SIBEC First and Second-generation Approximation Estimates: backgrounder

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Contents

Site Index Estimates by Site Series (SIBEC):
First and Second Generation-type Approximation Estimates
For Tree Species
In British Columbia

1 INTRODUCTION

British Columbia's Biogeoclimatic Ecosystem Classification (BEC) system organizes our knowledge of ecosystems and provides a framework within which to manage forest resources. This classification system has served as a foundation for forest management decisions for more than 30 years. Since the 1990s, foresters and scientists recognized that correlating BEC site factor information with measures of site productivity, or site index (SI), would greatly enhance our ability to manage certain forest stands. Since 1994 the SIBEC Project (EP1215) has worked to provide tree species site index estimates that reflect the average growth potential of tree species in forested site series in British Columbia. Data are collected to refine these relationships as First Approximation site index class estimates are replaced by second generation-type estimates.

This document provides background information for the first and second generation-type approximation site index estimates for tree species according to site units of the Biogeoclimatic Ecosystem Classification system of British Columbia. The estimates are presented in tabular form in two downloadable reports.

The background information consists of seven sections. Following this introduction, Section 2 explains the basics of site index. In Section 3, the general relationships between site index and site factors are discussed. Section 4 provides a summary of the methods used to generate the First Approximation and second generation-type site index estimates presented in the two reports. Section 5 outlines the content and format of the report tables. Section 6 explains how to use the tabular information presented in each report to estimate site index in the field. References to literature cited in this document are provided in Section 7.

Both reports are available in PDF format and as a downloadable Microsoft Excel file. The first "Site Index-Site Unit Report by Region" provides a compilation of site index estimates by biogeoclimatic unit for each forest region. The second "Site Index-Site Unit Report by Biogeoclimatic Unit" displays site index estimates by site series for each biogeoclimatic subzone/variant.

The site index estimates provided in these reports are currently a blend of First Approximation and second generation-type estimates. As new data are added to the provincial data warehouse, the proportion of second generation-type estimates will increase.

2 SITE INDEX EXPLAINED

Site index is the most common measure of forest site productivity and forest growth used in British Columbia. These estimates of site productivity serve as an important baseline for forest-level planning and help to formulate silviculture strategies.

2.1 What is Site Index?

For a particular target species, site index is the height of the largest diameter (at breast height) site tree on a 0.01 ha plot at breast height age 50, provided the tree is suitable. A suitable site tree is a vigorous dominant or co-dominant tree that has a full crown and a straight, disease-free, undamaged stem. It is free of suppression above breast height, is not repressed, and is not a wolf, open-grown, or veteran tree.

2.2 Why is Site Index Important in Forest Management?

Site index provides a numeric description of site productivity that enables forest managers to predict forest stand growth and the yield of timber at harvest.

Estimates of site index are important in the following areas of forest management.

- Silviculture: to describe site quality, formulate prescriptions, schedule and rank treatments, and predict stand growth and yield.
- Timber supply analyses: to estimate years to green-up, the size of the operable land base, the minimum harvestable age, the yield of regenerated stands, and the growth of existing stands.
- Inventory: to describe site quality and project inventory volume growth.

Site index allows the comparison of productive potential between sites across a broad range of existing stand conditions. For example, a stand of Douglas-fir that is taller at breast height age 50 than another similar-aged stand of the same species will have a higher site index. It should achieve a greater timber volume, and therefore be more productive, than the stand with the lower site index.

As measures of site productivity, these estimates influence timber supply analyses and the Chief Forester’s decisions on allowable annual cut. By allowing forest managers to predict the outcome of a particular forest practice, site index estimates are also important inputs to land-use decisions and analyses of silviculture investments.

2.3 What Tools are Available to Measure Site Index?

For many stands, more than one acceptable way exists to estimate site index. The methods either involve “direct” measurement of site trees and the subsequent calculation of site index, or the “indirect” estimation of site index from various site factors. These two types of methods differ both in their suitability for different stand conditions and their accuracy.

The most common site index estimation tools available in British Columbia involve the use of models—mathematical equations that allow one attribute to be estimated from other attributes (e.g., in growth intercept models, site index is estimated from height and breast height age). The three models briefly described here are each suited to specific stages of stand development (see Figure 1).

Height–age Models: Also known as site index models, or curves, the primary purpose of these models is to describe height development over time for different levels of site index. These models also allow estimates of site index from height and breast height age data. Each tree species requires a different model because height growth characteristics are not the same for all species. This method is best used for stands that have between 50- and 140-years growth above breast height.

Growth Intercept Models: These species-specific models are designed explicitly for young stands (5–50 years breast height age). The growth intercept technique estimates site index from the average annual height growth of site trees, which is determined either from the distance between annual branch whorls or from the height and breast height age of the tree.

Site Index–Biogeoclimatic Ecosystem Classification (SIBEC) Models: This comprehensive tool correlates site index with site series within biogeoclimatic ecosystem classification (BEC) units and site series. The BEC system is designed specifically for British Columbia's ecosystems. This model is best used for very young stands, very old stands, and stands not suitable for other methods.

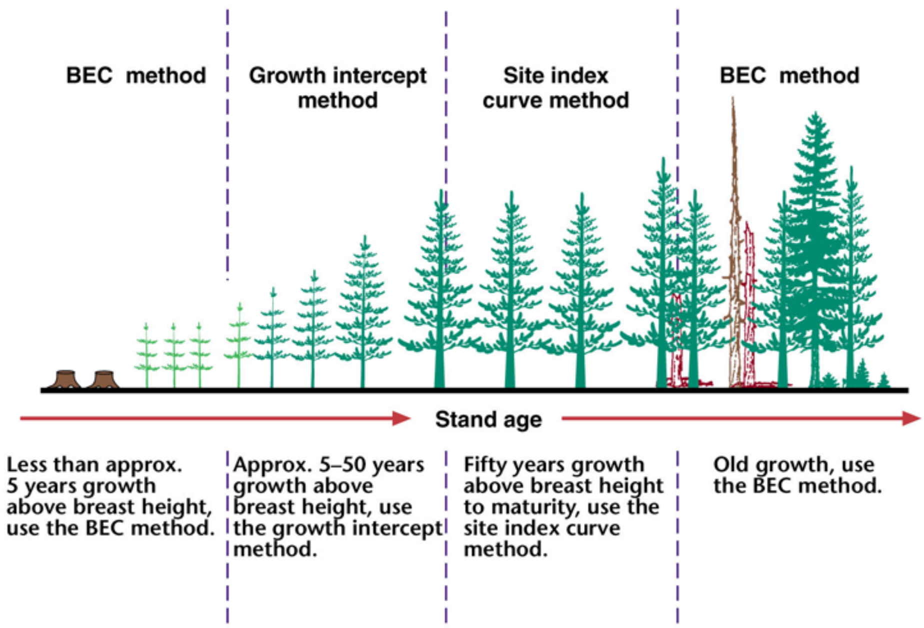

FIGURE 1. Site index methods used at various stand ages. The use of any of these methods depends on the type and quality of the available data.

Other site index tools currently in use, or being developed for use, within British Columbia include:

- *Species Conversion Models:* Estimate the site index of one species from that of another species in a mixed stand.
- *Old Growth Site Index (OGSI) Adjustments:* Estimate site index for a regenerated stand from an adjusted site index of an old-growth stand.

3 RELATIONSHIPS BETWEEN SITE INDEX AND SITE FACTORS

The biogeoclimatic ecosystem classification (BEC) system organizes our knowledge of ecosystems and serves as a framework within which to manage resources. It helps to divide landscapes into ecologically uniform segments at various levels of integration (regional, local, and chronological) and generalization (climatic, or “zonal,” vegetation, and site). At the local level of integration, landscapes are stratified using vegetation and soils information into vegetation and site units (i.e., site series and site associations).

A narrow range of environmental conditions or an “environmental gradient” distinguishes each site series. This gradient will usually provide distinct growth potentials for a given tree species over a fixed time period.

Tree growth is influenced by various site factors, which taken together, determine the site’s quality. These growth, or site, factors include climate (light and temperature) and soil moisture, nutrients, and aeration. In general, the potential tree growth, or site index, is greatest on moist sites and increases with soil fertility.

It is possible to use a simple equation to highlight the functional relationships between site index and site factors:

$$\text{site index} = f\,(\text{temperature, soil moisture, and soil nutrients})$$

On sites where these site factors are in balance, trees grow well and site index is higher; on sites where these factors are in excess or are deficient, trees grow less well and site index is lower. However, the site index of a species varies between biogeoclimatic units and the precise relationship is not always clear based on any single variable. The influence of climate or soil moisture or soil nutrients on site index is most likely a result of the interaction of site factors.

In this section, some relationships between site index and site factors are examined. The presence of these relationships has been documented for several species and sites (e.g., Green *et al.* 1989; Carter and Klinka 1990; Klinka and Carter 1990; Wang *et al.* 1994a, 1994b; Wang and Klinka 1995; Wang and Klinka 1996; Kayahara and Pearson 1996; Splechtna 2001).

3.1 Biogeoclimatic Units and Site Index

Biogeoclimatic units—biogeoclimatic subzones and their variants —represent groupings of contiguous ecosystems influenced by a discrete regional climate. Because climate is the most important determinant of plant growth, the site index for a given species will most likely vary from climate to climate or from subzone to subzone.

The effect of climate on site index is best detected by comparing site index on zonal sites between different subzones. For example, Douglas-fir site index shows a reasonably positive relationship with increasing precipitation in the selected sequence of Coastal Douglas-fir (CDF) and Coastal Western Hemlock (CWH) biogeoclimatic units; however, the relationship to the selected temperature variables is not as strong (see Table 1).

Table 1. Summary of selected climate data (average of stations) and estimated Douglas-fir (Fd) site index on zonal sites for some southern coastal biogeoclimatic subzones

SUBZONE[a]				
Variable	**CDFmm**	**CWHxm**	**CWHdm**	**CWHvm**
Mean annual precipitation (mm)	966	1603	1823	2787
Mean summer precipitation (mm)	170	293	384	577
Mean annual temperature (°C)	9.7	9.2	9.8	8.2
Accumulated degree days < 0°C	33	58	50	109
Accumulated degree days > 5°C	1929	1875	2050	1627
Fd site index (m @50 yr bh)	23.5	30.3	32.6	34.8

[a] Subzone abbreviations: CDFmm = Coastal Douglas-fir moist maritime; CWHxm = Coastal Western Hemlock very dry maritime; CWHdm = Coastal Western Hemlock dry maritime; CWHvm = Coastal Western Hemlock very wet maritime.

3.2 Soil Moisture and Site Index

In general, site index increases from water-deficient to moist sites and decreases from moist to wet sites. This trend is demonstrated for lodgepole pine and interior spruce using results from Kayahara *et al.* (1996) in Figure 2.

In this example, statistical analysis indicated the presence of a strong productivity gradient that coincided with the assumed soil moisture gradient. The mean site index of the study species increased from very dry to fresh sites, reached a plateau on moist sites, and then decreased from moist to wet sites (Figure 2). The highest mean site index of any study species always occurred on sites with no water deficit or surplus during the growing season. The lowest site index always occurred on very dry or wet sites.

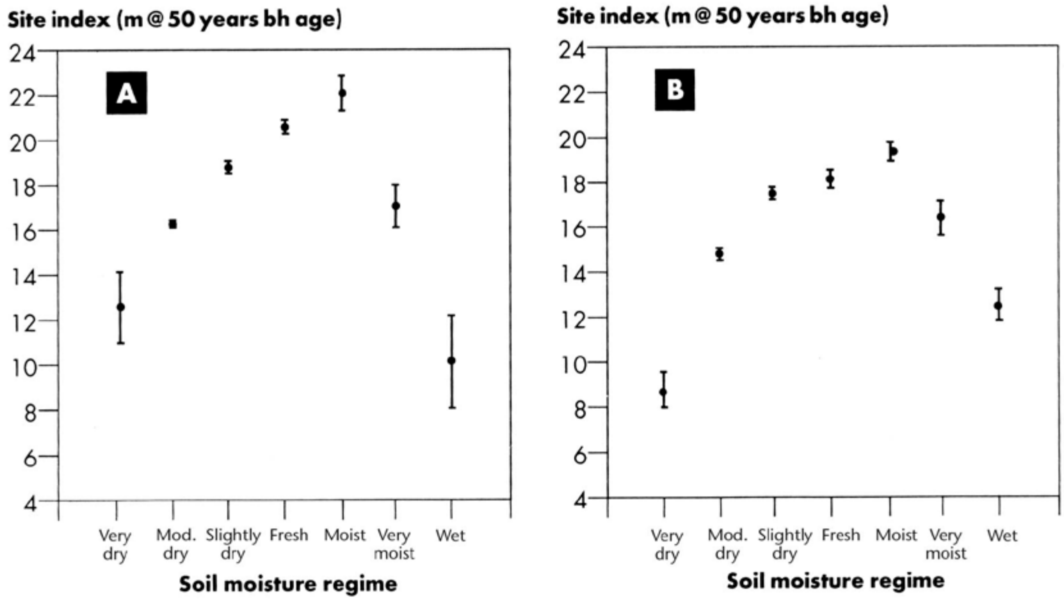

Figure 2. Categorical plots of lodgepole pine (A) and interior spruce (B) mean site index for Sub-Boreal Spruce zone stands on nutrient poor and medium sites according to actual soil moisture regimes. Vertical bars represent ±1 standard error.

3.3 Soil Nutrients and Site Index

Site index usually increases with an increasing supply of available soil nutrients, particularly nitrogen. This trend is demonstrated for lodgepole pine and interior spruce using results from Kayahara *et al.* (1996) in Figure 3.

In this example, a strong productivity gradient was evident that coincided with the assumed soil nutrient gradient. The mean site index of all study species increased consistently from very poor to very rich sites (Figure 3). The highest site index for all species always occurred on sites very rich in nitrogen.

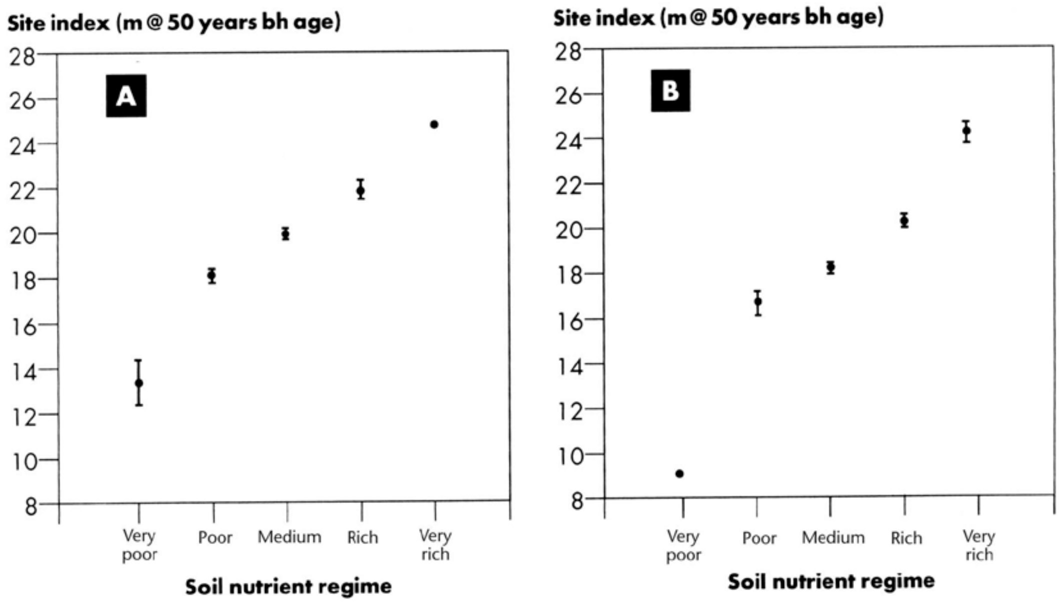

Figure 3. Categorical plots of lodgepole pine (A) and interior spruce (B) mean site index for Sub-Boreal Spruce zone stands on slightly dry and fresh sites according to soil nutrient regimes. Vertical bars represent ±1 standard error.

3.4 Integrating Site Factors and Site Index

The combined effect of soil moisture and nutrients on site index for a given climate or group of similar climates (subzones, or a group of climatically similar subzones) is most effectively displayed on the edatopic grid (Figure 4). Each cell (edatope) on the grid represents a group of sites with a very narrow range in soil moisture and nutrient conditions. Under any soil nutrient conditions, the site index of most species generally increases from very dry to moist sites and then decreases from moist to wet sites. Under any soil moisture conditions, site index generally increases from very poor through very rich sites.

This general trend is demonstrated for western hemlock in Figure 4. The site index estimates presented are for the most common, diagonal sequence of edatopes—slightly dry to moist and poor to rich.

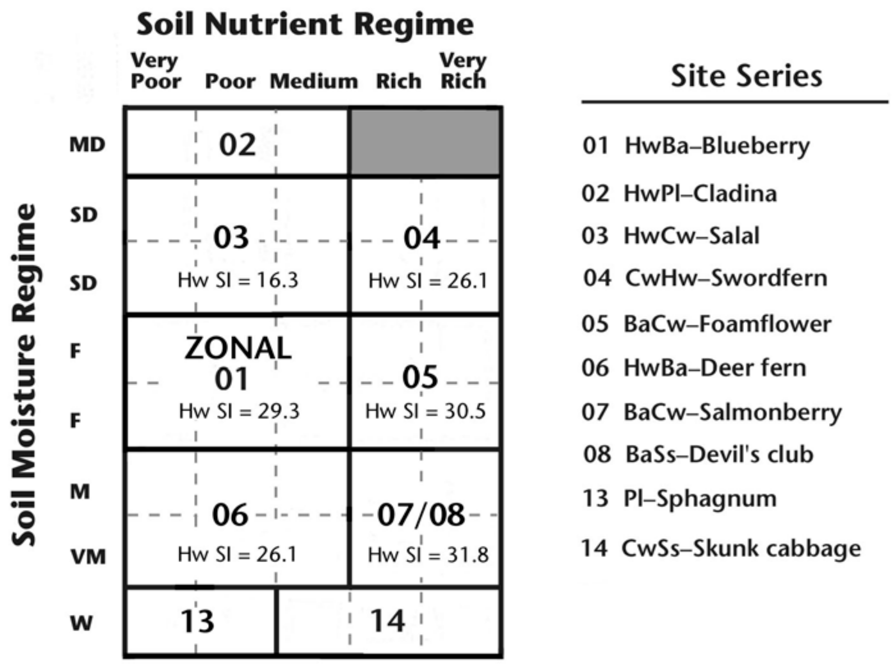

Figure 4. Edatopic grid for the Submontane Very Wet Maritime variant (CWHvm1) of the Coastal Western Hemlock zone. Mean site index is given for western hemlock (Hw).

3.5 Tree Species and Site Index

Broad similarities exist in the relationships between average site index and biogeoclimatic unit and edatopic grid position among tree species. However, within this broad, general pattern of similarities, important differences are also evident between species. These differences arise because species respond differently to a given combination or level of growth factors.

A typical example is provided in Figure 2. Average site index for both lodgepole pine and interior spruce increases with increasing soil moisture. However, the site index for pine is greater than for spruce on very dry to moist sites. On very moist and wet sites, the difference is less pronounced. Figure 3 shows the average site index of both species responding similarly to soil nutrients—again with pine showing a consistently higher site index.

4 PROCEDURES USED TO PRODUCE SIBEC APPROXIMATION ESTIMATES

The provincial SIBEC database was initially compiled in 1994–5 (Thrower *et al*. 1995), and the first approximation estimates of site index by site unit were completed and published in 1997 (B.C. Ministry of Forests 1997). At the time these estimates were released, they were considered the best available for the Biogeoclimatic Ecosystem Classification (BEC) site series and species combinations. At that time, the model developers realized that the accuracy and precision of these estimates would improve over time through a process of continued data acquisition and refinements to the analysis tools. The following points describe these refinements and the procedures used to generate the subsequent set of SIBEC approximations.

- SIBEC data and sampling standards were developed in 1997. These standards have received subsequent revisions and the most recent set of standards (version 5.3) came out in September 2009 (B.C. Ministry of Forests Site Productivity Working Group 2001).
- After 1995, new data were collected for the provincial SIBEC data warehouse, a central repository for ecological and mensuration data. These data came from work carried out on Tree Farm Licenses, Innovative Forest Practices Agreement lands, Permanent Sample Plots, and other projects. In 2000-01, the SIBEC data warehouse was re-designed and modelled to efficiently store and retrieve all data fields. A modified VENUS data model and application was developed for data entry, management of SIBEC plot data.
- In 2001–02, a SIBEC administrator analysis tool was designed and developed to create a SIBEC Reporting Data Mart (RDM). The RDM obtains specific data from the SIBEC data warehouse to complete mean site index calculations for each BEC site series/tree species combination. This process allows the generation of the site index–site series (SISU) reports by region, biogeoclimatic unit, and site association. If enough new data are available, these reports may be updated annually. After each update, the previous SIBEC RDM will be archived.
- The following methodology is used for analysis and reporting of new approximation estimates:
    - New data are added to the provincial SIBEC data warehouse. Site index is calculated for all plots with available data. Mean plot site index and its standard error are calculated for each BEC site series/species combination with a minimum sample size of 7.
    - A comparison report is generated for those BEC site series/species combinations that had changes in their mean site index over the first approximation set of estimates. These are reviewed by the SIBEC administrator and regional ecologists.
    - The mean site index and standard error are reported for those BEC site series/species combinations with a minimum sample size of 7. This new estimate replaces the first approximation estimate. Otherwise the first approximation site index class estimates are retained for the new approximation reports.

What are the main differences between the first approximation and the subsequent approximations?

- Improved accuracy: The second generation-type site index estimates in the subsequent approximations are obtained through the addition of new data collected following the revised SIBEC data and sampling standards for ecological and site tree data. In addition, previously collected data were reviewed, and those data not meeting the current collection and sampling standards were removed from the database.
- Increased precision: First approximation site index reliability ratings are replaced by the mean site index and standard error of the mean, and the estimates are reported if they meet a minimum sample size of 7.
- Expanded coverage: Site index estimates for some hardwood tree species are also included.

5 CONTENT AND FORMAT OF THE SITE INDEX-SITE UNIT REPORTS

The two site index reports provide estimates of average site index by site unit for tree species in British Columbia. These reports group the site index estimates by region and by biogeoclimatic unit.

5.1 Content of the Site Index-Site Unit Reports

Where a given tree species is present within the site series, a mean site index estimate is given along with its associated standard error and the number of sample plots on which the site index data are based. For those site series that do not meet the minimum sample size, they retain their first approximation site index class mid-points (see Table 2). Therefore, the estimates provided in the reports include:

- second generation-type site index estimates (mean site index and standard error of the mean) and
- first approximation site index class estimates.

See Section 4 for more information about these two types of estimates.

Table 2. Site index classes used in site index-site unit reports

Coast[a]		Interior[b]	
Site index	**Site class**	**Site index**	**Site class**
0.0–5.9	4	0.0–4.4	3
6.0–9.9	8	4.5–7.4	6
10.0–13.9	12	7.5–10.4	9
14.0–17.9	16	10.5–13.4	12
18.0–21.9	20	13.5–16.4	15
22.0–25.9	24	16.5–19.4	18
26.0–29.9	28	19.5–22.4	21
30.0–33.9	32	22.5–25.4	24
34.0–37.9	36	25.5–28.4	27
38.0–41.9	40	28.5–31.4	30
42.0–45.9	44	31.5–34.4	33
46.0–49.9	48	34.5–37.4	36
50.0–53.9	52	37.5–40.4	39

a CWH, CDF, and MH zones
b All other zones

In general, site index class estimates use 3-m classes, with the exception being the Coastal Western Hemlock (CWH), Coastal Douglas-fir (CDF), and Mountain Hemlock (MH) zones, where 4-m classes are used. Classes were used for first approximation estimates to dampen some of the inherent variability in the raw data, make it easier for experts to verify and adjust the regression estimates if required, and to suggest to users an approximate level of precision.

5.2 Format of the Site Index-Site Unit Reports

In the Site Index-Site Unit Report by Region, the tables for biogeoclimatic subzones and variants (BGC units) are indexed alphabetically by forest region and BGC units. There is one table for each forested BGC unit in the region.

Each regional BGC unit table contains a data column for each coniferous tree species occurring in the unit and a row for each of the reported site series. Point estimates of mean plot site index are accompanied by the associated sample size and the standard error. Site index class estimates are also included in this report (see Figure 5). Most non-forested site series (wetlands and grasslands) are excluded.

Figure 5. The tabular format of the Site Index-Site Unit Report by Region.

Vancouver CWHvm1

Site Series(*)	Name	Ba			Cw			Fd			Hw			Ss		
		#	si	se	#	si	se	#	si	se	#	si	se	#	si	se
01	HwBa - Blueberry	28	26.8	0.5	15	21.4	0.5	20	35.8	0.4	90	29.3	0.2	14	29.0	0.6
02	HwPl - Cladina					8.0			8.0		5	8.0	0.7			
03	HwCw - Salal				2	14.4	1.5	14	30.0	0.7	9	16.3	0.9			
04	CwHw - Sword fern	2	22.2	1.4	7	21.5	0.8		32.0		6	26.1	1.1	3	22.8	0.8
05	BaCw - Foamflower	23	29.8	0.4	7	22.0	0.7	17	38.0	0.5	35	30.3	0.4	25	31.0	0.5
06	HwBa - Deer fern	3	21.4	1.7	5	17.2	1.0				23	26.1	0.6	4	27.4	1.6
07	BaCw - Salmonberry	13	26.3	0.6	7	21.3	0.8				43	31.8	0.4	11	32.7	0.8
08	BaSs - Devil's club		28.0			24.0						28.0			28.0	
09	Ss - Salmonberry		28.0			24.0						28.0			28.0	
10	Act- Red-osier dogwood		28.0			24.0									32.0	
12	CwYc - Goldthread					12.0						16.0				
13	Pl - Sphagnum					8.0										
14	CwSs - Skunk cabbage					20.0						20.0		2	35.0	2.8

In the Site Index-Site Unit Report by Biogeoclimatic Unit, the tables are indexed alphabetically by biogeoclimatic subzones and variants (BGC units) and numerically by site series associations.

The Report by Biogeoclimatic Unit contains both mean plot site index estimate and site index class estimates. The site series data summary provided includes tree species abbreviations, sample size, mean site index and its standard error (see Figure 6).

Figure 6. The tabular format of the Site Index-Site Unit Report by Biogeoclimatic Unit.

				Site Series Summary		
BGC Unit	Site Series	Site Association	Species	Sample Size	Mean Site Index	Standard Error
CWHvm1	01	HwBa - Blueberry	Ss	14	29.0	0.6
CWHvm1	01a	HwBa - Blueberry, Mineral	Ba	25	30.0	0.4
CWHvm1	01a	HwBa - Blueberry, Mineral	Cw	12	21.8	0.6
CWHvm1	01a	HwBa - Blueberry, Mineral	Hw	31	26.6	0.3
CWHvm1	01a	HwBa - Blueberry, Mineral	Ss	24	31.0	0.4
CWHvm1	02	HwPl - Cladina	Hw	5	8.0	0.7

6 USING THE SIBEC MODEL TO ESTIMATE SITE INDEX IN THE FIELD

When required to estimate the site index for a selected species, several methods are often appropriate. These methods differ in their availability throughout the province, their suitability for different stand conditions, and their accuracy. The BEC method is appropriate where:

- stand conditions are unsuitable for using growth intercept or site index curve methods (see Figure 1), and
- a correct site identification of the area can be obtained.

Where sample tree conditions are suitable, careful use of either the growth intercept or site index curve methods is generally more accurate than the BEC method. Frequently though, stand conditions are unsuitable for these methods as, for example, in the situations listed below. Under each of these circumstances the BEC method is preferred.

- uneven-aged stands
- very old stands (age class 8 and 9)
- stands where sample trees are very large or rotten at breast height
- stands where many sample trees have stem damage (forks, broken tops, dead tops)
- stands with significant forest health problems
- stands that have received heavy partial cutting
- stands where treatment has modified sample tree height growth (e.g., fertilization temporarily accelerating height growth, or thinning shock temporarily slowing height growth)
- stands that regenerated densely, particularly lodgepole pine

A general procedure for applying the BEC method in the field follows.

1. Determine site series

The first step in using the BEC method to estimate site index for a stand is to determine the biogeoclimatic unit (zone, subzone/variant) and site series. Ideally, only one site series will exist; however, because of the inherent variability of many sites, a stand may contain more than one site series. For instance, if a surveyor using objectives other than ecological uniformity stratified the stand, more than one site series may result. In cases where stands contain more than one site series, estimate the percentage of stand area by site series.

2. Select the site index species

Select the desired site index species for the stand. The site index species is the tree species for which site index is estimated. Generally, site index is required for the leading species on both the inventory and silviculture forest cover map labels. In a forest cover map label, site index refers to the leading species on the particular site. Each species on a site has a unique site index.

When selecting site index species, check the tables in either the Site Index-Site Unit Report by Region or the Site Index-Site Unit Report by Biogeoclimatic Unit to see which species have site index estimates available for the site series in your stand. If the tables do not have entries for the leading species in your stand, consider using a species-site index conversion relationship. If no conversion is available, often the next best option is to apply the site index of a similar species to the other species.

3. Look up the site index value in the Site Index-Site Unit Report tables

Once zone, subzone/variant, site series, and species are identified for the stratum, proceed to the tables in the Site Index-Site Unit Report by Biogeoclimatic Unit to look up the site index estimate. As mentioned above, estimates may not be available for some site series-species combinations.

4. Compute average site index

If the stand contains more than one site series, it will be necessary to determine the average site index. To compute the average site index for the stand, average the site indices of each site series in the stand—weighting each value by the amount of the stand area in each site series.

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