THE CANADIAN ARCTIC–SUBARCTIC BIOGEOCLIMATIC ECOSYSTEM CLASSIFICATION (CASBEC):

Framework, key concepts, mapping, and applications

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Abstract

The Canadian arctic–subarctic Biogeoclimatic Ecosystem Classification (CASBEC) system is a framework for coordinating and standardizing the identification, interpretation, classification, and mapping of terrestrial ecological communities across arctic and subarctic landscapes of northern Canada. Based in strong ecological theory, the CASBEC system provides standardized protocols for nomenclature and classification, that results in a natural, hierarchical classification based on observable ecological components. This paper describes the need for such a system, the theory and structure of the classification approach, and methodologies for classifying and mapping arctic and subarctic terrestrial ecosystems. The Canadian community of northern terrestrial ecosystem researchers and consulting practitioners is invited to work together to implement the CASBEC system. Interest, input, and support for standardization will significantly improve the coordination, outreach, and impact of the many applied uses of the system in the areas of northern research, monitoring, and conservation.

Introduction

The Canadian arctic–subarctic Biogeoclimatic Ecosystem Classification (CASBEC) system is a framework for coordinating and standardizing the classification, interpretation, and mapping of terrestrial ecological communities across arctic and subarctic landscapes of northern Canada. Proposed as a common approach, the CASBEC system will facilitate coordinated ecological work in the same way that common nomenclature for plants

Suggested citation:

McLennan, D.S., MacKenzie, W. H., Meidinger, D., Ponomarenko, S., Wagner, J., McKillop, R.J., and Robitaille, H. T 2019. The Canadian Arctic–Subarctic Biogeoclimatic Ecosystem Classification (CASBEC): Framework, Mapping and Applications. Aqhaliat 2019, Polar Knowledge Canada, p. 8-22. DOI: 10.35298/pkc.2019.02

facilitates botanical studies—that is, to provide a common language for describing, classifying, and naming similar entities so that they can be studied and the results generalized across taxa. At present, the classification and naming of arctic–subarctic terrestrial ecological communities is not supported by a common approach. Adopting the CASBEC system would be an important step towards integrating local and regional classifications to provide one connected classification system across Canada's North. As discussed in this paper, the present lack of agreement makes it difficult to coordinate research and monitoring, extrapolate results regionally and nationally, coordinate regional habitat and cumulative effects assessments, and plan coordinated regional to national monitoring.

The CASBEC system

The CASBEC system draws its structure, approach, and methods from British Columbia's Biogeoclimatic Ecosystem Classification (BCBEC)[1] (Krajina, 1960; Pojar et al., 1987; Haeussler, 2011; MacKenzie and Meidinger, 2017). BCBEC is based on a century of ecosystem science, with roots in Europe (Pogrebnyak, 1930, 1955; Braun-Blanquet, 1932; 1951, 1964; Vorobyov, 1953; Sukachev, 1960; Sukachev and Dylis, 1964) and North America (Clements, 1916, 1936; Jenny, 1941; Major, 1951).

Central to the CASBEC system is a vegetation classification of northern ecosystems which links nationally to the Canadian National Vegetation Classification (CNVC, accessed 2019), and internationally to the Arctic Vegetation Archive (Walker and Raynolds, 2011; Walker et al., 2013).

The applicability of the BCBEC approach to arctic and subarctic landscapes is well-documented through its recent adoption by the Yukon Government (Environment Yukon, 2016), older arctic work (Lambert, 1968; Barrett, 1972), and recent work in Canada's arctic and subarctic national parks (Ponomarenko et al., 2014), and at the Canadian High Arctic Research Station (CHARS) area near Cambridge Bay, Nunavut (McLennan et al., 2018).

[1] *For a broader discussion of the history of the BCBEC see also Wali (1988).*

Following the approach of BCBEC, the CASBEC system comprises three integrated classifications described in Figure 1.

1. A central, hierarchical vegetation classification of the plant community component of terrestrial ecological communities, based on vegetation relevé data, following the BCBEC and Braun-Blanquet classification approach (MacKenzie and Meidinger, 2017).

2. A biogeoclimatic classification that uses the distribution of vegetation associations representing mature plant communities that occur on zonal sites to delineate the units of ecologically equivalent regional biogeoclimates.

3. An ecosite classification that combines reoccurring mature plant associations and the environments on which they occur to define ecologically equivalent site conditions.

Key concepts, such as zonal ecosystems and ecological equivalence, hold the structure of the CASBEC system together. These key concepts will be reviewed in the following section.

Terrestrial ecological community

The terrestrial ecological community (Figure 1) is the local scale ecosystem that occurs as a real entity in the landscape. It is the object of classification in the CASBEC system, marrying the biotic (plant community) and abiotic (ecological site) components of terrestrial landscapes. It includes all of the biota on a site, from soil microbes and invertebrates, through to the plants, pathogens, herbivores, and predators that comprise the local-scale ecosystem. The terrestrial ecological community also includes the physical environmental setting, the processes and factors that in part control biotic composition, abundance, and productivity, and the interactions among all abiotic and biotic components. In the

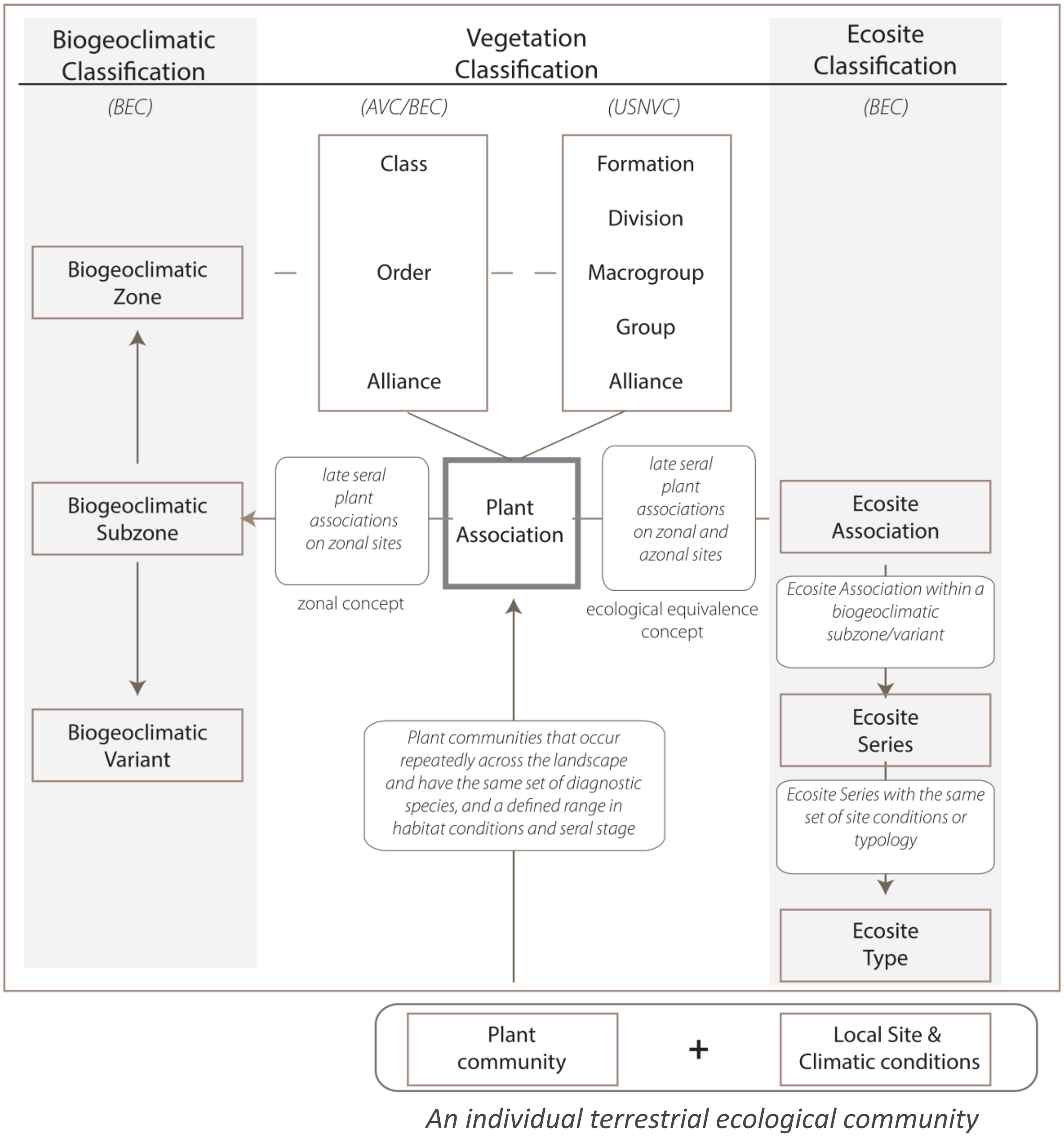

Figure 1: The CASBEC system framework showing Biogeoclimatic and Ecosite Classification linkages to the central Vegetation Classification, including to the higher units of the Biogeoclimatic Ecosystem Classification (BEC), Arctic Vegetation Classification (AVC) and to the United States National Vegetation Classification (USNVC). The Plant Association is central to the CASBEC system and links to biogeoclimatic and the ecosite classifications through the zonal and ecological equivalence concepts, respectively.

CASBEC system terrestrial ecological communities are grouped using overall similarity in plant communities (vegetation classification) and in site and soil properties (site classification). This creates relatively uniform classes that are useful for a range of research, monitoring, and land management applications.

Field collection of terrestrial ecological eommunity plot data

In the Arctic and Subarctic, the CASBEC system is just beginning to be applied. Intensive field collection of plot data for the range of terrestrial ecological communities in areas of study is required to build regional field guides, training courses, and other tools that technical-level users take advantage of in British Columbia. To build the classification, detailed ecosystem information (site, soil, and vegetation) is collected across the range of site conditions in the area of study. The goal of the field collection is to identify and sample all of the terrestrial ecological communities that occur. This information can then be formally classified and used to develop a local ecosystem classification, and often a terrestrial ecosystem map. Field teams with expertise in vascular and non-vascular species identification, soils description, and geomorphology are required for accurate descriptions of terrestrial ecological communities.

A field campaign for an area of study is best accomplished over two field seasons—the first season is a reconnaissance and broad ecosystem description phase used to develop a draft ecosystem classification, and the second season is used to confirm the classification and gather more data as required to finish the draft classification for the area. The following is a brief description of key steps and goals for a typical two-year campaign. In many cases the project will need to develop ecosystem maps, with the classified units as map polygons (mapping approaches will be covered in a future manuscript).

1. Gather as much ancillary information about the area of interest as possible. For example, studies, reports, and maps of bedrock geology, glacial and post-glacial history, surficial geology, soils, permafrost, vegetation, land cover/land use, and wildlife occurrence and habitat, as well as available remote sensing data, including recent and historical aerial photos, satellite imagery, and topographic data. Information from all sources is used to develop a working hypothesis of the vegetation and the main ecological factors controlling ecosystem composition, structure, productivity, and distribution (e.g., hydrologic gradients, key landforms, and soil properties). Analysis of the aerial photos, imagery, and topographic data provides important information of the spatial distribution of terrestrial ecological communities across the landscape (e.g., uplands and wetlands, floodplains, and estuaries) and is used to generate a sampling plan for the field season.
2. Design field sampling of site, soil, and vegetation characteristics across the range of potential local ecosystems and along predominant ecological gradients. Sites for sampling are preferentially selected following the definition of a terrestrial ecological community—an area of the landscape relatively uniform in vegetation composition and structure, and in soil and landform properties (De Cáceres et al., 2015). Plot size is commonly 25 m^2 – 400 m^2 to capture the full species list for the community.
3. Field methods to conduct the ecosystem descriptions are well-described in the manual developed for the BCBEC (BC MoFR-MoE, 2010). A Yukon version of this manual is in development, and Polar Knowledge Canada (POLAR) is working to develop an arctic–subarctic version of this manual. The following general field observations are made for each plot sampled:
   a. Estimate the percent cover by pre-defined height strata of all vascular and non-vascular plants growing on the predominant soil substrate. All plants must be identified to species, with voucher specimens collected as required for taxonomic validation (relevé process).
   b. Describe soil properties such as soil humus structure and classification, soil pedon strata, mineral and organic soil textures, soil depth and colour, and key soil processes such as mottling, gleying, and cryoturbation. Assign the proper soil classification following the Canadian System of Soil Classification (Soil Classification Working Group, 1998).
   c. Describe site characteristics such as elevation, aspect, slope angle and slope position, as well as landform, surficial material and active layer depth to permafrost.

Where specific map and inventory applications are intended, additional specialists may be part of the mapping crew. For example, if caribou habitat is the application, then a caribou specialist can accompany the team and assess the different ecosystems for their suitability as caribou habitat. Similarly, specialists in engineering applications may want to accompany the teams to assess the ecosystems for sources of gravel for road building or seasonal trafficability for mining exploration.

For the CASBEC system, field data are collected on standardized field forms that have been adapted from the BCBEC FS882 for arctic and subarctic conditions. Digital input approaches are currently being explored to better facilitate data entry and management. As part of the data security process, at the end of the ecosystem description of each plot digital images of all field forms are taken in the field. This also includes taking photos of the plot that include oblique and pan view angles, as well as photos of the soil profile, site setting, and any other factors of interest on the site. All plot data are entered into VPRO software (MacKenzie and Klassen, 2009) for synthesis, analysis, and tabulation.

From field data to the CASBEC system

Vegetation classification

To generate plant association units the CASBEC system uses vegetation classification[2] approaches. First initiated by Braun-Blanquet (1932, 1951, 1964), these approaches have been modified as described in Pojar et al. (1987), De Cáceres et al. (2015), and MacKenzie and Meidinger (2017). The goal is to group relevés with similar plant communities into classification units defined by a diagnostic combination of species (DCS) which differentiate them from the DCS of other units.

The plant association unit is a fundamental working unit. It can be generalized into broader functional levels based on floristic similarity, or functional/spatial factors through a combination of floristics, dominance, physiognomy, and biogeography as applied in USNVC (2016), Jennings et al. (2004, 2009), or the higher levels of the site component of the CASBEC system. In this way, geographically-restricted vegetation association classifications are built for local areas of study. With the goal of creating a consistent national classification across Canadian arctic and subarctic biomes, the CASBEC system analyses and merges local, project-based vegetation classification units from different geographic areas. Through a process of correlation, the CASBEC system compares the diagnostic combination of species between available local association units and identifies equivalent or divergent classification units.

Biogeoclimatic classification and zonal ecosystems

To classify and identify the geographic ranges of regional-scale biogeoclimatic subzones at a scale of 1:250 000 or finer (refer to Figure 1), the CASBEC system uses the zonal concept. The zonal concept[3] has been applied successfully in British Columbia (Pojar et al., 1987), and in other areas of Canada and the Arctic, e.g., Ecoregions Working Group (1989), Saucier et al. (1998), Circumpolar Arctic Vegetation Map (CAVM) Team (2003), Gould et al. (2003), Jorgenson and Meidinger (2015), and Baldwin et al. (2019).

Zonal sites are ecologically “average” sites with defined site characteristics such as being positioned on moderate, neutral-aspect slopes, and having well-drained soils of at least medium depth (circa 60 cm) with loamy texture and low (< 25%) coarse fragment content. The mature plant communities that occur on zonal sites are presumed to best reflect the ecological potential of regional climates and define the zonal ecosystem (Pojar et al., 1987; Ecoregions Working Group, 1989; CAVM Team, 2003). Changes in the distributions of zonal ecosystems across the Arctic and Subarctic are used to characterize and map biogeoclimatic subzones.

[2] *For more details on vegetation classification and tabling approaches in general, see Shimwell (1971) and Ellenberg (1988).*

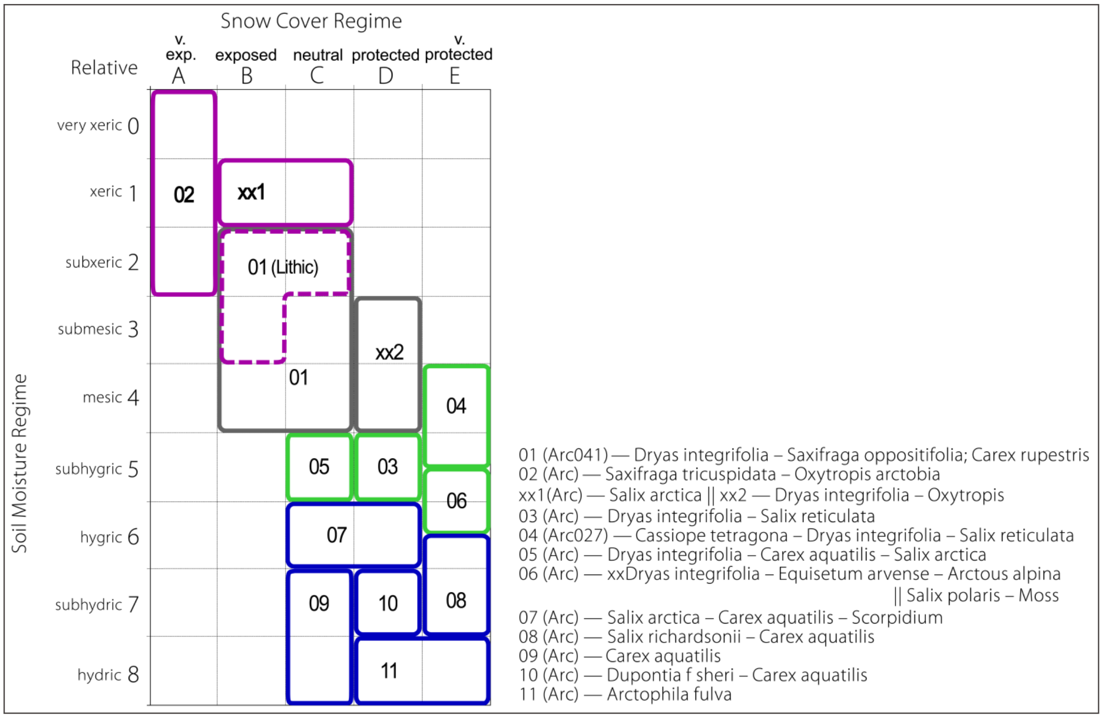

Figure 2: Draft edatopic grid developed for the CHARS Experimental and Reference Area in south-eastern Victoria Island (CAVM Zone D). Showing the relative positions of 11 ecosite series within a two-axis (soil moisture x snow protection) chionoedaphic grid.

Biogeoclimatic units are related in concept to the Circumpolar Arctic Vegetation Maps (CAVM Team 2003) but are at a finer scale. These units capture variability such as elevation zonation, focus more on the species composition of the zonal ecosystem rather than on physiognomic differences, and intersects information that the CAVM separates into subzone and floristic province into the single biogeoclimatic component of the CASBEC system.

Ecosite classification and ecological equivalence

In the CASBEC system, classified ecological site or "ecosite" taxa describe those areas of the landscape where the sum total of the environmental factors that interact to determine vegetation composition, structure, composition, and productivity are considered to be ecologically equivalent, as demonstrated and expressed by the occurrence of the same, late seral plant communities. Ecosites describe the range of environmental conditions within a biogeoclimatic subzone (i.e., within the same regional biogeoclimate) and support the same mature plant association or sub-association (ecosite series and types – refer to Figure 1). The dominant gradients differentiating ecosites are used to simplify and organize the environmental complexity created by physiographic variability across the landscape—the most common arctic and subarctic gradients within a biogeoclimatic unit are relative soil moisture and nutrient regime, and degree of winter snow protection. This simplification of key ecological site conditions can be expressed on an edatopic grid (Figure 2) to differentiate the environmental space of those ecosite series that occur within a biogeoclimatic subzone.

The CASBEC system products

Regional maps of biogeoclimatic subzones and zones

Biogeoclimatic maps are developed to delineate ecologically equivalent climate regions (biogeoclimatic zones and subzones) that provide regional climatic units under which local-scale ecosite series and ecosite types are defined and described. Examples of biogeoclimatic maps from British Columbia can be found online at https://www.for.gov.bc.ca/hre/becweb/resources/maps/.

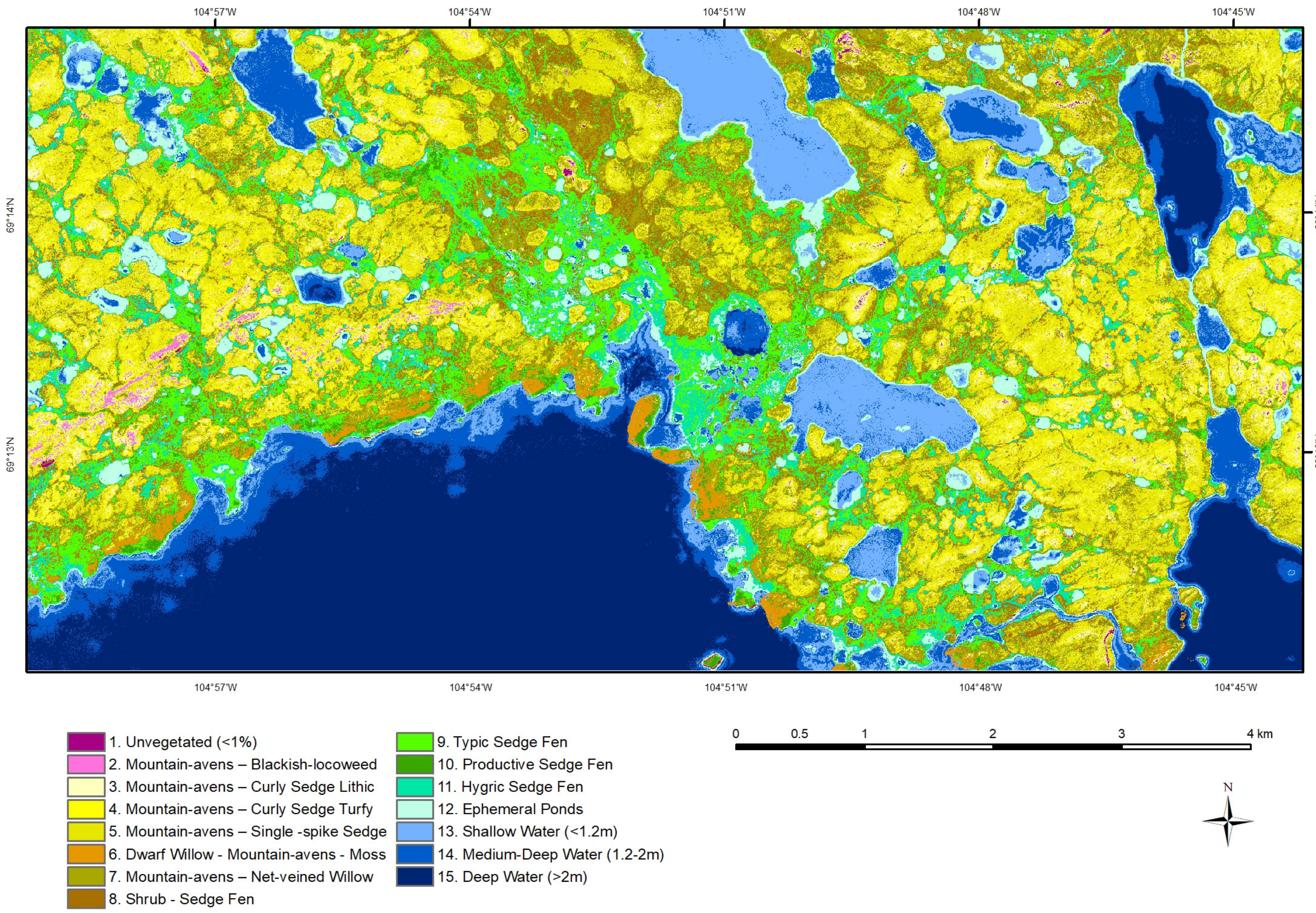

Figure 3: High resolution (50 cm World View2) mapping of ecosite series in the Experimental and Reference Area of the CHARS near Cambridge Bay, Nunavut. For map preparation and ecosystem interpretations see Ponomarenko et al. (2019).

In addition to the identification of the zonal ecosystem in the classification process, field and aerial surveys are conducted to document zonal ecosystem changes across elevational or latitudinal climatic gradients. As floristic diversity decreases with increasing latitude in the High Arctic, the disappearance or appearance of low shrub communities, or trees on azonal sites, become important supplementary evidence for mapping biogeoclimatic boundaries[4]. Zonal/sub-zonal boundaries are often finalized using generalized elevational or latitudinal limits to extrapolate the boundaries. Another consideration is the overriding effect bedrock geology can have on plant distributions—especially calcareous areas common in the Canadian arctic. In these cases, two different edatopic grids are required within the same regional biogeoclimate[5]. Within the regional-scale, biogeoclimatic context of biogeoclimatic maps, i.e., with biogeoclimatic subzones, one of the most useful and common products of the CASBEC system are local scale maps of ecosite series and types. Development and applications of maps of ecosite series and types is discussed further below.

Field guides for ecosites

Field guides for ecosite identification by biogeoclimatic unit are commonly produced for

[3] The Yukon Ecological and Landscape Classification Guidelines uses the term "reference sites" to describe this concept (Environment Yukon, 2016).
[4] For detailed descriptions of methods used for mapping biogeoclimatic subzones in British Columbia, see BC MoFR-MoE (BC MoFR-MoE, 2010).
[5] For regional ecosystem mapping in Quebec, see links under Ressources Naturelles du Quebec (accessed March 2019).

operational use of the classification. Field guide content and layout are well developed for BCBEC and we propose using the same approach for the CASBEC field guides. Field guides are available for all biogeoclimatic subzones in British Columbia – they can be viewed at https://www.for.gov.bc.ca/hre/becweb/resources/classificationreports/subzones/index.html.

Each field guide usually contains some background on the CASBEC system theory, information on how to use the guide, and an environmental overview for the subzone. The overview typically includes climate norms, physiography and bedrock geology, surficial geology, soils, permafrost, and vegetation descriptions. The core content of the field guides are the descriptions of the ecosite series including the main site, soil, and vegetation characteristics, as well as some management interpretations and wildlife use if they are available. To meet local needs for targeted management interpretations, ecosite types may also be described within each site series. Field guide appendices typically include keys to soil moisture and soil nutrient regime, a soil texturing key, a list of vascular and non-vascular plants, vegetation summary tables for ecosite series, and a classification and description of soil humus forms.

To provide assistance for classifying and mapping arctic and subarctic terrestrial ecosystems, field guides are presently being developed for southern areas of Yukon at https://yukon.ca/en/ecological-landscape-classification#find-elc-data-and-publications and arctic areas of Yukon (MacKenzie et al., 2018). A report on Wapusk National Park ecosystem mapping in Manitoba (Ponomarenko et al., 2014) has similar information to the BCBEC field guides, and POLAR staff are beginning work on field guides for CAVM Subzones E and D in the CHARS Experimental and Reference Area in the Kitikmeot Region of Nunavut.

Applications of the CASBEC system

The information and products derived from classifying and mapping terrestrial ecosystems are tools that can be applied to a wide range of research, monitoring, and land use management purposes. This is evidenced by the wide number of applications of the BCBEC since 1975 in British Columbia (MacKinnon et al., 1992). A detailed discussion of the CASBEC system applications is beyond the scope of this paper but a few arctic examples are provided here.

Using the CASBEC approach, ecosite maps have been developed primarily from optical remote sensing data, and other derived landscape variables. For example, slope position, elevation, and aspect, at a range of scales, have been used with optical imagery to develop conservation inventories, habitat mapping, and protected areas planning in northern national parks in Canada (Fraser et al., 2012; McLennan, 2012a, 2012b; Ponomarenko, 2014), and for industrial developments (Groupe Hémisphères, 2009). Related approaches are now used widely as baseline components of northern developments (Groupe Hémisphères, 2009; Groupe Hémisphères, 2014), and for mapping and interpreting surficial geology and permafrost features (Zhang et al., 2012, 2013; Cable et al., 2016; McKillop and Sacco, 2017).

From a research perspective, the units of the CASBEC system provides critical values for stratification in study design, for extrapolation of findings to new areas, and for coordination and comparison of long-term terrestrial ecosystem research and monitoring experiments within and between study areas (Figure 3; McLennan et al., 2018). The CASBEC system units are currently being used for the design and implementation of long-term ecosystem monitoring experiments at the CHARS campus near Cambridge Bay, Nunavut (McLennan et al., 2018).

Extrapolated climate surfaces (Hutchinson, 1991; Daly et al., 2002; Wang et al., 2012a; McKenney et al., 2013) have allowed the climatic dimensions of ecologically-equivalent climate regions to be defined and then applied in climate change modelling in several jurisdictions (Hamann and Wang, 2006; Wang et al., 2012b). With an accurate delineation of arctic and subarctic biogeoclimatic subzones these same techniques can be used to help predict future changes in composition and structure of arctic and subarctic terrestrial ecosystems.

Summary and discussion

The CASBEC system concepts such as zonal ecosystems and ecological equivalence employ vegetation communities as phytometers to distinguish regional biogeoclimatic subzones and local ecosite series. These key concepts assume ecosystem development under conditions of relative climatic stability and equilibrium and are supported by the estimated stability of North American and Eurasian tree lines for the last 3,000 to 4000 thousand years (Lavoie and Payette, 1996; MacDonald et al., 2000; Payette, 2006). This climatic consistency has helped create the distinctive patterns of vegetation floristics and physiognomy that we see in the Canadian arctic today (Edlund and Alt, 1989; CAVM Team, 2003; Gould et al., 2003). It is clear now that this equilibrium is rapidly changing, and arctic and subarctic plant communities are changing in response (Elmendorf et al., 2012 a, 2014; Pearson et al., 2013). As discussed by Haeussler (2011), biogeoclimatic approaches are already holistic and multi-scalar. To be relevant to climate driven ecosystem change, the CASBEC system will need to embrace concepts such as non-linear and non-equilibrium processes put forward by the evolving field of ecosystem complexity science (Manson, 2001; Bar Yam, 2003). This can be accomplished by adapting new and dynamic techniques, such as adaptive landscapes (Kauffman, 1995; Gavrilets, 2004) and agent-based modelling (Gilbert and Terna, 2000; Bonabeau, 2002), to understand and predict ecosystem change in a rapidly changing world.

This paper describes the need for a useful, standard approach for describing, classifying, and mapping terrestrial ecosystems in Canadian arctic and subarctic biomes. The CASBEC system adopts the theory, approach, and methods of the very successful and mature BCBEC system. This proposed system has proven to be a very useful tool for land management applications, and as an essential research frame in British Columbia. A formal, independent review (Vis-à-vis Management Resources, 2005) stated that BCBEC has resulted in “hundreds of millions of dollars” in economic benefits to the province of British Columbia. Although economic benefits related to forest industry applications are not relevant for northern ecosystems, benefits that are relevant include the creation of a “common language information infrastructure” used by researchers and land managers, a significant reduction in training costs, and credibility for research communications and land management decisions based on the broad acceptance of the BCBEC products.

In a similar way, broad adoption of the CASBEC system by the northern research and land management community would create a common language for researching, monitoring, and managing arctic and subarctic ecosystems. This would be accomplished by connecting and extrapolating regional to national research and monitoring activities, and streamlining the potential ecological impacts and mitigation strategies of northern developments. Finally, a standardized system would simplify training and create the possibility of developing CASBEC training courses at northern colleges, or through programs such as the Nunavut Environmental Technology Program.

This paper is put forward to the Canadian community of northern terrestrial ecosystem researchers and consulting practitioners. It proposes the implementation of the CASBEC system to standardize the classification and mapping of terrestrial ecological communities across arctic and subarctic landscapes of Canada. The CASBEC system is currently in its infancy and much remains to be done to make it as practical and useful as the BCBEC system in British Columbia. The first step in this process is agreement by the northern vegetation science community. This paper will be circulated broadly, and, given sufficient interest, a workshop will be planned to discuss system details and steps required for the adoption of the CASBEC system as a standard method for northern research, monitoring, and land use applications.

The Canadian community of northern terrestrial ecosystem researchers and consulting practitioners is invited to work together to implement the CASBEC system. Interest, input, and support for standardization will significantly improve the coordination, outreach, and impact of the many applied uses of the system in the areas of northern research, monitoring, and conservation.

Community considerations

A standardized and operational classification and mapping of regional and local ecosystems will benefit northern communities in the same way it can benefit northern research, monitoring, and land management applications. That is, by providing a holistic, integrative, and useful ecosystem template for understanding ecosystem change in the social-ecological context of community needs. The holistic approach utilized by the CASBEC system shares similarities with the holistic worldview that characterizes Indigenous knowledge, where the landscape is viewed as a complex and interacting system of abiotic and biotic interactions (Berkes, 2008, 2009). This system can be used to support a co-generation of knowledge approach to dealing with community issues, such as for understanding changing habitats for vital country food species (Jones et al., 2019).

As the CASBEC system matures in the North, it will be possible for technically-trained community members to use the system to meet their local community needs. This is evidenced by the long history of technical training and application of the BCBEC system in British Columbia. Once a draft local ecosystem classification has been developed for a biogeoclimatic subzone, community-based, technical-level users can be trained to use ecosystem keys and other tools, or draft field guides if they are available. These community-based users will be able to identify and interpret the ecosystem units and use the classification for the issues that meet the immediate needs of their communities.

Acknowledgements

The authors would like to acknowledge the pioneering work of Vladamir Krajina and his many students who conceptualized and developed biogeoclimatic ecosystem principles in British Columbia. In particular we would like to acknowledge the research and leadership of Drs. Karel Klinka and Jim Pojar, who worked to operationalize the BCBEC system, to mentor many students and practitioners, and to quantify and validate many of the qualitative categories that the biogeoclimatic process generates.

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