Reflections on the biogeoclimatic approach to ecosystem classification of forested landscape

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Abstract
The biogeoclimatic approach to ecosystem classification is unique in that it defines, albeit arbitrarily, an ecosystem, and draws from several of the European and North American schools of vegetation and environment classifications. Undisputedly, the classification has provided a predictive tool for foresters in British Columbia and has given impetus for developing similar classifications elsewhere. The aim of this classification system is to organize forest ecosystems according to relationships in climate, vegetation, site quality, and time. The system is vegetation driven and features three independent, but connected classifications: zonal, vegetation, and site. Site classification is a primary tool used for identifying quality of forest sites; furthermore, it provides a framework for accumulated, site-specific knowledge about ecological characteristics of plant species, sites, and ecosystems. As a result, the site classification supports a variety of stand- and forest-level decisions as well as forest productivity research.

Keywords
Ecosystem classification, biogeoclimatic, British Columbia, climate, vegetation, site quality, management decisions

Introduction

Among many classifications of forest landscapes devised in the last hundred years (e.g., Carmean 1975, Klijn, F. (ed.) 1994, Sims et al. 1996) only a few seem serving as a basis for management decisions. Even some of those classifications have not been successful in increasing ecological awareness among foresters and/or in improving management practices, because the users play a passive role in applying the classification (Jahn 1982, Kimmins 1977). In short, there is not an effective, common tool for understanding the ecosystems under management and predicting the consequences of management decisions. Some of the following factors may be responsible:

1. the object(s) of classification is undefined,
2. classification is based on either an environmental or vegetation approach,
3. the complex methodology involved limits the use of classification to experts, and
4. classification schemes are unable to account for a wide variety of ecological settings.

In our opinion, the biogeoclimatic ecosystem classification is one of few which survived the test of time and has been well serving forestry communities in British

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Columbia for over 30 years. The objective of this article is to highlight and outline some of the characteristics that lead to success, and to draw attention to some outstanding issues.

Wali (1988) summarized ecosystem studies carried out from 1950 to 1975 by Krajina and his students in British Columbia. Using these studies, Krajina (1969) presented not only a classification, i.e., biogeoclimatic ecosystem classification (BEC), but also a great deal of information on vegetation-environment relationships. Similar methodologies of data analysis facilitated synthesis of the results at the trans-regional (provincial) level. Next, new information was collected and interpreted by the Forest Service Ecological Program Staff and made available to foresters using the revised framework of the original classification given by Pojar et al. (1987). Since that time there have been only minor improvements in the concepts and system of the classification. A new approximation addressing the system and developing new interpretations are desired, in particular concerning stand dynamics.

The classification system

If the number and variation of ecosystems in a forest is large, we assemble individual ecosystems that are alike with selected characteristics. Classification produces classes of similar ecosystems through characterization and assigning names to the framed classes. All classifications require that the concept of what is to be studied (classified) be defined as different concepts (definitions) would result in different classifications (and confusion). Krajina (1965) adopted Sukachev's biogeocoenose (Sukachev and Dylis 1964) as a **local** ecosystem that is considered to be a landscape segment relatively uniform in climate, soil, vegetation, animals, and microorganisms. The physical environment (site, ecotope, or habitat) of an ecosystem is represented by climate and soil (including topography); the biotic community is represented by vegetation, animals, and microorganisms. Vegetation and soils form as a result of the integrated effects of climate, topography, parent materials, organisms, and time (Jenny 1941, Major 1951). As vegetation and soil are the principally studied ecosystem components they form the basis for the classification. A group of similar local ecosystems influenced by a particular regional climate represents a **regional** ecosystem.

Understanding forest ecosystems means understanding vegetation-environment relationships and vegetation succession. Therefore, a good classification should organize ecosystems in ways that show the greatest number of relationships in the most important properties. As ideas on organizing things or thoughts vary from one person to another, a good classification should display intellectual economy of thoughts. This means by using all available knowledge on the things studied, it classifies them in a way that is easily retained in memory and is easy to convey through instructions. These two pivotal tenets guided the development of the BEC system.

To show relationships among ecosystems in form, space, and time, the system organizes ecosystems at local, regional, and chronological levels of integration. As a result of the analysis and synthesis of vegetation and environment data, the system includes three independent but connected hierarchical classifications: vegetation, zonal (climatic) and site.

The purpose of the local integration level is to organize ecosystems according to similarities in the form (composition and structure) of vegetation and sites features. This task is accomplished in vegetation and site classification, respectively. The purpose of the regional integration level is to organize ecosystems according to similarities in their distribution in a climatic space. This task is accomplished in zonal classification. Using units of the vegetation and site classifications, the purpose of the chronological integration level is to organize ecosystems into site-specific chronosequences according to the type of disturbance and time.

Vegetation classification

Using modifications of the Braun-Blanquet approach (e.g., Mueller-Dombios and Ellenberg 1974, Whittaker 1980), vegetation classification organises local ecosystems according to similarities in the composition of plant species. Although floristic properties are used as differentiating characteristics, an implicit consideration is given to site characteristics to frame floristically as well as environmentally consistent units. Delineated vegetation units are arranged into a hierarchy based on the plant association and diagnostic combination of species (Table 1). The major departure from the Braun-Blanquet approach includes (i) a simplified nomenclature and (ii) no requirement for character-species, i.e., for the species that differentiate in an absolute sense among plant associations and higher units. In consequence, differentiation is relative and based on the criteria adopted for differential species that are associated with more than one vegetation unit in a hierarchy, with presence class >III (>41%) and at least two presence classes greater than in other units of the same category and circumscription (Pojar et al. 1987).

Table 1: *Example of vegetation classification for forested landscape of coastal British Columbia using the order category and simplified Latin nomenclature. The seven orders are arranged more or less according to ascending soil moisture and nutrients. Orders are most suitable for general instructions. Each order includes all ecosystems dominated by a shade-tolerant tree species capable of self-regeneration, except Populus trichocarpa order; coastal Pinus contorta is a non-serotinous species.*

1.	Quercus garryana
2.	Pseudotsuga menziesii – Mahonia nervosa
3.	Tsuga heterophylla – Rhytidiadelphus loreus
4.	Tsuga mertensiana
5.	Thuja plicata – Tiarella trifoliata
6.	Populus trichocarpa
7.	Pinus contorta

Although it is advantageous for the development of a stable classification to sample and study undisturbed, old-seral plant communities, where they are absent, the system can be developed for areas with disturbed vegetation, albeit with uncertainties about endpoints of vegetation succession. The study of disturbed ecosystems is necessary for understanding succession and the development of site-specific chronosequences, and vegetation management.

Climatic classification
Using the zonal ecosystems as defined by Pojar et al. (1987), zonal (climatic) classification identifies regional ecosystems and organizes them according to the distribution in the climatic space. The resulting zonal units summarize relationships between ecosystems and regional climate. The climatic space is chosen because climate is the most fundamental determinant of the nature of terrestrial ecosystems (Major 1951, 1963). Where possible, zonal plant associations are identified within the vegetation classification, thus forming a bridge between vegetation and climate and defining subzones. Each subzone has a characteristic pattern of ecosystems in a vegetation-inferred climatic space. Subzones may be differentiated into variants and aggregated into zones, regions, and formations (Table 2).

Table 2: *Example of zonal classification using the zone category. Each of the 14 zones of British Columbia has a distinctive climate. The zones are arranged around descending elevation, continentality, and temperature.*

Name	*Climatic type*
1. Alpine Tundra	alpine tundra
2. Spruce-Willow-Birch	cold continental subalpine boreal
3. Mountain Hemlock	maritime subalpine boreal
4. Engelmann Spruce – Subalpine Fir	cool continental subalpine boreal
5. Montane Spruce	mild continental subalpine boreal
6. Boreal White and Black Spruce	cold continental montane boreal
7. Sub-boreal Pine – Spruce	cool continental montane boreal
8. Sub-boreal Spruce	dry cold continental montane boreal
9. Bunchgrass	continental cool semiarid
10. Ponderosa Pine	dry continental cool temperate
11. Interior Douglas-fir	moist continental cool temperate
12. Interior Western Hemlock	wet continental cool temperate
13. Coastal Douglas-fir	dry mesothermal
14. Coastal Western Hemlock	wet mesothermal

The zonal concept occurs in the traditional ecological literature; although, without explicit and satisfactory definition. In areas with a long history of vegetation disturbance and scarcely occurring zonal sites, examination of topographic sequences or landscape pattern of ecosystems in tentative subzones could be used for differentiation (e.g., Damman 1979). Zonal classification can also be based on climatic data providing their availability for a large area in conjunction with vegetation criteria. Pyatt et al. (2001) used this approach in developing the ecological site classification in Great Britain.

Like the zonal concept, regional climate also evades an explicit definition. The resulting difficulties in differentiating between regional and local climates (i.e., in delineating subzones) typically in the areas of climatic localism, such as in subalpine-boreal (snowy) climates or between north- and south-facing slopes in cold or hot climates. The corollary problem concerns specification of the minimum area of a zonal unit.

Site classification

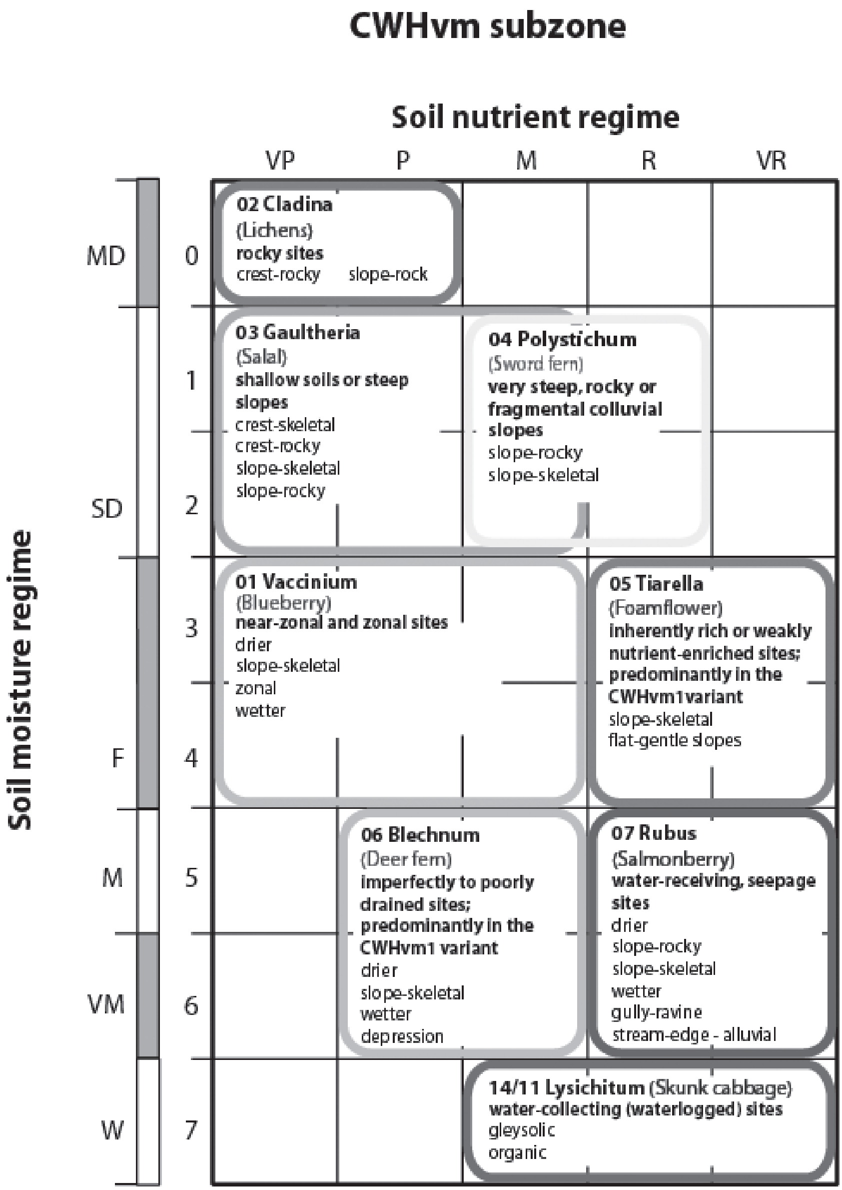
Both climate and soil are expressions of the combined effect of many individual environmental factors each, indirectly or directly, influencing vascular plants. Plants are dependent on light and heat (climate), soil moisture, soil nutrients, and soil temperature, which are all site factors with a direct influence on plants (Pogrebnyak 1930, Major 1963, Bakuzis 1969). Ecologically-equivalent sites are those that have similar site quality or the same combination of direct environmental factors.

Local ecosystems are organized according to similarities in site quality using climate, soil moisture, and soil nutrients as differentiating characteristics, regardless of the vegetation present on the site. A combination of these environmental properties defines the quality of a site. Site associations, as basic units, may be differentiated into site series and phases and aggregated into site groups. Independence from vegetation is the major cause for site units to be selected for ecosystem identification and many management interpretations.

When the vegetation and zonal classifications are developed, the plant associations that are ecologically equivalent, i.e., that have similar site quality, vegetation, and productivity potentials (Cajander 1926, Bakuzis 1969) are used to delineate each site association. This transformation of one or more plant associations into a single site association is possible owing to available environmental data for each plant association. The site association is conceptually similar to the forest type of several European classifications (e.g., Jahn 1982) and to the habitat type of Daubenmire (1968).

The essential part of site classification is the edatopic grid (Pogrebnyak 1930) – a two-dimensional ordination of selected soil gradients. Instead of gradients, the BEC system uses two ordinal classes: soil moisture regimes (SMRs) and soil nutrient regimes (SNRs). A variety of grid designs have been used by ecologists to display relations among plant species or plant communities to chosen environmental gradients (e.g., Bakuzis 1969, Krajina 1969, Mayer 1977, Arbeitskreis Standortskartierung 1978, Whittaker 1978, Ellenberg 1988, Pyatt et al. 2001, Klinka et al. 2002) (Table 3).

Table 3: *Example of site classification showing an edatopic grid for the very wet maritime (vm) subzone of the Coastal Western Hemlock (CWH) zone using the site series category and simplified Latin nomenclature (generic common names are in parentheses). The grid displays eight forested site series sites occurring within the UBC Malcolm Knapp Research Forest in relation to soil moisture and nutrient regimes. Edaphic adjectives listed for each site series designate phases indicating encountered topographic and soil variations.*



Adopting Hills's (1952) suggestion in addressing problems of climatic localism, three edatopic grids could be considered for many subzones instead of one main grid. The first grid would portray the ecosystems influenced by 'normal' local climate; the second grid, the ecosystems influenced by 'cooler' than normal climate; and the third grid, the ecosystems influenced by 'warmer' than normal climate.

Soil moisture regime, defined as the average amount of soil water annually available for evapotranspiration by vascular plants over several years, is used in relative and actual sense. Krajina (1969) used nine relative SMR classes and applied them consistently in different climates to show variations of forest productivity of major tree species in relation to the pattern of vegetation units. A subjective synthesis of soil properties and indicator plants has been used to infer the nine relative SMRs of forest sites; however, in arid and humid climates this number may be excessive and may not reflect real soil moisture patterns. Most importantly, relative SMRs do not inform about actual soil moisture conditions as the relationship between relative and actual SMRs varies with climate.

Klinka et al. (1984) proposed a quantitative classification of actual SMRs based on annual water balance (Thornthwaite 1948) and vascular plant activity (Major 1963, 1977). They used the occurrence and duration of phases of water use, complemented by the ratio between actual and potential evapotranspiration (AET/PET), and the occurrence, depth, and dynamics of the water table, to differentiae among nine actual SMRs. As a result, it was possible to establish relations between relative and actual SMRs in any climate. However, further studies of vegetation-soil moisture relationships in different regions are necessary to account for the ecological significance of soil water in relation to soil temperature, aeration, and nutrient availability.

Soil nutrient regime, defined as the amount of essential soil nutrients that are available to vascular plants over a period of several years, is also used in both relative and absolute sense. Krajina (1969) used six SNR classes and applied them in different climates and for different soil moisture conditions. A subjective synthesis of soil properties and indicator plants was used to infer the actual SNR of forest sites. However, similar to relative SMRs, there were inconsistencies in identifying relative SNRs in areas with different soil parent materials; for example, rich sites in granitic landscapes were deemed poorer than those in volcanic landscapes.

Several studies attempting to quantify SNRs across British Columbia (Courtin et al. 1988, Kabzems and Klinka 1987a & b, Klinka et al. 1994, Chen et al. 1998, Splechtna and Klinka 2001) showed that mineralizable-N in the upper mineral soil layer is the most useful measure of easily available plant nitrogen and in characterizing SNRs. These studies, however, did not account for nutrient availability in non-glaciated, residual soils, such as calcareous, alkaline, and saline soils. Intricate relationships among climate, topography, soil, and organisms complicate evaluations of SNRs and as a result the quantitative characterization of SNRs remains inadequately developed. Some of the uncertainties include (i) appropriate analytical methods for determining the amounts of available soil nutrients, (ii) determining external input of nutrients by laterally moving ground water, and (iii) quantifying the nutrient uptake facilitated by mycorrhizal fungi (Courtin et al. 1988).

Site-specific stand dynamics

Any plant community that develops in a particular site depends on its characteristics, disturbance type, chance, and time (Chen and Popadiouk 2002). Consequently, a number of different plant communities may occur through time on the same site. To show the relationship among ecosystems in time, site-specific chronosequences of plant associations are construed to describe vegetation succession (dynamics) for a particular site unit. This is done by assigning the plant associations with the same equivalent site quality to a particular site association which in turn provides a site-specific framework for arranging plant associations according to disturbance and/or treatment, and succession status along the chronosequence. With minor exceptions (Klinka et al. 1985, Hamilton 1988), site-specific chronosequences have not been yet developed in British Columbia.

Relations of the classification to management

Due to management activities manipulating ecosystems, an ecosystem-specific approach is suggested as a best practice. In turn, a forest that consists of many different ecosystems needs to be stratified into ecologically uniform segments. When it is stratified, management of the forest can be simplified while at the same time providing a sound ecological foundation. A consistent and ecologically meaningful stratification requires an appropriate classification system.

We consider the biogeoclimatic ecosystem classification to be a right tool for ecosystem-specific management and ecosystem studies. It serves as a predictive tool to support a variety of stand- and forest-level decisions. The stand-level decisions are related to specific vegetation, zonal, or site unit; the forest-level decisions are based on a matrix applicable to the units over the whole region. The ways in which the classification is adapted for, and used by, resource managers were described by MacKinnon et al. (1992).

The classification provides for portability of experience and research by integrating our contemporary understanding of vegetation-environment relationships and forest succession. Portability is based on the presumption that similar ecosystems will respond in the similar way to the same disturbance or treatment. Predictions are based on the presumption that each plant species is adapted to a certain range of environmental conditions, and each species will grow and respond in ways that depend on the sites or ecosystems in which it grows. Fortunately, much information about the ecological characteristics of plant species, sites, and ecosystems has come from ecosystem studies used to develop the classification.

One of the most important keys to a successful application of the classification is the user's ability to identify in a consistent manner the quality of forest sites, i.e., site units. Identification is based on a synthesis of topographic, soil, and plant indicator species data. A variety of aids for site identification are provided in field guides, all sharing edatopic grids of site series for a particular subzone. Field guides also contain selected predictions and interpretations concerning silviculture (e.g., brush hazard, site preparation including sensitivity to fire, tree species selection, stock type, stocking standards, stand tending such as tree species- and site-specific fertilisation decision-making, and reproduction methods), range, recreation, and wildlife.

The major contributions to site identification and silvicultural decision-making are: (i) identifying plant species that could be used as indicators of climate, soil moisture, soil nutrients, ground surface materials, or special edaphic conditions (Klinka et al. 1989), (ii) devising humus form classification (Green et al. 1992), and (iii) proposing criteria for tree species selection (Klinka and Feller 1984).

Relations of the classification to forest productivity research

The site classification is also used as framework for forest productivity studies. The most important research focus was on was quantifying forest productivity-site quality relationships. The paradigm adopted for this work came from recognizing the environmental determinants of forest productivity and knowledge of the importance of productivity itself.

Height growth and site index models were developed for several crop tree species for which there were no local data, only imported models from outside the province. The models for Douglas fir (Carter and Klinka 1990, Klinka and Carter 1990); Pacific silver fir (Splechtna and Klinka 2001); subalpine fir, Engelmann spruce, and lodgepole pine (Chen and Klinka 2000, Klinka and Chen 2003); western larch (Brisco et al. 2002); trembling aspen (Chen et al. 1998, Chen et al. 2002; Nigh et al. 2002); western hemlock (Kayahara et al. 1994, Kayahara and Schroff 1997); white spruce (Wang et al. 1994, Wang and Klinka 1995); and black spruce (Nigh et al. 2002) provided the means for more accurately predicting potential forest productivity and growth and yield of natural and managed stands in the provincial forest.

Potential application of the biogeoclimatic approach to forested landscapes of Ireland

It may appear to the reader that the biogeoclimatic approach has no or limited application to Ireland which features ecosystems with a long history of disturbance and plantations of non-native tree species. It is our firm belief the approach can be applied, albeit with some modifications as done by Pyatt et al. (2001), who developed the ecological site classification for forestry in similarly disturbed landscapes of Great Britain.

Instead of vegetation, the classification approach in Ireland is to be environmentally driven. A preliminary stratification of climate, soil, and vegetation is developed through field reconnaissance and review of pertinent resource information (e.g., climate data, forest cover maps, geology, landform, and soil reports).

Zonal classification could be derived from multivariate analysis of long-term climatic records, corroborated by examination of topographic sequences, in conjunction with soil data and floristic records as suggested by Damman (1979).

On each sample plot, vegetation and environment data are collected; however, the emphasis of data collection and analysis is placed on developing soil moisture and nutrient regime classifications in order to conceptually simplify the physical environment (site) of each local ecosystem into three main elements: climate, soil moisture, and soil nutrients. As a result, local ecosystems will be organized in site classification according to similarities in site quality using climate, soil moisture, and soil nutrients as differentiating characteristics regardless of the vegetation present on the site.

Conclusions

The application of biogeoclimatic ecosystem classification in British Columbia over the past 30 years has resulted in an increased ecological awareness among foresters and improved forest management practices. Foresters now have an effective tool for understanding the ecosystems they manage and are able to predict the consequences of their decisions. Using the framework provided by the classification, results of research and operational trials can be successfully extrapolated to other areas.

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