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Ecoclimatic Zonation of Yukon (Canada) and Ecoclinal Variation in Vegetation

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ABSTRACT. An ecological climatic zonation of Canada's Yukon Territory (1:1 000 000 scale) was developed from field observations, aerial photographs, ecological literature, forest cover maps, and regression models. The 11 recognized ecoclimatic regions include Arctic (1), Subarctic (1), Alpine (4), Subalpine (1), and Boreal (4) entities. Region differentiation was based on vegetation thought to reflect climate more strongly than soil or topographic conditions. Sites with such vegetation are referred to as "reference sites." The concept of a reference site was used because conventional zonal site criteria are difficult to apply in mountainous terrain and at high latitudes, where permafrost is an integral environmental component. Alpine regions were differentiated from other ecoclimatic regions through regression analysis of tree line elevations ($n = 188$, $\geq 76\%$ explained variance). An ecocline of vegetation types for each region was developed on the basis of ecological moisture regimes. The climatic distinctiveness of regions was tested by statistical comparison and ordination of monthly temperature and precipitation data (1984–2007) from 26 and 24 meteorological recording locations, respectively. Significant differences ($p < 0.001$) between regions were found in temperature and most precipitation variables. A latitudinal gradient was evident among ordinated meteorological recording locations. Non-forest vegetation represents at least 70–75% of Yukon. Forests with closed and semi-closed canopies occurred primarily south of 64˚ N latitude at low elevations.

Key words: bioclimatic zone, climate, ecoclimatic region, ecology, reference site, vegetation, Yukon, zonation

RÉSUMÉ. Une zonation écoclimatique du Territoire du Yukon, au Canada, a été réalisée (moyennant une échelle de 1:1 000 000) à partir d'observations sur le terrain, de photographies aériennes, de documentation de nature écologique, de cartes du couvert forestier et de modèles de régression. Les 11 régions écoclimatiques se divisent en entités, soit l'entité arctique (1), l'entité subarctique (1), les entités alpines (4), l'entité subalpine (1) et les entités boréales (4). Les régions ont été différenciées en fonction de la végétation car celle-ci semblait refléter le climat de manière plus importante que les conditions pédologiques ou topographiques. Les sites dotés d'une telle végétation sont appelés « lieux de référence ». Le concept du lieu de référence a été utilisé parce qu'il est difficile d'appliquer le critère classique du lieu zonal en terrain montagneux et en latitude élevée, là où le pergélisol fait partie intégrante de l'environnement. Les régions alpines ont été différenciées des autres régions écoclimatiques grâce à l'analyse de régression des élévations de la limite forestière ($n = 188$, ≥ 76 % variance expliquée). L'écocline des types de végétation de chaque région a été préparé en fonction des régimes hygrométriques écologiques. Le caractère distinctif des régions a été mis à l'épreuve au moyen de comparaisons statistiques et de l'ordination des données portant sur les températures et les précipitations mensuelles (1984-2007) depuis 26 et 24 emplacements d'observations météorologiques, respectivement. Des différences considérables ($p < 0{,}001$) ont été relevées entre les régions sur le plan des variables des températures et de la plupart des précipitations. Un gradient latitudinal s'avérait évident au sein des emplacements d'observations météorologiques ayant fait l'objet d'une ordination. La végétation non forestière représente au moins 70 % à 75 % du Yukon. Les forêts dotées d'un couvert fermé ou semi-fermé se trouvent surtout au sud du 64˚ N de latitude, en basse altitude.

Mots clés : zone bioclimatique, climat, région écoclimatique, écologie, lieu de référence, végétation, Yukon, zonation

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INTRODUCTION

Vegetation in northern North America ranges from boreal forests to Arctic tundra because ambient temperatures decrease with increasing latitude, which creates a distinctive zonation in eastern and central Canada (Ecoregions Working Group, 1989; Ecological Stratification Working Group, 1995). This pattern, however, is less apparent in British Columbia and the Yukon, where mountain ranges disrupt the general global atmospheric circulation pattern. This rugged terrain also complicates the recognition and mapping of climatic zones (Bailey et al., 1985) because changing elevations, slope gradients, and slope orientations cause variability in temperatures and moisture availability that influence vegetation composition. Vegetation on relatively level terrain with deep, well to moderately well drained, medium-textured soil is conventionally considered more reflective of climate (zonal sites) than either

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soil or terrain conditions (Mueller-Dombois and Ellenberg, 1974:408). Unfortunately, zonal sites are uncommon in mountainous terrain and where permafrost is an integral part of the landscape, as in northern Yukon. In addition, wildfires and secondary ecological succession create temporal variation in vegetation structure and composition, which further confuses the recognition of climatically representative ecosystems. Despite this terrain and ecological variability, it should be possible to stratify Yukon into climate zones by using vegetation as an indicator, without the necessity of a dense network of long-term meteorological recording stations (Mackey et al., 1996), and stratification may also be a more practical approach in complex terrain (Farr and Hard, 1987). Stratification of landscapes according to climate can have both scientific and applied applications, which include its use as a basis for ecological analyses, land-use planning, and assessment of contemporary climate change.

Four classification schemes have been developed to characterize the regional ecology of the Yukon. These include three national classifications at a scale of 1:7 500 000 (Rowe, 1972; Ecoregions Working Group, 1989; Ecological Stratification Working Group, 1995) and one Yukon-specific classification at 1:2 500 000 (Oswald and Senyk, 1977). As a basis for representing Yukon's climatic zonation, the primary limitation of the Rowe (1972) forest regions and Ecoregions Working Group (1989) ecoclimatic regions classifications is their small scale of mapping, whereas the Oswald and Senyk (1977) and Ecological Stratification Working Group (1995) ecoregion classifications appear more strongly driven by landscape physiography than by climate. In the two latter classifications, multiple climatic/ecological zones were reported in most of the identified landscape units. For instance, Smith et al. (2004) reported 14 occurrences of Alpine, 9 of Subalpine, and 11 of Boreal zones among 23 purportedly unique landscape units recognized by the Ecological Stratification Working Group (1995). Such repetition suggests that considerable biological and climatic diversity occurs within each zone, or alternatively, that a more meaningful approach is needed to adequately portray the ecology and climatic zonation of the territory.

The Yukon has lagged behind other western Canadian jurisdictions with respect to the development of a relatively large-scale climatic zonation (e.g., 1:1 000 000 scale). In comparison, the biogeoclimatic classification of British Columbia was initiated by V.J. Krajina in 1949 (Meidinger and Pojar, 1991:52), whereas Alberta introduced its initial climatic classification in 1981 (Strong, 1992) and was followed shortly thereafter by other Prairie Provinces. Although these and other classifications sometimes used different nomenclature and were occasionally based on different ecological philosophies, their overall intent was to depict climatic zonation. Creation of a similar ecological framework for the Yukon has probably been delayed because of its remote location, sparse population (~0.07 people/km^2), minimal ground access, and limited internal research capacity. The growing interest in mineral extraction (gold, silver, copper, lead, and zinc) and related developments that compete with other interests could necessitate a more comprehensive understanding of ecological resources than currently exists in order to manage environmental impacts. The objectives of this analysis were (1) to develop a more comprehensive regional ecological classification of the Yukon than currently exists based on vegetation; (2) to develop an ecological topographic sequence of plant communities (an ecocline) to characterize the vegetation and ecology of each region; (3) to identify the climatically representative vegetation; and (4) to assess temperature and precipitation data to evaluate the climatic distinctiveness of the vegetation-derived regions.

MATERIALS AND METHODS

Study Area

The Yukon (482 443 km^2) is found in northwestern Canada, east of the State of Alaska (USA) and west of the Northwest Territories between 60˚ and 70˚ N latitude. The southern two-thirds of the territory is dominated by NNW–SSE trending mountains that range up to 5959 m in elevation, with sea level along the northern boundary. Summers are cool and relatively short, and winters are cold and five or more months long. Whitehorse (60.7˚ N) has average May–August temperatures of 11˚C with December–March temperatures averaging -13˚C. In contrast, temperatures at Shingle Point (68.9˚ N) are about 6˚C colder in May–August and 11˚C colder in December–March (Environment Canada, 2011a). Because of the cold climate, evergreen tree species such as *Picea albertiana* ssp. *albertiana* (Strong and Hills, 2006) (western white spruce; equivalent to *Picea glauca* × *engelmannii*, Cody, 2000) and *Picea mariana* (black spruce) are common components of the vegetation.

Classification and Mapping

The fundamental unit of classification (1:1 000 000 scale) was the ecoclimatic region (originally termed a land region, but revised to ecoregion in the late 1970s) and was defined as an area "characterized by a distinctive regional climate as expressed by vegetation" (Lacate, 1969:4). The phrase "ecoclimatic region" was selected for use in this study to avoid confusion with those applications of the term "ecoregion" that do not conform to its original definition (cf. Bailey et al., 1985; Ecoregions Working Group, 1989: footnote 1; Ecological Stratification Working Group, 1995:3). Recognition of climatically representative vegetation was based on sites that were "neither protected from nor exposed to local climatic extremes" with "neither a lack nor an excess of soil nutrients" (Ecoregions Working Group, 1989:1). Mature seral vegetation was used to differentiate regions because it provided greater potential for separating climatically and ecologically different areas than climatic climax vegetation, which is similar throughout much of the territory. Terrain with gradients of less than 5% and medium-textured soils with submesic to mesic moisture regimes were considered zonal sites, when available. Where only gradients with slopes of more than 5% occurred, vegetation that consistently occurred on multiple aspects, at similar elevations, and with submesic to mesic moisture regimes was considered to be climatically representative. In northern latitudes with Cryosolic soils (nomenclature follows Soil Classification Working Group, 1998), sites on low-gradient terrain with submesic to subhygric midsummer active layers were considered to be climatically representative. Because it was not possible to identify all climatically representative ecosystems using conventional zonal criteria, all climatically representative ecosystems are referred to as reference sites. Such "sites" represent a combination of ecological conditions rather than any specific geographical location (Natural Resources Canada, 2012). Reference sites were not necessarily the most abundant ecosystems within an ecoclimatic region.

To facilitate the systematic summarization of synecological relationships by ecoclimatic region, an ecoclinal sequence was compiled for each region according to a gradient of ecological moisture regimes (Luttmerding et al., 1990:35). These sequences were based primarily on what were perceived as recurring plant communities and secondarily on slope aspect. Sequences were developed from field-observed ecosystems at multiple locations within each region. If a region was not accessible or an ecocline contained gaps with respect to moisture regime classes, sequences were either compiled or supplemented with ecosystems from other ecological studies. The basic unit of plant community description was the vegetation type, which represents plant communities named according to dominant species by stratum (Classification Level VI: National Vegetation Working Group, 1990:7). Vegetation type naming followed the convention of listing dominant species by stratum (i.e., uppermost first), with co-dominants listed according to their relative abundance. Stratum changes were noted by a slash (/) between species names, and a dash (–) was used to indicate co-occurring species within a stratum. Botanical nomenclature was based on Cody (2000), Anderson et al. (1990), and Brodo et al. (2001), unless otherwise indicated.

Differentiation and mapping of ecoclimatic regions was based on location and distribution of reference sites and associated environmental indicators. For example, Arctic and alpine areas were differentiated from boreal, subalpine, and subarctic areas on the basis of whether the tree line was latitudinal or elevational. If a physical boundary such as a mountain ridge was not present, boundaries between subarctic and the most northerly boreal region were somewhat arbitrary because vegetation is similar in these adjoining regions. Subalpine ecosystems between alpine and boreal regions were recognized on the basis of the open structure of the subalpine tree canopy compared to boreal areas and location on mid-elevation slopes in mountainous terrain. Mapping and differentiation of boreal ecoclimatic regions relied on the interpretation of mapped forest cover data in conjunction with contour map information to identify reference sites that indicated a given ecoclimatic region. When reference sites were lacking, ecoclines were used to assign an area to an ecoclimatic region. An initial mapping of ecoclimatic region boundaries was reviewed on the ground, where possible, and revised as necessary. Ecoclimatic region nomenclature approximated the system used by the Ecoregions Working Group (1989).

Mapping information was derived from the synthesis and interpretation of forest cover maps (Yukon Forest Management Branch, 2009), publicly available synecological studies, and aerial photographs of various ages and scales (Yukon Energy, Mines and Resources Library, Whitehorse). Field investigations during the summers of 2010 and 2011 included primarily areas near readily accessible roads; one exception was a hiking trip into the Kotaneelee area in the extreme southeast corner of the territory. The availability of reference materials for mapping was sufficient to cover all of the territory at least once. Satellite imagery was not used because of its small scale, its limited resolution, and the greater difficulty of differentiating vegetation occurrence patterns in the landscape with this imagery compared to aerial photography.

Alpine Tree Line

Distinguishing between elevation-induced climatic or alpine tree lines and geomorphic tree lines that result from steep slopes, substrate factors, and slope instability was often problematic. To provide an objective method for mapping the lower limit of the alpine climatic zone, up to five pairs of north and south tree line elevations were compiled for each 1:250 000 scale Canada National Topographic Series (NTS) map of Yukon areas located south of the Arctic zone. After a stereoscopic review of aerial photographs, those locations considered to be the best available examples were selected for measurement. Whenever possible, measurements were done on opposing slopes that occurred in close proximity. Once identified, each aerial photograph location was compared with the corresponding 1:50 000 scale NTS map to determine its elevation.

Models of tree line elevations were constructed using regression analysis based on the average value of each north-south tree line pair. A three-dimensional regression model using quadratic smoothing was developed for areas south of 66˚ N, whereas a simple linear model was found adequate for areas north of 64˚ (Fig. 1). The reliability of the three-dimensional model was evaluated on the basis of the correlation between observed values and values predicted by the regression. The amount of variance explained by the models was considered equal to the square of the associated coefficient of correlation (r or R). STATISTICA computer software (Statsoft, 1995) was used for these analyses. Mapping of climatic tree lines was based

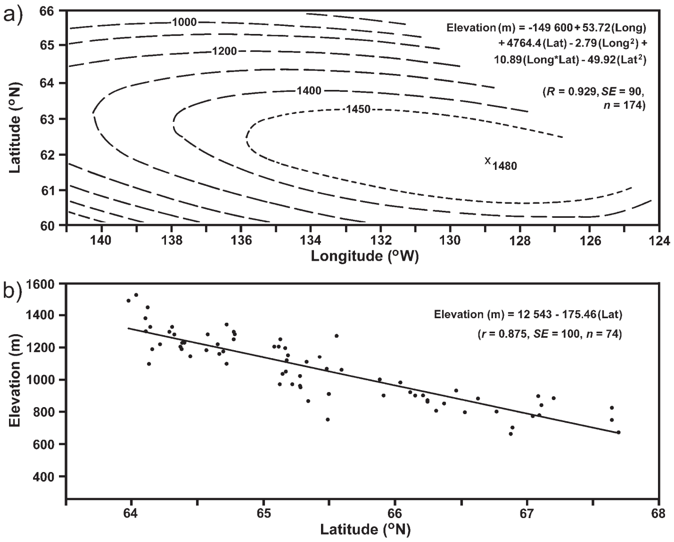

FIG. 1. Variation in elevation-induced tree line within Yukon based on: a) a three-dimensional model (60˚–66˚ N latitude); and b) a linear regression model (64˚–68˚ N). Isolines represent elevations (m) in the three-dimensional model.

on regression-predicted elevations, plus one standard error (SE), that were specific to individual 1:50 000-scale NTS maps.

Climate Data Analysis

Among the available records from Yukon meteorological stations (Environment Canada, 2011b), the longest temperature and precipitation recording period with the most stations and fewest missing monthly values was judged to extend from 1984 to 2007. All 26 included stations had missing monthly data (average ~10%), and Environment Canada assigned monthly values that were derived from incomplete sets of daily measurement. It was necessary to accept these assigned values as accurate; otherwise, no analysis (or only a very limited one) would have been possible. Missing values were estimated either by incorporating values from a nearby station (e.g., merger of Ross River YTG and Ross River A station records) or by using a control station. For the latter, Pelly Ranch (station 2100880) was used because it had nearly complete monthly temperature and precipitation records (1 missing value and 19 Environment Canada assigned values, mostly due to a single missing daily measurement within a given month), and because it was more centrally located within the territory (62.817˚ N, 137.367˚ W) than another comparable station (Mayo Road). Missing values were estimated (E_{ij}) using the algorithm:

$$E_{ij} = D_{ij} + (C_j - M_j)$$

where D equals the reported monthly value of the control station, C equals the average monthly value for the control station (1984–2007), M equals the average monthly value for the station with the missing value based on the reported data, i equals year, and j represents the calendar month.

Kruskal-Wallis tests were used to determine whether significant ($p < 0.05$) differences occurred among ecoclimatic regions with two or more meteorological stations. Comparisons were based on STATISTICA computer software (Statsoft, 1995). Scheffé rank tests ($\alpha = 0.050$, Miller, 1966: formula 110) were used to identify which regions differed within significant Kruskal-Wallis tests. Monthly average temperature and total precipitation data were ordinated using detrended correspondence analysis (McCune and Mefford, 1999) to illustrate relative relationships among meteorological recording locations and their associated ecoclimatic region. To ordinate the meteorological data, it was necessary to reduce the analysis time frame to 1987–2007 to accommodate software limitations. Explained ordination variance was determined using relative Euclidean distance.

RESULTS AND INTERPRETATION

Ecoclimatic Regions

Eleven ecoclimatic regions were recognized in six broadly defined ecoclimatic provinces (*sensu* Ecoregions Working Group, 1989). These six provinces, listed from south to north, are Mid-Boreal, Mid-Cordilleran, Northern Pacific Cordilleran, Northern Cordilleran, Subarctic, and Arctic (Fig. 2). Excluding consideration of high-elevation regions, the six ecoclimatic provinces generally formed latitudinal bands. The ecological characteristics of the eleven ecoclimatic regions are summarized below.

Mid-Boreal Subhumid (MBs): The MBs region occurs in the extreme southeast corner of the Yukon (Fig. 2) and is the smallest region in the territory (Table 1). The reference vegetation is forest stands that are dominated by 20–30 m tall, closed-canopied, *Populus tremuloides* (aspen) and also include a 1–2 m tall shrub stratum of *Viburnum edule* (low-bush cranberry) and *Rosa acicularis* (prickly rose) (Fig. 3). Herbs such as *Aralia nudicaulis* (wild sarsaparilla) and *Rubus pubescens* (dwarf raspberry) commonly occur in the understory vegetation (Jeffrey, 1964:27), as well as *Calamagrostis canadensis* (marsh reedgrass). The understory vegetation of drier *P. tremuloides* stands is dominated by *R. acicularis*. Subhygric sites develop *Populus balsamifera* (balsam poplar) stands with *Alnus incana* (river alder) and *Salix* spp. (willows) that are often more than 3 m tall, and *V. edule*. These sites sometimes include such Yukon rarities as *Maianthemum canadensis* (wild lily-of-the-valley) (Cody, 2000:616) and *Matteuccia struthiopteris* (ostrich fern). *Betula papyrifera* (paper birch) trees are common in this ecoclimatic region. Upland forests are rapidly succeeded by *Picea albertiana*, which at maturity can reach heights of 25–35 m. Besides having deciduous rather than coniferous forest reference vegetation (cf. MCb), the MBs region is structurally more diverse, botanically richer, and more productive in terms of phytomass than other regions in the Yukon. Gray Luvisolic soils occur on reference sites, which is also atypical of the territory. *Picea albertiana*/

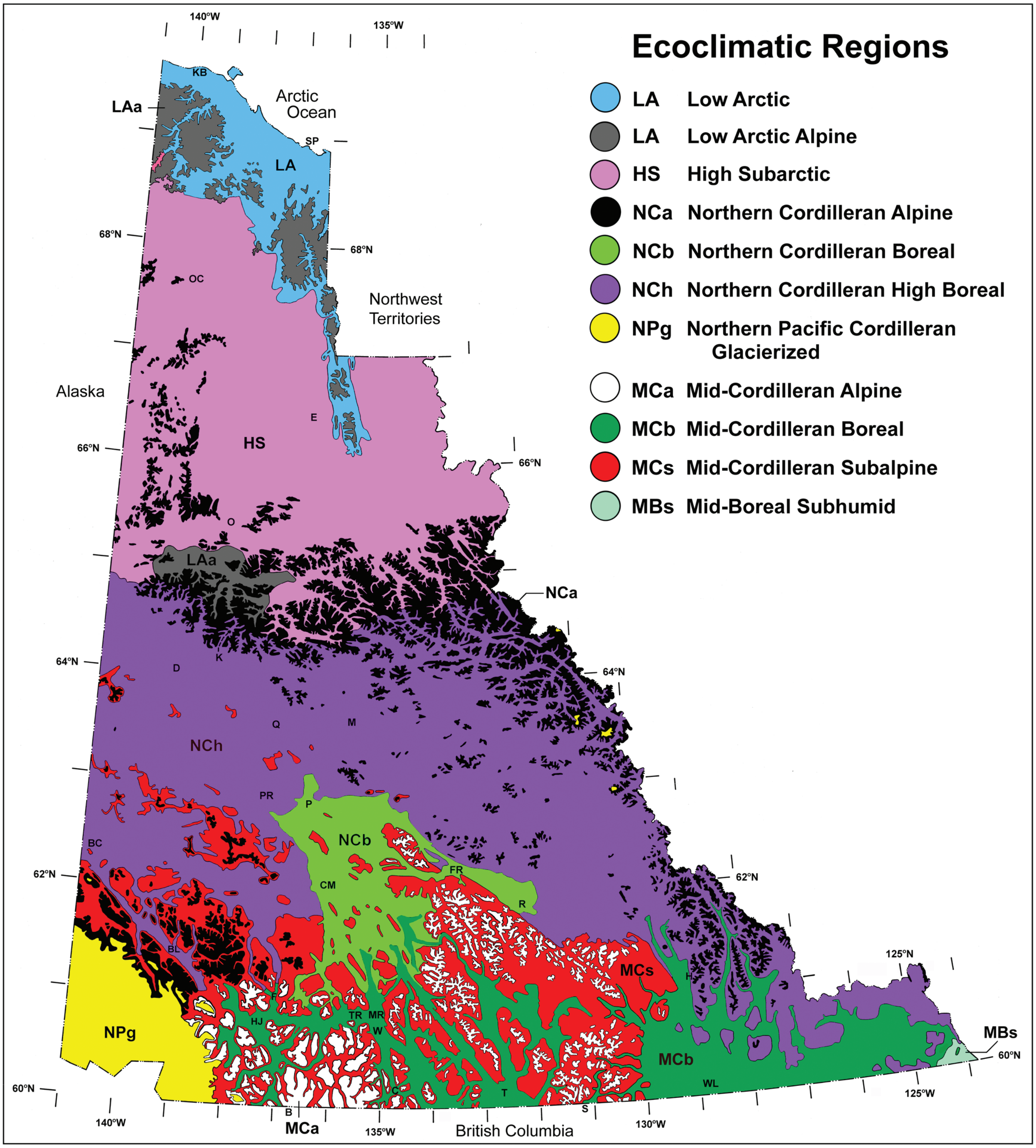

FIG. 2. Ecoclimatic regions of Yukon. Letters other than ecoclimatic regions indicate the location of selected settlements and meteorological station locations: B – Blanchard River; BC – Beaver Creek; BL – Burwash Landing; C – Carcross; CM – Carmacks; D – Dawson City; E – Eagle Plains; F – Otter Falls; FR – Faro; H – Hour Lake; HJ – Haines Junction; K – Klondike; KB – Komakuk Beach; M – Mayo; MR – Mayo Road; O – Ogilvie River; OC – Old Crow; P – Pelly Crossing; PR – Pelly Ranch; Q – McQueston; R – Ross River; S – Swift River; SP – Shingle Point; T – Teslin; TR – Takhini Ranch; W – Whitehorse; and WL – Watson Lake.

Hylocomium splendens (stairstep moss) is the potential climatic climax vegetation.

Mid-Cordilleran Boreal (MCb): This region occurs primarily south of 61° N at low elevations and in valley bottoms (Fig. 2). Its reference sites have closed and semi-closed canopied stands of *Pinus contorta* ssp. *latifolia* (lodgepole pine). Mature *P. contorta* seldom exceed 20 m in height and are typically shorter. In the western portion

TABLE 1. Estimated percent areal extent of ecoclimatic regions in Yukon based on Figure 2.

Ecoclimatic region		Area (%)
MBs	Mid-Boreal Subhumid	0.1
MCb	Mid-Cordilleran Boreal	8.9
MCs	Mid-Cordilleran Subalpine	12.8
MCa	Mid-Cordilleran Alpine	3.0
NPg	Northern Pacific Cordilleran Glacierized	3.4
NCb	Northern Cordilleran Boreal	2.9
NCh	Northern Cordilleran High Boreal	32.8
NCa	Northern Cordilleran Alpine	9.2
HS	High Subarctic	20.3
LA	Low Arctic	3.6
LAa	Low Arctic Alpine	3.0

of the region, the understory vegetation is characterized by *Shepherdia canadensis* (buffaloberry), whereas *Ledum groenlandicum* (Labrador tea) is more prominent on reference sites in the eastern portion (Fig. 3). Associated understory species commonly include *Vaccinium vitis-idaea* (bog cranberry), *Cornus canadensis* (bunchberry), *Hylocomium splenden*s, and *Pleurozium schreberi* (Schreber's moss) (Strong, 2002). *Calamagrostis purpurascens* (purple reedgrass) also occurs in association with *S. canadensis*. Brunisolic soils are characteristic of MCb reference sites, although Gray Luvisolic soils may commonly occur in the eastern extreme of the region (White et al., 1992). The lack of *P. contorta* at low elevations in the far western portion of the region (Champagne to Haines Junction area) is likely the result of high soil NaCl and pH levels (Day, 1962). *Picea albertiana*, *Picea mariana*, and sometime *Abies lasiocarpa* with *Hylocomium splendens* are the potential climatic climax species on submesic to hygric sites.

Stands on submesic coarse-textured soils develop a ground cover of *Arctostaphylos uva-ursi* (bearberry), whereas drier sites have reduced *P. contorta* cover and an abundance of *Cladina* spp. (reindeer lichens) (Fig. 3). In contrast, warm south-facing slopes develop *Populus tremuloides*/*Rosa acicularis* and *P. tremuloides*/*A. uva-ursi* stands, with the latter occupying the driest sites. *C. purpurascens*–*A. uva-ursi* vegetation occurs on subxeric steep southfacing slopes. Wetlands of *Salix* spp. and *Carex aquatilis* (water sedge) develop where early summer flooding and water pooling occur, whereas *P. mariana*-dominated vegetation develops where near-surface soils are wet, but not continuously flooded with water, and often have a poor nutrient status (Fig. 3).

Mid-Cordilleran Subalpine (MCs): The MCs ecoclimatic region occurs primarily west of 129˚ W and south of 62˚ N, although unmapped examples may extend into the Dawson area (Fig. 2). Topographically, this region occurs at mid-elevations in mountainous terrain above boreal regions (MCb, NCb, and NCh) and below alpine regions (MCa and NCa areas < 64.5˚ N). The MCs region has an elevation range of less than 400 m. Scattered, stout conifer trees 13 m or more in height occur on reference sites within a matrix of tall (1.5–3 m), relatively dense *Betula glandulosa* (dwarf birch) and *Salix* spp. (Danby and Hik, 2007: Fig. 2b). *Picea albertiana* is the most common tree, but *Abies lasiocarpa* (subalpine fir), *Pinus contorta* var. *yukonensis* (Yukon pine; Strong, 2010), *Pinus contorta* spp. *latifolia*, and *Picea mariana* also occur. *Picea mariana* is more frequent near the NCh zone than near other ecoclimatic regions, whereas *A. lasiocarpa* is most common at higher elevations. Tree and shrub heights decrease with increasing elevation. In the core of its geographical range, ground vegetation on reference sites is often modest in abundance and composed of scattered forbs, graminoids, ericaceous shrubs, and lichens (e.g., *Cladonia* spp.). High-elevation sites, north aspects, and more northern locations (e.g., in NCh) have less herb and greater moss cover (Ayotte, 2002:84). Steep north aspects at lower elevations can develop tall (5–6 m) *Salix* stands that include scattered conifer trees. Grass patches and *Populus tremuloides* stands occasionally occur on southwest slopes, which are warmer and drier than reference sites (Fig. 3). Eutric Brunisolic soils appear to be the most abundant soil great group, but Dystric Brunisols also occur. Cryosolic soils are more frequent in proximity to the NCh on steep north aspects.

Mid-Cordilleran Alpine (MCa): Mid-Cordilleran Alpine has a discontinuous distribution in southern Yukon because it occurs only at high elevations. Because it was difficult to confirm the extent of the MCa region, the working model arbitrarily limited its occurrences to southern Yukon areas with MCs vegetation (Fig. 2). This arbitrary limit was necessary because few alpine vegetation studies have been conducted in Yukon and ground access to the region's more than 200 map polygons was very limited. Many small alpine areas were unmappable at a 1:1 000 000 scale. The lower elevation limit of the MCa increases from ~1100 m in the southwest portion of the territory to ~1480 m in the eastern portion of its range (Fig. 1a). Tree lines are higher on south aspects than on north aspects, with a differential of 110–155 m (based on second and third quartile data values; n = 188). This differential did not vary with latitude (based on correlation $p > 0.050$). Vegetation in the MCa region is highly variable in composition because of macro- and microtopographic variability and the associated microclimatic differences. Vegetation cover and stature decrease with increasing elevation.

Reference sites are dominated by moderately dense stands of *Betula glandulosa* and *Salix* spp. with a height of less than 1 m (Fig. 3). Ground species in this vegetation include *Vaccinium uliginosum* (bog bilberry), *Empetrum nigrum* (crowberry), *Cladonia* spp. (lichens), *Flavocetraria cucullata* (curled snow lichen), and *Polytrichum* spp. (haircap mosses). Sites that are exposed to wind or with coarse-textured soils often have *Dryas integrifolia* (smooth-leaved mountain-aven) as the dominant species, whereas open-growing *Betula glandulosa* stands with *Stereocaulon* spp. (coral lichens) occur on thin dry soils. *Dryas* vegetation is typically under 15 cm tall. Steep southerly aspects with warm and dry conditions develop *Festuca altaica*–*Artemisia norvegica* (northern rough fescue–wormwood) vegetation. *Kobresia myosuroides* (kobresia) vegetation occurs

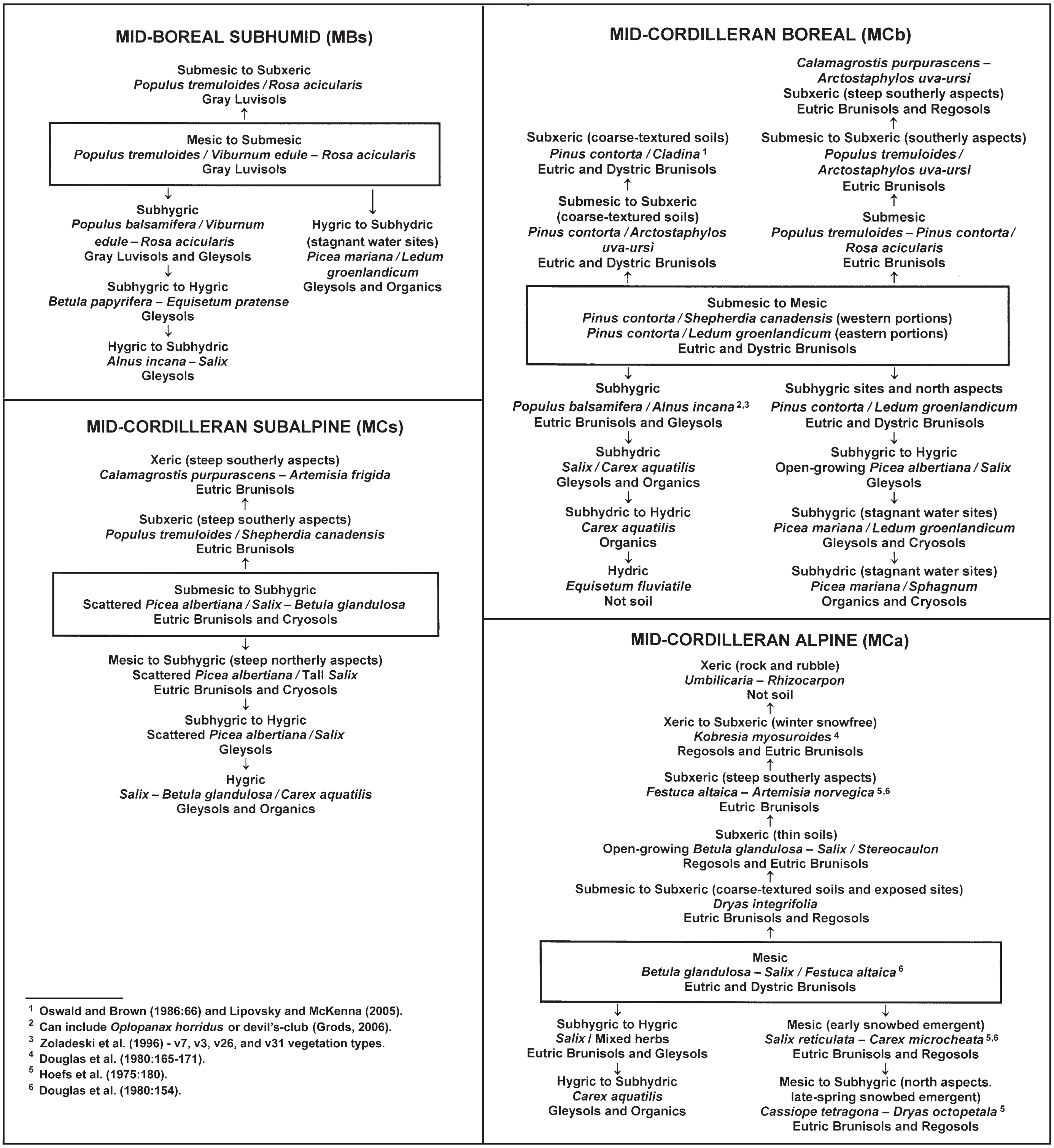

FIG. 3. Mid-Boreal and Mid-Cordilleran ecocline sequences in Yukon, excluding riparian ecosystems. Boxes indicate climatic reference vegetation and the anticipated soils. Vegetation types are arranged primarily according to ecological moisture regimes.

on sites with subxeric conditions and limited winter snow cover (Douglas et al., 1980). On moist sites, open-growing tall (~1 m tall) and low-growing (< 10 cm tall) *Salix*-dominant vegetations develop in response to surface water flow and melting snowbeds, respectively (Fig. 3). The former vegetation often includes a diverse mixture of mesophytic herbs such as *Polemonium acutiflorum* (Jacob's-ladder) and *Senecio triangularis* (groundsel). *Cassiope tetragona* (white heather) stands are usually associated with cool northern aspect. Soil profile development is often limited by the cold climate and shallow surficial materials.

North Pacific Cordilleran Glacierized (NPg): The majority of this region occurs in the St. Elias Mountains (southwest Yukon) within or near Kluane National Park. Small disjunct examples also occur between ~62.5˚ and 64.5˚ N at high elevations along the east side of the territory (Fig. 2). The NPg occurs above the MCa and NCa regions and is differentiated from them by the occurrence of icefields. Areas not occupied by glaciers are likely unvegetated, or at best, have a spare, discontinuous cover of low-growing plants (e.g., mosses, lichens, or very cold-hardy vascular plants). Where unconsolidated surficial materials occur, Cryosolic (Douglas et al., 1980:189) and Regosolic soils are common.

Northern Cordilleran Boreal (NCb): The NCb region occurs in the central portion of southern Yukon (Fig. 2) in a topographic depression between the east and west flanks of the Yukon Plateau (Bostock, 1948). The region is surrounded by the NCh region on three sides and abuts the MCb region at its southern limit. Its upper elevation limit is formed by the MCs region.

Mature seral vegetation on reference sites is dominated by closed-canopied *Populus tremuloides* trees (≤ 15 m tall), often with a large proportion of *Picea albertiana* seedlings and trees. Such stands are usually of fire origin. Medium height (< 50 cm tall) *Shepherdia canadensis*, *Rosa acicularis*, and *Calamagrostis purpurascens* form the understory vegetation, with a scattered cover of 2 – 5 m tall *Salix* (Strong, 2009). *Populus tremuloides* stands tend to contain only 10 – 20 vascular and nonvascular plant species, with a combined foliar cover of 50% or less. Such stands are floristically poor compared to those of southern boreal forests (Strong and Redburn, 2009). *Picea albertiana* establish early in the successional development of reference stands and reach heights of 20 – 25 m. As a result, *P. albertiana* can replace *P. tremuloides* as the dominant trees within 100 years after stand initiation (Strong, 2009). Climax understory vegetation is dominated by *Hylocomium splendens* in conjunction with species such as *Peltigera aphthosa* and *P. malacea* (dog-tongue lichens). Eutric Brunisolic soils are characteristic of upland sites.

Dry south-facing slopes develop *P. tremuloides*/*Arctostaphylos uva-ursi* stands, whereas *Calamagrostis purpurascens* – *Artemisia frigida* (pasture sage) vegetation is a common landscape component on steep southerly aspects. Sanborn (2010) suggests that some of the Brunisolic-like soils that occur in association with *C. purpurascens* could technically be considered Dark Brown Chernozems. *Pinus contorta* ssp. *latifolia* stands also occur in the region, but appear to be limited to coarse-textured soils and steep south-facing slopes. *Salix* spp. and *Carex aquatilis* are the principal species of wetlands (Fig. 4).

Northern Cordilleran High Boreal (NCh): NCh occurs north of the MCb region to about 64.5˚ N (Fig. 2) and represents the most northern component of the boreal forest. The region is ecologically complex because of its diverse terrain, which ranges from undulating and rolling topography to steep mountains slopes. MCs and Northern Cordilleran Alpine (NCa) form the upper elevation limit of this region. The boundary between the NCh and High Subarctic (HS) regions is somewhat arbitrary because both include the same tree species. Occurrence of the NCh is more strongly determined by elevation than by latitude, compared to HS. Tree densities and heights are greater on reference sites in the NCh than in the HS, although they decrease with increasing elevation. The NCh comprises one-third of the Yukon Territory (Table 1).

Reference sites have moderately dense (< 10 m tall) *Picea mariana* stands that often include *Picea albertiana*. The ground vegetation is dominated by *Ledum groenlandicum* and *Hylocomium splendens*. In the eastern half of the region, *Betula glandulosa* is a common tall shrub in this vegetation (Fig. 4). The soils are primarily Cryosols, but Dystric Brunisols sometime occur. Non-permafrost, mesic (not south-facing) sites within areas dominated by *Picea mariana* sometimes develop *Betula papyrifera* stands. In contrast, south-facing slopes with *Populus tremuloides* stands will be replaced by *P. albertiana*. *Picea albertiana* trees on southerly slopes (a common occurrence) are often taller (15 – 20 m) and larger than those of reference sites. Steeply sloping sites develop graminoid vegetation dominated by *Calamagrostis purpurascens*, *Festuca altaica*, or sometimes *Elymus* spp. (wheatgrasses). *Artemisia* spp. (sage or wormwood) are an abundant secondary component of these grass stands. Coarse-textured soils can develop open-growing *P. albertiana* stands, with a relatively continuous stratum of ground lichens such as *Cladina rangiferina* (grey reindeer), *Cladina stellaris* (star-tipped reindeer), and *Flavocetraria cucullata* (Kojima, 1996: Fig. 3b). Plant communities intermediate to the *P. albertiana*/*Cladina* and reference vegetation likely occur, but were not observed or found in the literature searched. Subhygric to subhydric sites, steep north-facing slopes, and depressions are typically vegetated by open-growing stunted (< 5 m tall) *P. mariana*, with a thick moss stratum that insulates the underlying permafrost. *Salix* spp. and *Carex aquatilis* stands occur on subhydric and hydric sites, respectively.

Northern Cordilleran Alpine (NCa): Examples of the NCa ecoclimatic region occur throughout the NCh and HS in the Yukon, with the greatest concentrations in the Ogilvie and Selwyn Mountains (Bostock, 1948), northeast of Kluane National Park, and along the eastern edge of the territory south of 63˚ N (Fig. 2). This region occurs at elevations ranging from 1480 m in the southeast to ~665 m in the north (Fig. 1), which represents a 175 m decrease per degree of latitude increase from 64˚ to 68˚ N (Fig. 1b). A 110 – 155 m differential in tree line elevation occurs between north and south slopes. The NCa is the most extensive alpine ecoclimatic region in the Yukon (Table 1).

Stands of *Betula glandulosa* and *Salix* spp. less than 1 m tall, with a ground stratum of lichens and feathermosses, form the reference vegetation (Fig. 4). Graminoids and forbs are normally absent or have very limited cover. Cryosolic soils are associated with reference sites. *Hylocomium splendens* is the dominant ground species

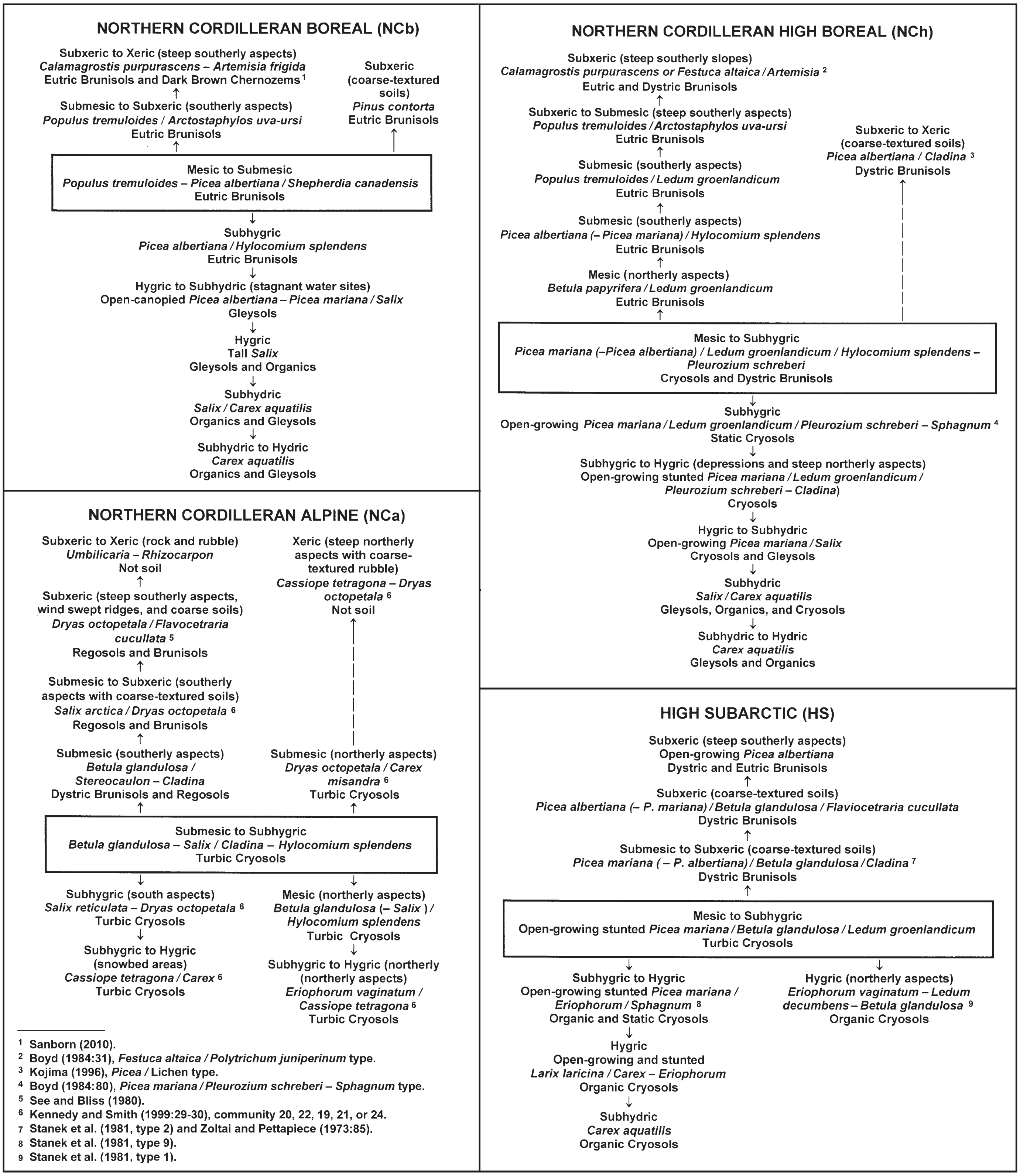

FIG. 4. Northern Cordilleran and High Subarctic ecocline sequences in Yukon, excluding riparian ecosystems. Boxes indicate climatic reference vegetation and the anticipated soils. Vegetation types are arranged primarily according to ecological moisture regimes.

on low-gradient north aspects, whereas *Stereocaulon* spp. are associated with drier sites. Low-growing *Dryas* spp. and *Salix* spp. vegetation develops on southerly slopes with submesic to subxeric moisture regimes that lack permafrost. Physiognomically similar vegetation occurs on north aspects, but includes *Carex misandra* (sedge) and

Cassiope tetragona with *Dryas octopetala* (white mountain-aven) (Fig. 4).

High Subarctic (HS): The HS ecoclimatic region occurs geographically and ecologically between the Low Arctic and the NCh, and spans 4.5° of latitude in the northern one-third of the territory (Fig. 2). The latitudinal tree line forms the northern limit of the region (slightly modified from Wiken et al., 1981). Open-growing and stunted evergreen forests dominate the landscape, with tree heights and densities decreasing with increasing latitude. Permafrost is common in the landscape. HS is the second largest ecoclimatic region in the Yukon (Table 1).

Reference sites have open-growing, stunted (5–10 m tall) *Picea mariana* trees. Spaces between trees are occupied by medium-height (1–1.5 m tall) *Betula glandulosa*, sometimes with *Salix* spp. The ground vegetation includes cold-hardy species such as *Ledum groenlandicum*, *Vaccinium vitis-idaea*, *Hylocomium splendens*, and *Cladonia* spp. (Stanek et al., 1981:16–19; Boggs and Sturdy, 2005:57–60). *Picea mariana* stands with *Picea albertiana* occur on coarse-textured soils that develop a lichen ground stratum, whereas open-growing *P. albertiana* stands occur on steep southerly aspects. Open-growing 3–5 m tall *P. mariana* in association with *Eriophorum* spp. (cottongrasses) and *Sphagnum* spp. (peat mosses) develop on subhygric to hygric sites. Similar stands dominated by *Larix lariciana* (tamarack) occur on hygric sites. Reference and wetter sites have Cryosolic soils, with Brunisols occurring on drier sites.

Low Arctic (LA): The Low Arctic region occupies a ~120 km wide band south of the Arctic Ocean and extends southward along the lower slopes of the Richardson Mountain (Fig. 2). The southern boundary is formed by the latitudinal tree line. LA is predicted to occur below 600 and 470 m elevation (south and north, respectively) in the western portions of its range, and below 1000 m around the southern Richardson Mountains on the basis of Fig. 1b. Permafrost is relatively continuous in this ecoclimatic region.

Reference sites have tussocky tundra dominated by *Eriophorum vaginatum–Ledum decumbens–Betula glandulosa* (sheathed cottongrass–northern Labrador tea–dwarf birch) vegetation (< 30 cm tall) (Fig. 5). Low-growing (< 10 cm) *Salix arctica*– and *S. reticulata–Dryas integrifolia* (arctic willow– and net-veined willow–smooth-leaved mountain-aven) vegetation is associated with submesic sites, whereas ~1 m tall *Salix alaxensis* (felt-leaved willow), *B. glandulosa*, and *Alnus crispa* (green alder) stands can occur on drier sites (Zoltai and Pettapiece, 1973; Wiken et al., 1981). Scattered and stunted *Picea albertiana* are sometimes present on steep southerly aspects at low elevations, where the topography enhances the local thermal regime. Sites wetter than the reference sites are vegetated by graminoids with hydrophilic mosses. Submesic and wetter sites have Cryosolic soils, with the active layer increasing in depth with better site drainage (Zoltai and Pettapiece, 1973:19). On Herschel Island, Smith et al. (1989) reported active layers of 45–50 cm on reference sites.

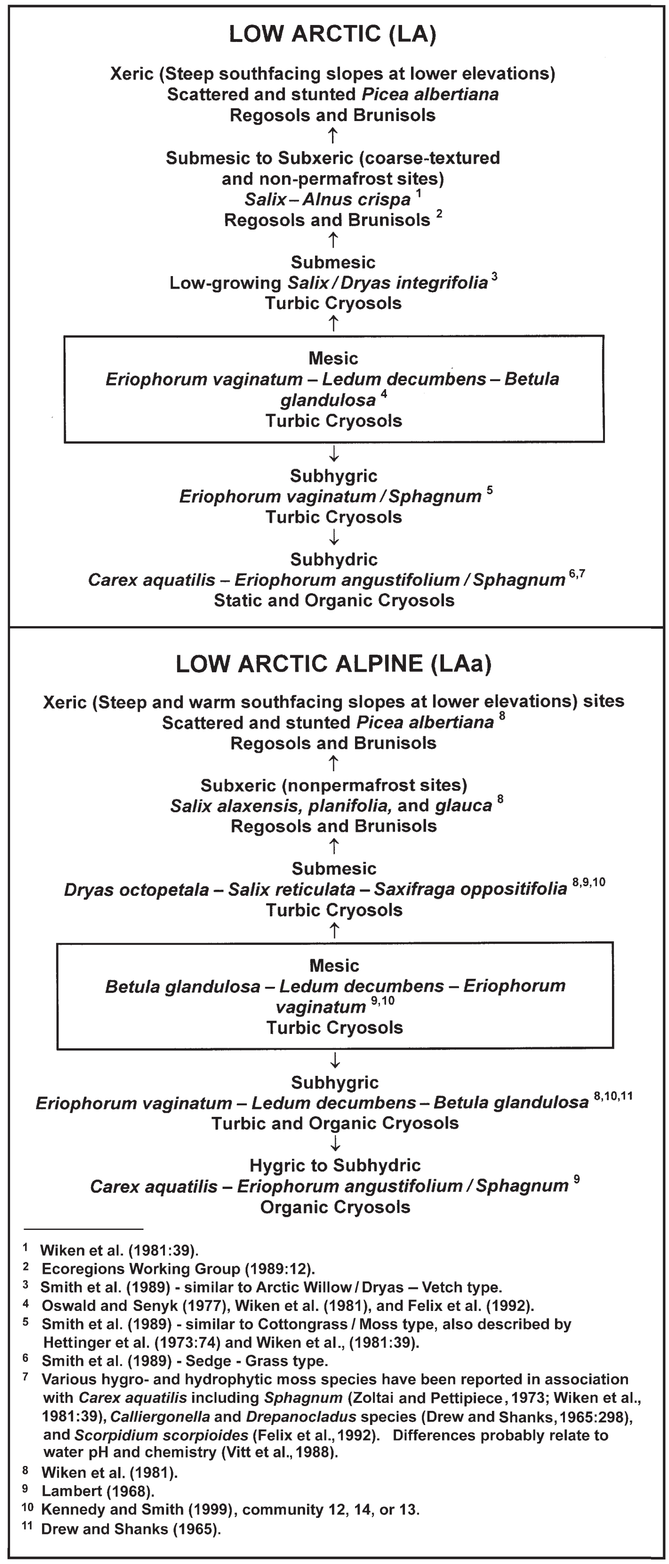

FIG. 5. Low Arctic ecocline sequences in Yukon, excluding riparian ecosystems. Boxes indicate climatic reference vegetation and anticipated soils. Vegetation types are arranged primarily according to ecological moisture regimes.

Low Arctic Alpine (LAa): Recognition of the Low Arctic Alpine ecoclimatic region is somewhat theoretical, based on the assumption that high-elevation sites have different climatic regimes compared to low elevation sites because of adiabatic cooling, although this region was also recognized by Simpson et al. (2002:1179) in Alaska and by the CAVM Team (2003). Delineation of this region was based on the northward projection of the lower limit of alpine vegetation using the regression model presented in Fig. 1b (see LA summary for lower elevation limits). This ecoclimatic region has a discontinuous distribution at mid to upper elevations in the British and Richardson Mountains (Fig. 2). It also appears to occur at high elevations along the north face of the Ogilvie Mountains in the vicinity of Tombstone Territorial Park in central Yukon. Much of the landscape consists of colluvium, stone stripes, frost polygons, and associated cryoturbation features. Unvegetated and sparsely vegetated areas are common (Wiken et al., 1981).

This ecoclimatic region has tundra vegetation that is dominated by low-growing shrubs (Wiken et al., 1981:18) with graminoids, ground lichens, and mosses. Reference sites appear to be a mixture of *Betula glandulosa* and *Ledum decumbens* with *Eriophorum vaginatum*. *Dryas octopetala* and low-growing shrubs such as *Salix reticulata* with *Saxifraga oppositifolia* (purple saxifrage) occur on submesic sites. The reference vegetation of the LA region occurs on subhygric sites in the LAa (Fig. 5). Wet sites develop *Carex aquatilis*-dominated stands. *Salix* spp. and open-growing *Picea albertiana* stands occasionally occur on dry and warm sites, respectively. Turbic Cryosolic soils predominate on submesic and subhygric upland sites, with a 35–75 cm deep active layer (Wiken et al., 1981).

Climate Conditions

The warmest monthly temperatures (15˚C) within the territory occurred in the NCb and NCh regions during July (Table 2). In June and August, temperatures were similar within the MCb and HS regions, but distinctly colder in the LA. Although data were available for only one MCa meteorological station (Blanchard River near British Columbia border and east of Kluane National Park), summer temperatures appeared cooler than in other regions (Table 2) except the LA. In contrast, temperatures in the NPg were likely much colder than in MCa or LA areas (Marcus and LaBelle, 1970:110). January temperatures were 32˚–40˚C colder than July values. MCb areas had the warmest winter (November–March) values (-8˚ to -18˚C) in the territory. Overall winter temperatures were 10˚C colder in northern than in southern Yukon (Table 2). Winter MCa temperatures appeared to be similar to or warmer than those in the MCb region. On an annual basis, a gradient of decreasing annual temperature with increasing latitude was apparent among regions, with temperatures ranging from -1.1˚ to -9.9˚C (Table 2). Despite similar monthly and seasonal temperatures in the NCb and NCh regions, annual temperatures were ~1.1˚C warmer in the NCb.

Monthly summer precipitation was greatest in the HS and NCh regions. Peak precipitation occurred in July, with 24–33% less precipitation during June and August. For the one MCa station, maximum precipitation occurred in September. Total summer precipitation was similar in the HS and NCh (~205 mm), whereas the NCb and MCb regions received about 173 mm. Although NCb precipitation totals were only about 16% less than NCh totals, the NCb region occurred within an area considered by Jätzold (2000:6) to have the potential for severe evaporation deficits in April–June. Winter precipitation was 22 mm or less (water equivalent) per month in subarctic and boreal regions, with total winter precipitation of 72–92 mm. Northern regions received ~2.4 times more summer than winter precipitation, but the differential was less in Mid-Cordilleran regions (Table 2). Although significant differences occurred among regions, the range in annual total precipitation was not great (~300 ± 21 mm or 7%).

Climate Data Ordination

Figure 6a illustrates the relative similarity of assessed meteorological recording locations based on ordinated 1984–2007 monthly temperatures. The horizontal axis appeared to represent a gradient of increasing latitude from right to left and decreasing temperature from bottom to top. The ordination explained 89% of the variance in temperatures, with the horizontal axis accounting for three-fourths of the total. Meteorological recording locations within the same ecoclimatic region generally occurred in closer proximity than those of different regions (Fig. 6a). The location of individual regions approximated their relative spatial sequence within the Yukon landscape based on an upward arc from MCb through NCb and NCh to LA. The position of meteorological recording locations in the ordination suggested that NCb temperatures were more closely associated with the NCh regime than with the MCb regime. Of the 26 assessed locations, only Watson Lake was inconsistently located with respect to its ecoclimatic region classification (Fig. 6a). This anomaly could be due to its location adjacent to a lake, or its greater exposure to winter Arctic fronts than other MCb locations. The Klondike (NCh) and Eagle Plains (HS) sites were disjunct from other members of their region, but also represented the most northern and highest-elevation recording sites, when adjusted for latitude, within their respective regions.

The ordination of monthly total precipitation in Figure 6b, although graphically somewhat different from the temperature data in Figure 6a, suggested similar ecological trends. MCb sites occurred in the lower portion of the ordination, with NCb and HS sites progressively higher along the vertical axis, suggesting a latitudinal gradient. NCb sites occurred between the NCh and MCb regions. No precipitation data were available for the LA. The horizontal axis appeared to represent a complex gradient based on temporal variability in precipitation regimes. The Figure 6b ordination explained 59% of the variance in data (horizontal axis = 32%). Of the 24 sites assessed, Swift River represented the only inconsistency with respect to classification. Swift River was closely associated with three NCh

TABLE 2. Median monthly temperatures and total precipitation of Yukon ecoclimatic regions based on 1984–2007 meteorological data, with comparisons using Kruskal-Wallis tests.[1]

Ecoclimatic Region	Number of stations	Apr	Summer May	June	July	Aug	Sept	Oct	Winter Nov	Dec	Jan	Feb	Mar	Season[2] Summer	Winter	Year
Median Temperature (˚C)																
Low Arctic	2	-16a[3]	-4a	6a	10a	8a	2a	-8a	-19ab	-22ab	-24ab	-25a	-24a	4a	-23a	-9.9a
High Subarctic	3	-9a	3b	12b	14b	10b	4a	-9a	-22a	-23a	-26a	-24a	-20a	8b	-23a	-7.9a
Northern Cordilleran High Boreal	8	0b	7c	13bc	15c	12c	6b	-4b	-16bc	-20bc	-23b	-18b	-12b	10d	-17b	-3.4b
Northern Cordilleran Boreal	3	1b	7c	13c	15c	12c	6bc	-2c	-15c	-18c	-22b	-16b	-10bc	11d	-16b	-2.3c
Mid-Cordilleran Boreal	9	1b	7c	12b	14b	12c	7c	0d	-11d	-14d	-18c	-13c	-8c	10c	-13c	-1.1d
Mid-Cordilleran Alpine[4]	1	-2	4	9	11	9	5	-1	-10	-10	-14	-11	-9	8	-10	-1.5
	p	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.001	<0.001
Total Precipitation (mm)																
High Subarctic	3	8b	20a	43ab	52bc	53c	32a	30b	16a	20ab	13a	14a	11b	203b	84b	322b
Northern Cordilleran High Boreal	8	8ab	25b	42b	61c	41bc	30a	24ab	20a	21b	16ab	12a	10ab	208b	86b	324b
Northern Cordilleran Boreal	3	5a	22ab	31a	46ab	34ab	29a	20a	18a	16a	14a	10a	8a	177a	72a	279a
Mid-Cordilleran Boreal	9	5a	19a	32a	42a	38a	32a	25ab	21a	20b	22b	14a	9ab	169a	92b	306a
Mid-Cordilleran Alpine[4]	1	16	16	36	45	45	73	54	49	29	46	31	22	208	224	522
	p	0.001	<0.001	<0.001	<0.001	<0.001	0.810	0.001	0.008	0.011	<0.001	0.021	0.004	<0.001	<0.001	<0.001

[1] Only ecoclimatic regions with meteorological data were included in the summary.

[2] Summer is defined as May through September, and winter, as November through March. Summer included those months with median temperatures above 1˚C except in the Low Arctic, where temperatures were below 1˚C in May. April and October were considered seasonal transitional months.

[3] Ecoclimatic regions by time period followed by the same letter do not differ at $\alpha = 0.050$ based on Scheffé rank tests.

[4] Excluded from Kruskal-Wallis test.

sites (Fig. 6b), although it is classified as MCb and occurred along the Yukon–British Columbia border. Extensive areas of the MCs and MCa regions occurred close to the Swift River location; therefore, it might be subject to somewhat greater precipitation than other MCb areas.

DISCUSSION

The original intent of this study was to develop an ecologically based climatic zonation of Yukon based on vegetation, independent of any existing classification, using modified zonal site criteria. Once this zonation was compiled, however, a strong similarity was apparent with the Ecoregions Working Group (1989) classification based on the location and vegetation characteristics of the mapped polygons. The Rowe (1972) classification had broad similarities to Figure 2 at the forest region level. A weak resemblance to the Oswald and Senyk (1977) and the Ecological Stratification Working Group (1995) classifications occurred in part because physiography was excluded as a variable in the current classification. The effects of physiography and topographic variation were indirectly reflected in the ecological response of vegetation to changing local and regional elevation. Although these latter classifications recognized the existence of definable elevation-induced climate zones within "ecoregions," few were formally classified or mapped, nor were quantitative assessments done to identify climatic differences. Several differences occurred between Figure 2 and the Ecoregions Working Group (1989) classification. Beside greater mapping detail, these differences included (1) reclassification of the Alpine

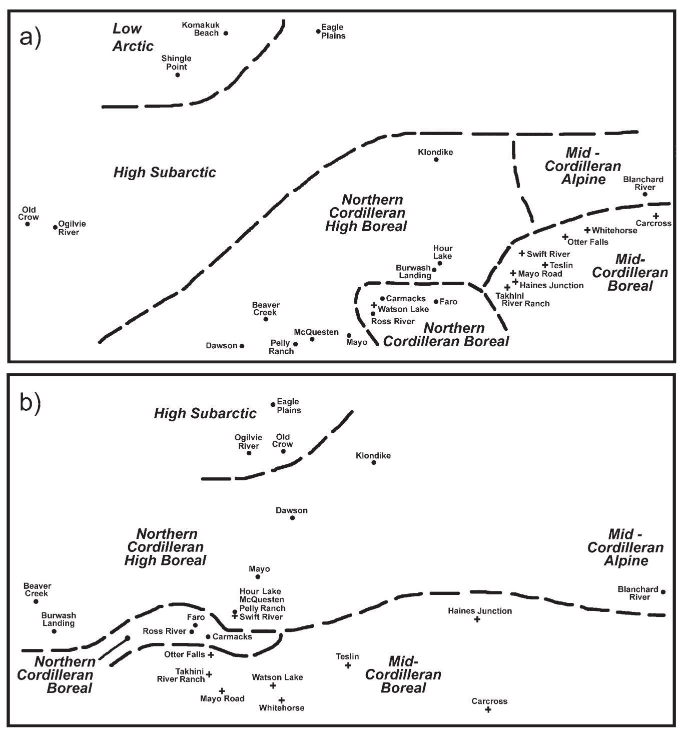

FIG. 6. Detrended correspondence analyses of a) monthly average temperatures and b) monthly total precipitation (1987–2007) based on 26 and 24 Yukon locations, respectively, and segregated by ecoclimatic region. Only ecoclimatic regions with adequate meteorological data were included in the analyses. Sites within the Mid-Cordilleran Boreal ecoclimatic region were indicated with a plus (+) symbol to facilitate the visual recognition of inconsistencies between the ecological (cf. Fig. 2) and meteorological data classifications.

Northern Subarctic Cordilleran or NSCa as LAa; (2) subdivision and reclassification of the original NCb as NCb and NCh; (3) northward expansion of the MCb from northern British Columbia; and (4) reduction in area of the MBs. Most importantly, quantifiable temperature and precipitation differences were identified among tested ecoclimatic regions.

Despite the occurrence of NNW–SSE trending mountains, latitudinal climatic zones were apparent in Figure 2, if elevation-induced ecoclimatic regions are overlooked: MCb → NCh → HS → LA (south to north). The LA and HS regions were comparable to those recognized by the Ecoregions Working Group (1989) in central and eastern Canada. The NCh region was compatible with the characteristics of the High Boreal (HB) ecoclimatic province on the basis of prominent *Picea mariana* with ericaceous shrubs and feathermosses on reference sites (Ecoregions Working Group, 1989). Although the MCb region occurred as a latitudinal band across southern Yukon (Fig. 2), it represented the northern limit of an extensive longitudinal transition zone between boreal and cordilleran flora along the eastern slopes of the Rocky Mountains from southwestern Alberta to the Yukon (Strong, 1992, 2002). It is also noteworthy that some elevation-induced regions occurred in more than one ecoclimatic province, usually as a northward extension beyond their primary area of concentration (e.g., MCs occurring in the Northern Cordilleran ecoclimatic province). The ecoclimatic diversity in the Yukon, based on amount of area per region, was greater than in Alberta (43 858 km^2 versus 50 860 km^2/region; Strong, 1992), but slightly less than in British Columbia (39 525 km^2/region; Ecoregions Working Group, 1989). British Columbia also had twice as many regions as the Yukon.

The recognized ecoclimatic regions (Fig. 2) are compatible with the vegetation biomes recognized in Alaska (Simpson et al., 2002: Fig. 11b, 2007:344) and subsequently supported by discriminant analysis modeling of climate and environment variables (Simpson et al., 2007:360). The only major difference was subdivision of the Alaskan boreal vegetation biome (also referred to as Subarctic; Simpson et al., 2007:343) into HS and NCh ecoclimatic regions in the Yukon. In some respects, the HS does represent a northward latitudinal continuation of the NCh, when based on vegetation composition, without regard to the physiognomy of the reference vegetation (i.e., stunted open-growing trees versus taller semi-closed tree stands). In support of this subdivision, some of the climatic parameters modeled by Simpson et al. (2002, 2007:347–349), particularly temperatures, tended to point toward a difference between the north and south portions of the Alaskan boreal vegetation biome along the Yukon border. Along the southern Yukon border, three biogeoclimatic zones have been recognized in British Columbia (Meidinger and Pojar, 1991): Alpine Tundra, Spruce–Willow–Birch, and Boreal White and Black Spruce. The Alpine Tundra zone encompassed the NPg, MCa, and NCa ecoclimatic regions, whereas the Spruce–Willow–Birch zone was equivalent to the MCs. The MCb and MBs regions were part of the British Columbia Boreal White and Black Spruce zone and would be recognized at a subzone level of classification (Meidinger and Pojar, 1991:241). Along the Yukon/Northwest Territories border, the majority of adjoining land south of 65.5˚ N consisted of alpine ecosystems (NWT Ecosystem Classification Group, 2010:4, 147). In the far south, the NCh region had vegetation similar to the NWT High Boreal and Mid-Boreal ecoregions (NWT Ecosystem Classification Group, 2010:134, 144). Land adjacent to the southeastern tip of the Yukon was not included in the 2010 NWT ecoregion classification. HS was recognized in the north on both sides of the border, except that the southern limit was considered part of the Low Subarctic region in the NWT. It was difficult to match the LA region in the Yukon with its equivalent in the NWT because of the north–south trending Richardson Mountains along the territorial boundary, but it appeared similar to the NWT Southern Arctic ecoregion in location and ecological characteristics (NWT Ecosystem Classification Group, 2010:4). In conclusion, the proposed Yukon ecoclimatic regions were comparable to the ecological units recognized in Alaska and British Columbia and similar to those in the NWT classification. These similarities occurred despite the use of different approaches to classification.

The appropriate construct of an ecological landscape classification system has been debated in North America since at least the late 1960s (e.g., the basis for Lacate, 1969; Orians, 1993; Bailey et al., 1985). At broad scales of classification, a dichotomy of approaches has developed in Canada. One approach is based on climate/vegetation zonation as the initial basis of landscape subdivision (e.g., British Columbia: Meidinger and Pojar, 1991; Alberta: Strong, 1992; Ontario: Mackey et al., 1996; Québec: Ministère des Ressources Naturelles, de la Faune et des Parcs, 2003), followed by subdivisions based on physiography and landscape patterns down to individual synecological types at increasingly larger scales of analysis. The two uppermost levels of classification are similar in concept to ecoclimatic province and ecoclimatic region. The other (aggregative) approach relies essentially on the simultaneous classification of very broadly defined climate zones and physiography features, referred to as ecozones and ecoregions (Oswald and Senyk, 1977; Ecological Stratification Working Group, 1995). Superficially, the latter approach might seem more comprehensive and ecologically holistic than just using climate as the initial criterion for landscape classification, but climatic zones are major ecosystems with different biological potentials that have developed in response to global circulation patterns and topographic variability. With respect to topographic variability, the critical factor is elevation change, rather than geologic origin or configuration. The aggregative approach may be viable in areas where the terrain is relatively simple, but from a hierarchical classification perspective, it results in the grouping of different climatic and ecological types (e.g., alpine + subalpine + boreal), and the taxonomic segregation of like ecosystems in mountainous areas (e.g., subalpine climatic zones with similar vegetation occur in both Yukon's Pelly Mountain and Southern Lakes ecoregions; Ecological Stratification Working Group, 1995). Even the inclusion of a new classification stratum above the ecoregion level (Marshall et al., 1999) does not appear to resolve these pragmatic concerns. The aggregative approach may be a convenient national and international administrative tool (Marshall et al., 1999; Hirvonen, 2001), but as currently designed, it will lead to the duplication of ecological landscape types at increasingly larger scales of analysis. Solving these problems might prove expensive if users must reconfigure major geographical information system databases to eliminate such taxonomic and ecological inconsistencies. As applied in Yukon, the aggregative approach (e.g., Oswald and Senyk, 1977; Ecological Stratification Working Group, 1995) provides a less ecologically meaningful perspective than a system that uses climate alone as the initial basis for landscape classification.

Successive approximation (*sensu* Poore, 1962) is a concept that is applicable to the development of ecoclimatic region classifications. It applies because the slow, sporadic, and spatially uneven accumulation of synecological data within a large geographical area often requires multiple iterations to develop a comprehensive classification. It would therefore be unrealistic to consider Figure 2 the final classification for the Yukon; rather, it is the next step. Future research might (1) challenge what was considered reference vegetation in an ecoclimatic region, (2) expand the ecocline sequences, (3) refine boundary locations, (4) subdivide regions (e.g., upper and lower HS and NCh), and (5) evaluate latitude-driven botanical and phytosociological differences within elevation-induced regions (such as the MCa and NCa) that occur in more than one ecoclimatic province. Without a regional context as a starting point for landscape analysis, little systematic progress will be made toward a comprehensive understanding and management of Yukon's ecological resources.

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