-01A: *Cochleariopsion groenlandicae* Hadač 1989
4	**EXTRAZONAL BOREAL VEGETATION OCCURRING IN THE ARCTIC ZONE**	
4.01	**Boreal coniferous forest enclaves within the tundra zone**	**PIC: *Vaccinio-Piceetea* Br.-Bl. in Br.-Bl. et al. 1939 (EuroAsia)** **LIP: *Linnaeo americanae-Piceatea marianae* Rivas-Martínez. Sánchez-Mata & Costa 1999 (North America)**
		No units at this point
4.02	**Subalpine and subarctic herb-rich alder and willow scrub and krummholz**	**VIR: *Betulo carpaticae-Alnetea viridis* Rejmánek ex Boeuf, Theurillat, Willner, Mucina et Simler in Boeuf et al. 2014**
		VIR-01: *Alnetalia viridis* Rübel ex Karner et Willner in Willner et Grabherr 2007
4.02.1	Moist to dry alder *(Alnus viridis*) communities and alder savannas	VIR-01A: *Alnion viridis* Schnyder 1930
		VIR-03: *Salicetalia glauco-lanatae* Boeuf et al. ex Mucina et Daniëls in Mucina et al. 2016
4.02.2	Willow shrublands along streams, rivers, and water tracks on hill slopes	VIR-03A: *Salicion phylicifoliae* Dierssen 1992

Table 1. cont.

Habitat type code	Habitat description	Closest equivalent Br.-Bl. unit
4.02.3	Herb-rich willow scrub and krummholz, subzones D and E	VIR-03B: *Salicion callicarpaeae* Daniëls in Mucina et al. 2016
5	**AZONAL ARCTIC HABITATS**	
5.01	***SALT MARSHES, SAND DUNES, SEA CLIFFS***	
5.01.1	**Wet saline coastal marshes**	**JUN: *Juncetea maritimi* Br.-Bl. In Br.-Bl. et al. 1952**
		JUN-04: *Puccinellietalia phryganodis* Hadač 1946
5.01.1.1	Coastal salt-marshes	JUN-04A: *Puccinellion phryganodis* Hadač 1946
5.01.2	**Tall-grass swards, sand dunes**	**AMM: *Ammophiletea* Br.-Bl. et Tx. ex Westhoff et al. 1946**
		AMM-01: *Ammophiletalia* Br.-Bl. et Tx. ex Westhoff et al. 1946
5.01.2.1	Tall-grass swards, sand dunes (*Leymus arenarius*) (+ for now other undescribed saline coastal embryonic communities)	AMM-01C: *Elymion arenarii* Christiansen 1927
5.02	***TALUS, SCREES, AND BOULDER FIELDS (see also habitat codes 5.08.1 to 5.08.4 for epilithic moss- and lichen-dominated communities)***	
5.02.1	**Rock-crevices, ledges, faces of rocky cliffs & walls**	**ASP: *Asplenietea trichomanis* (Br.-Bl. in Meier et Br.-Bl. 1934) Oberd. 1977**
		ASP-11: *Androsacetalia vandellii* Br.-Bl. in Meier et Br.-Bl. 1934 nom. corr
5.02.1.1	Siliceous rock crevices, ledges, faces and walls	ASP-11A: *Saxifragion cotyledonis* Nordhagen ex Mucina et Chytrý in Mucina et al. 2016
5.02.2	**Scree habitats and course alluvium**	**THL: *Thlaspietea rotundifolii* Br.-Bl. 1948**
		THL-01: *Thlaspietalia rotundifolii* Br.-Bl. in Br.-Bl. et Jenny 1926
5.02.2.1	Base-rich and neutral screes and moraines	THL-01M: *Arenarion norvegicae* Nordhagen 1935
		THL-02: *Arabidetalia caeruleae* Rübel ex Nordhagen 1937
5.02.2.2	Herb-rich snow-beds, stabilized course calcareous soils	THL-02A: *Saxifrago oppositifoliae-Oxyrion digynae* Gjaerevoll 1950
		THL-06: *Androsacetalia alpinae* Br.-Bl. in Br.-Bl. et Jenny 1926
5.02.2.3	Herb-rich vegetation, damp coarse gravels, siliceous substrates of Iceland	THL-06A: *Antitrichio-Rhodiolion roseae* Hadač 1971
		THL-08: *Epilobietalia fleischeri* Moor 1958 nom. conserv. propos.
5.02.2.4	Ruderal riparian floodplain and terrace vegetation (*Epilobium latifolium)*	THL-08C: *Calamagrostion neglectae* Nordhagen ex de Molenaar 1976
5.03	***SNOWBEDS AND WET COLD FROST-ACTIVE SOILS***	
5.03.1	**Late-melting snowbeds and wet cold frost-active soils**	**HER: *Salicetea herbaceae* Br.-Bl. 1948**
		HER-01: *Salicetalia herbaceae* Br.-Bl. In Br.-Bl. et Jenny 1926

Table 1. cont.

Habitat type code	Habitat description	Closest equivalent Br.-Bl. unit
5.03.1.1	Prostrate dwarf-shrub snowbeds on acidic siliceous substrates	HER-01H: *Cassiopo-Salicion herbaceae* Nordhagen 1943
5.03.1.2	Wet late-melting snowbeds and frost boils, cold acidic fine-grained soils	HER-01J: *Saxifrago stellaris-Oxyrion digynae* Gjaerevoll 1950
		HER-02: *Carici podocarpe-Anemonetalia parviflorae* Peinado et al. 2005
5.03.1.3	Amphiberingian late-melting snowbed communities	HER-02A: *Taraxaco alaskani-Salicion rotundifoliae* Peinado et al. 2005
5.03.1.4	Early melting snowbed communities of the Alasko-Yukonian phytogeographical sector	HER-02B: *Solidagini arcticae-Dryadion alaskensis* Peinado et al. 2005
5.04	***SPRINGS***	
5.04.1	**Cold oligotrophic springs in the boreal and arctic zones of northern Europe**	**MON: *Montio-Cardaminetea* Br.-Bl. et Tx. ex Klika et Hadač 1947**
		MON-02: *Montio-Cardaminetalia* Pawlowski et al. 1928
		No units at this point
5.05	***FRESH WATER BODIES***	
5.05.1	**Aquatic rooted floating or submerged macro-phyte vegetation of meso-eutrophic water**	POT: *Potamogetonetea* Klika in Klika et Novák 1941
		POT-01: *Potamogetonetalia* Koch 1926
5.05.1.1	Aquatic forb marshes	POT-01A: *Potamogetonion* Libbert 1931
5.05.2	**Pond and lake margins with aquatic grasses**	**PHR: *Phragmito-Magnocaricetea* Klika in Klika et Novák 1941**
		PHR-07 *Arctophiletalia fulvae* Petryakov et Gogoleva in Kholod 2007
5.05.2.1	Aquatic grass marshes	PHR-07A: *Arctophilion fulvae* Pestryakov et Gogoleva in Kholod 2007
5.06	***MIRES (wetlands)***	
5.06.1	**Fens, base-rich wetlands**	**SCH: *Scheuchzerio palustris-Caricetea fuscae* Tx 1937**
		SCH-01: *Caricetalia davallianae* Br.-Bl. 1950 nom. conserv. propos.
5.06.1.1	Sedge fens on calcareous mineral substrates	SCH-01C *Caricion atrofusco-saxatilis* Nordhagen 1943
		SCH-02: *Sphagno warnstorfii-Tomentypnetalia* Lapshina 2010
5.06.1.2	Sedge-brown-moss fens on peats and peaty mineral soils	SCH-02A: *Saxifrago-Tomentypnion* Lapshina 2010
5.06.1.3	Moist to wet coastal sedge-grass tundra calcareous slightly saline soils (*Carex stans-Saxifraga cernua, Dupontia fisheri*)	SCH-02B: *Caricion stantis* Matveyeva 1994
		SCH-03: *Caricetalia fuscae* Koch 1926
5.06.1.4	Poor fens, slightly acidic organic soils (sedge-dwarf-shrub-*Sphagnum*)	SCH-03B: *Caricion fuscae* Koch 1926 nom. conserv. propos.
5.06.1.5	Wet acidic sedge forb mires of Aleutian Islands	No units at this point

Table 1. cont.

Habitat type code	Habitat description	Closest equivalent Br.-Bl. unit
5.06.1.6	Moist to wet grassy meadows (*Calamagrostis canadensis*, *Polemonium acutiflorum*, *Potentilla palustris*)	No units at this point
5.06.2	**Bogs, wetlands on acidic ombrotrophic soils**	**OXY: *Oxycocco-Sphagnetea* Br.-Bl. et Tx. ex Westhoff et al. 1946**
		OXY-02: Sphagnetalia medii Kästner et Flössner 1933
5.06.2.1	Tussock tundra (*Eriophorum vaginatum*)	OXY-02B: *Sphagnion medii* Kästner et Flössner 1933
5.06.2.2	Dwarf-shrub and peat-moss raised bog vegetation in the boreal and Arctic zones	OXY-02A*: Oxycocco microcarpi-Empetrion hermaphroditi* Nordhagen ex Du Rietz 1954 nom. conserv. propos.
5.07	***RIPARIAN SHRUBLANDS and GALLERY FORESTS***	
5.07.1	**Riparian habitats, willow *(Salix*) shrublands and poplar (*Populus*) forests**	**PUR: *Salicetea purpureae* Moor 1958**
		PUR-04: *Populetalia balsamiferae* Breen 2014
5.07.1.1	Floodplains, springs, aufeis deposits and warm south facing slopes with balsam poplar (*Populus balsamifera*)	PUR-04A: *Eurybio-Populion balsamiferae* Breen 2014
5.08	***BRYOPHYTE AND LICHEN VEGETATION***	
5.08.1	**Bryophyte communities on sunny exposed siliceous rocks, boulders and screes**	**RAC: *Racomitrietea heterostichi* Neumayr 1971**
5.08.2	**Bryophyte communities on exposed limestone rocks and screes**	**SAP: *Schistidietea apocarpi* Ježek et Vondráček 1962**
5.08.3	**Ombrophilous lichen communities of siliceous rock surfaces**	**RHI: *Rhizocarpetea geographici* Wirth 1972**
5.08.4	**Mainly crustose lichen communities on moderately to highly nutrient-rich limestone substrates**	**VNI: *Verrucarietea nigrescentis* Wirth 1980**
5.08.5	**Bryophyte and lichen vegetation on dry acid to subneutral, silty-sandy and gravelly soils**	**CER: *Ceratodonto purpurei-Polytrichetea piliferi* Mohan 1978**
5.08.6	**Bryophyte and lichen vegetation on subneutral and calcareous soils**	**PSO: *Psoretea decipientis* Mattick ex Follmann 1974**
5.09	***ANTHROPOGENIC and RUDERAL VEGETATION***	
5.09.1	**Human-disturbed habitats in the subarctic and Arctic zones of Russia, Siberia and North America**	**ARC: *Matricario-Poetea arcticae* A. Ishbirdin in Sumina 2012**
5.09.1.1	Ruderal vegetation of natural disturbances (e.g., lake bluff erosion)	No units at this point

of codes that describe the habitat type (e.g. see Table 1), including bedrock geology, parent material, landform, surficial geomorphology, slope, aspect, elevation, soil pH, site-moisture regime, evidence of animal activity, and forms and degrees of disturbance. In the Arctic, special attention is needed to describe the permafrost, active-layer depth, patterned-ground features, evidence of cryoturbation, snow depth and snow duration. A soil sample should be taken for analysis of the soil chemical and physical properties in the upper mineral horizon, or from the rooting zone in very thick organic soils.

Vegetation data: Cover estimates should be made for groups of plant growth forms (e.g. cover of shrubs by size classes, graminoids, forbs, bryophytes, and lichens) and plant species. Voucher collections of all species recorded during the survey should be sent to at least one Arctic herbarium to document the occurrence of all recorded plants.

Ancillary data: In addition to the site description described above, ancillary data that are collected either at the time of the vegetation sample or at a later date might include, for example, a peak-season biomass clip harvest, ground-based leaf-area-index (LAI) and spectral-reflectance measurements, detailed soil survey data, additional collections of other organism (for example, insects, or plant and soil material for genomic studies). It is also important to note all known data collected from the plot in a data report that includes a full record of the methods, and publications resulting from the data. To accomplish all this and to maximize the value of the vegetation data for biodiversity, ecosystem, and remote-sensing studies, it is best to work with teams of experts who can provide additional measurements and expertise.

Site protection: Finally, it is important to protect the plot from disturbance by the vegetation scientists and other researchers, so that the plot can be used in the future for time-series analysis of change. If the plots are at an Arctic observatory station, where multiple visits to the plots are likely, it may be necessary to construct boardwalks to prevent damage to the tundra.

Need for inclusion of physiognomic information in the clustering approach

The methods used for determining lower and higher-level groupings should be repeatable after adding new plot data to the archive and subsequent classification. The grouping of the available plot data into existing vegetation units is now being tested by cluster analyzes (Fig. 3, described above and in Walker et al. 2016a). Plot-grouping algorithms, based on similarity of species composition and cover, are used to define clusters of plots. We have found that unsupervised classifications, where unequally represented vegetation types have been merged with other similar or successionally-related plots, are often unable to distinguish ecologically different groups at higher levels of dissimilarity. A formalized expert system based on a formal language for the description of vegetation units, which will be understandable and relatively easy to use is needed for vegetation classification in this biome.

An important consideration is the physical structure of the vegetation. Traditional phytosociology is based primarily on floristic information, but many papers emphasize the necessity of also including a structural concept in vegetation classification (e.g., Rejmánek 1977; Pignatti et al. 1995; Šibík 2007; Faber-Langendoen et al. 2014, this volume). Expert systems based on a formal language for the description of vegetation units that include structural information are currently under development (Chytrý 2000, 2012; Landucci et al. 2015). These expert systems will logically combine a variety of factors, including species, species groups, functional types and their cover. This will permit definition of units based on a combination of structural and floristic information in a manner similar to that currently used for purely floristic-defined units (Landucci et al. 2015).

In the near future, the existing habitat- and florisitic-based classification for the Arctic will be harmonized with physiognomic criteria. The definition of new Arctic units will be defined by their floristic composition, vegetation structure, ecology, and distributional area together with the functional role and history of the sites. According to the methodological concept of Dengler et al. (2004), character species at higher syntaxonomical levels will be determined for the structural types. This makes it possible to separate units with similar floristic composition but very different structure into separate syntaxonomic units (Šibík et al. 2008). The already-existing relevant units from different parts of the Arctic will be compared with the proposed new units and a final decision based on a variety of criteria including, floristic, physiognomic, evolutionary history and biogeography will be used to evaluate them either as separate (vicariant) syntaxa or new units.

Data sharing and crosswalks between Arctic classification approaches

The Arctic is part of several nations, and data stored in the AVA should be shared with other national and international vegetation databases. The species and environmental data of the AVA-AK are archived as comma-separated-variable (.csv) files in the Alaska Arctic Geoecological Atlas at the University of Alaska (http://alaskaaga.gina.alaska.edu) and at the NASA Oak Ridge Natural Laboratories Distributed Archive Center (ORNL DAAC) archives for the ABoVE project (http://daac.ornl.gov/cgi-bin/dataset_lister.pl?p=34). The AVA-AK data will also be archived in the VegBank database (http://vegbank.org, Peet et al. 2012a, b) for analysis within the United States National Vegetation Classification (USNVC) system, and the VPro database used for the Canadian National Vegetation Classification (CNVC) (MacKenzie 2014). Exchange standards are being developed to facilitate the transfer of plot data between databases (Wiser et al. 2011).

Crosswalks between different national approaches will need to be made to determine their correspondence to each other and to unambiguously link the formal definitions with already characterized units. Table 2 is an attempt to do this for one common Arctic vegetation type, the *Dryas octopetala* communities of the USNVC (EcoVeg) approach (Flagstad & Boggs 2016) and the Br.-Bl. approach (Cooper 1986, 1989). The exercise attempted to match the terminology across hierarchical levels in each approach. In this case, the hierarchies of the Br.-Bl. and EcoVeg approaches are difficult to match. For example, the EcoVeg approach has more details of characterization at the higher physiognomic and biogeographical levels (Class, Subclass, Formation, Division); whereas, the Br-Bl. approach has more detail at the plant community level (alliances and associations). Furthermore, while many of the same terms are used in the hierarchies of the two approaches (e.g. class, alliance, association) the contents of unit levels with equivalent names are not necessarily parallel. The associations and alliances of the US-NVC are intended to be at least similar with those of the Br.-Bl. approach, but the class levels have very little similarity. The histories of the two approaches explain some of the differences. Braun-Blanquet vegetation units are created based on data from small geographically well differentiated regions, which is generally results in a bottom-up view; whereas, the EcoVeg classification is a hybrid approach with the bottom two levels being bottom-up and the top six level having a top-down approach. In part this derives from the huge area of unmapped land of North America with relatively undisturbed areas in comparison with Europe. More recently this has been necessitated by the expansion by NatureServe, Inc. (http://www.natureserve.org/) of the USNVC initiative to an International Vegetation Classification (IVC) program based on the broader EcoVeg approach (Faber-Langendoen et al. 2014)

Traditionally, there has not been strong focus on above-class levels in Europe, where most authors consider classes as the highest units of vegetation (Hadač 1967). More recently, however, European phanerogamic classes have been grouped according to zonal concepts of Walter (1973) into two major groups: (1) zonal and intrazonal vegetation and (2) azonal vegetation (see Mucina et al. 2016). At the plant community level, the new checklist of European vegetation units, also takes advantage of a tradition of grouping on the basis of broad habitat-type designations (e.g. aquatic, shoreline and swamp vegetation; springs, fens and bogs; rock fissures and screes; high-altitude vegetation; grasslands and meadows; scrub vegetation; forests; anthropogenic vegetation; see Ellenberg 1988; Rodwell et al. 2002; Jarolímek & Šibík 2008). These groupings may offer opportunities for better linkages between the two methods at upper and lower levels in both classification schemes.

Table 2. An example of a hierarchical crosswalk between individual approaches to compare similar plant communities, in this case *Dryas octopetala* communities described according to the USNVC (EcoVeg) (Flagstad & Boggs 2016) and the Br.-Bl. approach (Cooper 1986, 1989). The comparison is possible only at hierarchical levels that allow us to unambiguously link the selected vegetation units with already characterized vegetation types (syntaxa). Individual judgement is necessary to make the crosswalk since hierarchical ranks can represent a variety of ranks. For examples a "macrogroup" in the EcoVeg approach will not always represent a single "alliance" in the Br.-Bl. approach. Similarly, one "group" (EcoVeg) can symbolize more than one "association" in the sense of original author(s).

USNVC (Flagstad & Boggs 2016)		**Br.-Bl. Approach (Walker et al. hoc loco)**	
Hierarchical Rank	Unit	Hierarchical Rank	Unit
Class	Cryomorphic Scrub, Herb & Cryptogam Vegetation Class		N/A
Subclass	Temperate to Polar Alpine & Tundra Vegetation Subclass	Zonal "group"	Vegetation of the Arctic Zone
Formation	Polar Tundra & Barrens Formation	Class	*Carici rupestris-Kobresietea* Ohba 1974
Division	*Salix arctica-Ledum palustre* ssp. *decumbens / Dryas integrifolia* Tundra Division	Order	N/A
Macrogroup	*Salix alaxensis-Dryas octopetala-Eriophorum vaginatum* Tundra Macrogroup		N/A
Group	*Dryas octopetala-Dryas integrifolia* Dwarf-shrub Tundra Group	Alliance	*Pediculari kanei-Dryadion octopetalae* Cooper 1986 prov.
Alliance	–	Association	*Caricetum scirpoideo-rupestris* Cooper 1989 *Carex scirpoidea-Dryas octopetala* comm.
Association	–	Subassociation, Facies, Variants	N/A

Conclusion

It has been over two decades since the idea for the AVC was first proposed at the 1992 Arctic Workshop in Boulder, and it is still mostly a conceptual framework for an eventual classification. However, it now appears that the necessary tools to complete the task are in place. The completion and future maintenance of the Pan-Arctic Species List is critical for moving forward. Recent advances in database software and international standards for planning, building, and documenting vegetation classifications (Wiser et al. 2011; Peet & Roberts 2013) now make the idea of a circumpolar Arctic vegetation database feasible. Renewed international interest in vegetation classification, as demonstrated by the recent conceptual roadmap for large-scale vegetation classifications (De Cáceres et al. 2015), the EVA (Chytrý et al. 2015) and EVC in Europe (Mucina et al. 2016), the EcoVeg initiative in the U.S. (Faber-Langendoen et al. 2014, 2017), and the BEC approach in Canada (MacKenzie & Meidinger this volume) are providing useful insights and models needed to complete the task.

A key to the future development of the AVC will be to ensure that all the Arctic countries participate in the effort by developing archives of data that satisfy the needs of their national interests and also satisfy the need for standardized data that are useful to the circumpolar user groups. The Br.-Bl. approach will likely continue to be the dominant classification approach for most Arctic countries, while the EcoVeg and BEC approaches will gain momentum for classification in Arctic North America. It is important that the AVA accommodate all these approaches to classification. Our initial classification effort will use the Br.-Bl. approach, but an independent classification using the same dataset and the EcoVeg and the BEC approaches would help evaluate, compare, and improve all the methods. The zonal and habitat-type elements of the new checklist of European vegetation types (Mucina et al. 2016) are also reflected in the checklist of Arctic habitat-types and equivalent Br.-Bl. units presented in this paper (Table 1).

Among the advantages of clearly defined and unified criteria used for classification of vegetation will be the creation of opportunities to apply and use it in public sectors since the vegetation reflects not only the abiotic conditions of the sites but also the evolutionary history, human impact and many other ecological and evolutionary processes including climate changes. Applied outcomes of such vegetation classification can be oriented towards better-informed vegetation-change models and landcover analyses, more competent decisions by policymakers, and raised environmental awareness of educators and the public.

Author contributions

D.A.W. organized the project and is the primary author of the paper. A.L.B., F.J.A.D., N.V.M., S.H., H.B., M.D.W., M.K.R., J.S. & R.P. contributed conceptual ideas related to the AVA. J.S. provided major help with analysis and wrote several sections. A.L.B. & L.A.D. J.S. and S.H. developed the AVA. L.W.W., M.B. & H.E.E. developed the web portal and made major contributions to the ancillary data sets. W.H.M., E.L & D.T. compiled the Canadian datasets. F.J.A.D & H.B. compiled the Greenland datasets. L.N. & D.T. compiled the Svalbard datasets. A.M.F., S.H., I.S.J., and S.S.T. compiled the Boreal North Atlantic and Aleutian datasets, K.E., N.K., N.V.M., V.R. & M.T. compiled the Russian datasets. All authors reviewed and contributed revisions of the manuscript.

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