TECHNICAL REPORT 004

SIBEC Site Index Estimates in Support of Forest Management in British Columbia

2003

SITE PRODUCTIVITY

BRITISH COLUMBIA

Ministry of Forests Forest Science Program

SIBEC Site Index Estimates in Support of Forest Management in British Columbia

Shirley Mah and Gordon Nigh

British Columbia

Ministry of Forests Forest Science Program

NOTE: The Technical Report Series supersedes the Working Paper Series.
Working Paper 64, published 2002, was the last of that series.

National Library of Canada Cataloging in Publication Data

Mah, Shirley.
SIBEC site index estimates in support of forest management in British Columbia

(Technical report ; 004)

Includes bibliographical references: p.
ISBN 0-7726-4910-3

1. Site index (Forestry) - British Columbia. 2. Forests and forestry - British Columbia - Mensuration. 3. Trees - British Columbia - Growth. 4. Forest productivity - British Columbia. I. Nigh Gordon D., (Gordon Donald), 1956- . II. Title. IV. Series: Technical report (British Columbia. Forest Science Program) ; 004.

SD396.M43 2003   634.9' 285   C2003-960033-5

Citation:
Mah, S. and G.D. Nigh. 2003. SIBEC site index estimates in support of forest management in British Columbia. Res. Br., B.C. Min. For., Victoria, B.C. Tech. Rep. 004.
www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr004.htm

Copies of this report may be obtained, depending on supply, from:
Crown Publications
521 Fort Street
Victoria, BC V8W 1E7
Phone: (250) 386-4636
email: crown@pinc.com
www.crownpub.bc.ca

For more information on Forest Science Program publications, visit our web site at
www.for.gov.bc.ca/hfd/pubs/index.htm

ABSTRACT

In response to a request by the Chief Forester of British Columbia, we evaluated the accuracy (unbiasedness) of the Site Index by Biogeoclimatic Ecosystem Classification site series (SIBEC) estimates for use in supporting allowable annual cut (AAC) determinations. Using data from the Old Growth Site Index project, we found that the first approximation SIBEC estimates are less biased than the site index estimates used in the forest inventory for old-growth stands. We therefore concluded that the first and second approximation SIBEC estimates are suitable for supporting AAC determinations and other timber management decisions (such as silvicultural investments). Estimates of site productivity in the second approximation SIBEC estimates are based on a minimum sample size and have a known level of precision. SIBEC estimates of productivity are generally higher than inventory estimates of productivity for old-growth stands. Ongoing SIBEC sampling is required to calibrate the SIBEC model. This will further improve the quality of the estimates for application in resource management.

ACKNOWLEDGEMENTS

We thank John Barker, Jim Thrower, Ian Cameron, Eleanor McWilliams, Guillaume Therien, David Carson, Darrell Errico, Peter Ott, Vera Sit, Janna Jessee, Albert Nussbaum, Chris Fletcher, Pat Martin, and Rob Drummond for valuable review comments. We also thank Del Meidinger, Ray Coupé, Dennis Lloyd, and Allen Banner for their helpful review of an earlier draft.

CONTENTS

INTRODUCTION

In early 2001, we received a request from the Chief Forester of British Columbia to report to him whether the Site Index by BEC site series (SIBEC) estimates of site index, in combination with Predictive Ecosystem Mapping, were reliable enough to support allowable annual cut (AAC) determinations. He also asked whether any statistical test or other measure could be used to demonstrate that SIBEC site index estimates are more accurate for young stands, thrifty stands, or old stands (L. Pedersen, Chief Forester of British Columbia, pers. comm., April 2001). To answer those questions, we conducted an analysis to examine the level of bias of the SIBEC site index estimates and the forest inventory site index estimates for old stands. This report presents our findings. The results of this analysis are intended to help the Chief Forester assess the suitability of using SIBEC estimates to make AAC determinations. They should also prove useful in other aspects of forest management decision-making such as the selection of tree species for regeneration and the prioritizing of treatments on managed stands.

The accuracy of the mapping technique also plays an important role in the application of SIBEC estimates in timber supply analyses. The estimates are usually applied using ecosystem mapping, either predictive (PEM) or terrestrial (TEM), but may also be applied by sampling the landbase to determine the proportion of each BEC site series. The standards for assessing the accuracy of ecosystem mapping were beyond the scope of this review. Interested readers can learn more about some of those standards in *Ecosystem Mapping Accuracy and Timber Supply Applications* (Meidinger 2001). As well, although we restrict our discussion in this report to the SIBEC project, readers should be aware that other approaches for applying ecologically based site index estimates are also used in British Columbia. Among those are a biophysical approach (Smith 1995), site productivity groups (J.S. Thrower & Associates Ltd. 1997), and ratio-adjusted site index estimates (J.S. Thrower & Associates Ltd. 2002).

THE SIBEC PROJECT

Initiation of the SIBEC project (EP 1215) in 1994 was motivated by a need for better site index estimates than those obtained from the forest inventory for old-growth stands. The observed differences between the tree growth of regenerated stands and the forest inventory site index for the previous old-growth stands on the same site had also prompted initiation of the Morice and Lakes study (Goudie 1996) and the Old Growth Site Index (OGSI) project (Nussbaum 1998). The results from the latter project showed that, because the site productivity of old forest stands is underestimated in the forest inventory's site index attribute, more accurate estimates of site index are required. The OGSI results can be used to adjust forest inventory site indices for polygons at the BEC zone level. SIBEC, on the other hand, provides site index estimates at the BEC site-series level and for more tree species and stand conditions.

The SIBEC model uses model-based inference to relate site index to BEC site series for coniferous tree species in British Columbia (B.C. Ministry of

Forests 1997). While model-based inference does not require random sampling, it is prudent to consider a sampling design that is objective, rational, and non-informative (Särndal 1978). Irrespective of the sampling strategy, inference in a model-based approach stems from the model. The adopted SIBEC model for the second approximation estimates leads to an unbiased estimate of mean site index. (See Appendix 1 for the model equation and a discussion on model-based versus design-based sampling inference.)

Research studies (e.g., Green et al. 1989; Klinka and Carter 1990) report strong relationships between site index and environmental factors such as soil moisture and nutrient regime. Using these relationships, one can assign a site index that reflects the potential productivity for a given species to a site that has been classified to BEC site series. The SIBEC model is intended for use where conventional methods (site index curves and growth intercept models) cannot be applied reliably in old-growth or very young stands, for example. Therefore, the SIBEC model is appropriate for assigning site index to future stands once the overmature stands are harvested, and for young stands carrying the site index attribute from the previous old-growth stand. No consensus has yet been reached on application of the SIBEC estimates in thrifty stands upon harvest.

DATA SOURCES

Data for this study were obtained from the OGSI project (Nussbaum 1998). These data consist of 355 plots established in lodgepole pine (*Pinus contorta* var. *latifolia*), interior spruce (*Picea glauca*, *Picea engelmannii*, and their hybrid), and coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) forest types. Each plot has two sub-plots: one in the old-growth stand and one in the adjacent second-growth stand—the assumption being that the sub-plots had comparable productivity based on the BEC site series. Formal BEC evaluation standards and procedures were used to determine the classification of each plot.

Three site indices were therefore available from the OGSI project: the old-growth site index, a second-growth site index, and the site index from the forest inventory for the old-growth stand. The forest inventory site index estimates were derived from photo-interpreted age and height attributes. Since the plots had been classified to BEC site series, we obtained a fourth site index from the first approximation SIBEC estimates (B.C. Ministry of Forests 1997).

METHODS

To evaluate the bias of the SIBEC site index estimates and that of the forest inventory site index estimates, the growth intercept site indices from the second-growth stands in the OGSI project were designated as the best available estimates of site index. The growth intercept method uses early tree height growth, which correlates closely with measured site index (Carmean 1975; Hagglund 1981; Clutter et al. 1983). The average difference from the growth intercept site index was calculated for the SIBEC and the forest inventory site index estimates for all species and grouped by reliability classes (low, medium, and high—generally based on sample size). Although we were unable to compare the site index estimates against a direct measurement of site index (e.g., from stem analysis), this study does provide information on the relative accuracy of the different methods of estimating site index.

RESULTS

We found that both SIBEC and the forest inventory underestimated site index, although the first approximation SIBEC estimates were consistently less underestimated regardless of their reliability ratings (Table 1).

Meidinger et al. (2001) found similar trends for the BEC subzones and variants in the North Coast and Bulkley pilot areas. The results in that study showed the SIBEC estimates of productivity to be consistently higher than the forest inventory site index estimates, but a comparison to a benchmark was not available (Table 2).

TABLE 1 *Comparison of average site index estimates from Old Growth Site Index (OGSI) second-growth paired plots, the forest inventory label, and the first approximation SIBEC estimates, grouped by SIBEC reliability classes*

SIBEC reliability	OGSI (second growth)	Forest inventory site index		First approx. SIBEC site index		Number of plots
		Value	% bias	Value	% bias	
High	21.82	16.83	-23	19.93	-9	159
Medium	20.63	16.08	-22	17.57	-15	122
Low	20.30	14.02	-31	17.46	-14	74
All plots	21.09	15.99	-24	18.60	-12	355

TABLE 2 *Mean differences in site index between SIBEC site index and the forest inventory site index for the North Coast and Bulkley pilot projects. All differences were significantly different from zero; results from Meidinger et al. (2001).*

BEC subzones and variants	SIBEC – forest inventory site index estimates	
	Mean difference (m)	Number of samples
CWHvm	+10.13	745
CWHws2	+9.61	7 660
CWHvh2	+7.67	6 303
MHmm1	+4.54	15
MHwh1	+2.53	399
SBSmc2	+4.07	24 796
SBSdk	+2.72	2 593
ESSFwv	+2.90	5 441
ESSFmk	+3.63	2 230
ESSFmc	+2.06	30 133

Our analysis showed that the first approximation SIBEC estimates have less bias than the site index estimates from the forest inventory when compared to the growth intercept–based site index estimates. Consequently, the SIBEC-based site indices are more reliable than the site index estimates derived from the forest inventory for old-growth stands. However, a review of the data used for the first approximation SIBEC showed that estimates for some BEC subzones and variants were based on sparse data (Figure A2.1 in Appendix 2 shows the geographic extent of these biogeoclimatic units). Also, there are biogeoclimatic units with elevation limits to their application because of pending ecological classification work (Appendix 3). Through future sampling and classification, existing estimates will be improved and these lists will be updated.

The decision to replace forest cover site index estimates with SIBEC-based site index estimates rests on the quality of the SIBEC estimates. We based our assessment of quality on accuracy, which is the synthesis of two statistical measures: unbiasedness and precision.

Unbiasedness of the SIBEC estimates

Our analysis shows that some first approximation SIBEC estimates are biased. In the following discussion, "bias" refers to a systematic over- or under-estimation of site index. The SIBEC model was developed through regression analysis, using data from available sources in 1995. Although these data were based on ground measurements and were screened for quality and reliability, there were still some unsuitable trees with growth suppression, damage, and imprecise age and height measurements. Data from these unsuitable trees were taken into account when regional ecologists reviewed the SIBEC model for goodness of fit and biological consistency and then made adjustments to the estimates based on ecological principles. These adjustments did not fully remove the bias.

To ensure consistent data for calibration of the model, sampling standards were introduced for SIBEC in 1997 (Nigh et al. 1997) and were later revised (B.C. Ministry of Forests 2001). Data collected using the SIBEC sampling standards supplement the original data in generating the second approximation SIBEC estimates. Furthermore, unsuitable data have been removed from the SIBEC database for the second approximation estimates, making it unnecessary to account for these data in the model.

Second approximation SIBEC estimates were improved using the following methodology:

1. Data that did not adequately meet current sampling standards were removed from the provincial data warehouse (B.C. Ministry of Forests 2001).
2. New data were pooled with the existing data, and the site index mean and standard error were recalculated for each BEC site series / species combination.
3. Site index estimates based on a minimum sample size of seven or more are reported.

Precision of the SIBEC estimates

Precision is a measure of the variation in the population mean site index and is expressed as the standard error of the mean for each site series / species combination. Forest inventory site index estimates do not have available estimates of precision to compare to SIBEC estimates. We concluded that the SIBEC model's ecological basis and data lead to better site index information for old-growth stands than does the forest inventory because of the requirement to have proper site trees to estimate site index.

First approximation SIBEC estimates were placed in 3- and 4-m site index classes and assigned reliability ratings. The site index classes were reported instead of actual mean site indices to reflect the uncertainty in the precision of the estimates. The reliability ratings were internal to the SIBEC estimates and were not to be used for a comparison of SIBEC estimates to other estimates (e.g., forest inventory, growth intercept).

As the results in Table 1 show, the reliability ratings do not correlate strongly with bias, making them of limited use for rating the level of bias of the estimates. The second approximation SIBEC would report only those estimates with sufficient data to pass the minimum sample size criteria. Site series with data that do not pass the sample size criteria would retain their first approximation SIBEC estimate. Continued sampling would increase the number of site series / species with estimates of precision, and the proportion of first approximation to future SIBEC estimates will decrease. Currently, the minimum sample size is seven. The estimated means would have a range of precision, and subsequent sampling should be continued until a target error margin that balances uncertainty (risk) with pragmatism is achieved. We propose that this target width be ±1 m at 95% probability level (i.e., that the estimated mean be no farther than 1 m either side of the true mean 95% of the time).

In timber supply analyses, the acceptable level of precision depends on the management unit. The Table Interpolation Program for Stand Yield (TIPSY) (Mitchell et al. 2002) generates much of the managed stand yield information for timber supply. A test was carried out in TIPSY (version 3.06) to see what a change of ±1 m site index would mean in terms of harvest volume expressed at culmination of mean annual increment (m^3/ha). Table 3 shows a change in volume of 6–11%, depending on the species and geographic location. Larger percent changes in volume are expected on lower-elevation sites. Even with a ±1 m standard, the potential change in volume is not considered trivial.

The viability of silvicultural investments may be strongly influenced by this variability. However, the impact that large variations in site index estimates have on the short-term timber supply depends on the availability of old-growth stands for harvest, constraints on the rate of harvest, and other factors. Knowledge of the particular BEC subzones and variants and the

TABLE 3 *Change in regenerated stand harvest volume in response to ±1 m change in average tree site index for coastal and interior British Columbia*

	Tree species	Average site index	% change in volume (m^3/ha)	
			+1 m	-1 m
Coast	Douglas-fir	29.0	7.0	7.3
	Western hemlock	27.5	5.8	6.9
Interior	Lodgepole pine	19.0	11.0	11.0
	White spruce	19.0	7.2	8.0

precision of the SIBEC estimates for that management unit will provide the basis for determining their impact on timber supply. With this knowledge, timber supply analysts will be able to apply meaningful sensitivity analyses.

CONCLUSIONS

The first approximation SIBEC estimates of productivity have less bias than the forest inventory site index estimates for old-growth stands. The clear trend observed in the study is that first approximation SIBEC estimates are higher than the site index estimates currently used in the forest inventory. However, estimates for some BEC subzones and variants are based on sparse data or have upper elevation limits. Precision (in terms of standard error of the mean) will be explicitly included in the next generation of SIBEC estimates, and in this way will provide more information on the variability of the site index estimates. This will present an improvement over current reporting of site index in the forest inventory.

A large proportion of the SIBEC model still requires additional data for priority BEC site series in order to move to second-generation estimates. This is a considerable undertaking and can succeed only through continued collaboration among licensees, consultants, and staff in the Ministry of Forests and Ministry of Sustainable Resource Management. In the interim, first approximation SIBEC estimates provide more reliable estimates of productivity in support of AAC determinations and silvicultural investment decisions than do inventory estimates based on age/height approaches for old-growth stands.

APPENDIX 1 SIBEC model and sampling inference in model-based versus design-based approaches

The SIBEC project follows a model-based approach whereby the population mean site index is a random variable and is regarded as a realization of a random process from what is called the superpopulation or superpopulation model (Thompson 1992; Gregoire 1998). The adopted SIBEC model describes the assumptions about the structure of the process believed to be responsible for generating the observed population. In statistical terms, the model is:

$$SI_k \mid SS, Sp = \mu_{SS,Sp} + \sigma_{SS,Sp} \cdot \varepsilon_k, \quad \varepsilon_k \sim N(0,1), \quad \operatorname{cov}(\varepsilon_k, \varepsilon_{k'}) = 0 \tag{1}$$

where *SI* is site index (m), *SS* is the target site series, *Sp* is the target species, | is the conditional operator, *k* is the observation identifier, ε is a normally distributed error term, and $\mu_{SS,Sp}$ and $\sigma_{SS,Sp}$ are unknown model parameters for the target site series and species, representing the mean and standard deviation of the site index, respectively. Equation (1) implies that $\mu_{SS,Sp}$ is the mean site index for site series *SS* and species *Sp*, and the standard deviation of the site indices for the given site series and species is $\sigma_{SS,Sp.}$ The model also specifies that the deviations from the mean are uncorrelated.

The objective of SIBEC sampling and analysis is to estimate the model parameters $\mu_{SS,Sp}$ and $\sigma_{SS,Sp}$ through the values observed in the population. Implicit in the model specification is that the site series is classified correctly and the site index is estimated using proper site trees and models. The model makes no assumption about the means or variances being the same across different site series or species.

A brief discussion on design-based and model-based inference in survey sampling is now presented, as inference and bias are defined differently depending on the framework used. In a design-based approach (or randomization theory), the population is regarded as fixed and inference is based on the distribution of estimates generated by the sampling design (Gregoire 1998). The probabilistic nature of the sampling design is crucial, as it is the only source of randomness ascribed to each of the possible samples in the reference set (Gregoire 1998).

Irrespective of the sampling strategy, model-based inference stems solely from the model, contingent on a given sample. The SIBEC project uses probabilistic and purposive sampling for calibration of the SIBEC model. Some form of random sampling is encouraged where a sampling frame based on ecological mapping is available. Where no ecological mapping is available, data can be obtained more economically by using available information such as biogeoclimatic maps, forest cover maps, and aerial photographs to target areas with potentially suitable plots. Random sampling would likely require greater expenditure, both in time and cost, and could result in common site series being oversampled and less common site series being undersampled.

Model-based inference is used extensively in growth and yield modelling and experimental design. For example, with a model such as Y = f(X), the observations can be selected purposively with respect to X (Gregoire 1998), and in fact this is what Demaerschalk and Kozak (1974) espouse. However, the observations must still be selected without regard to the Y values (Gregoire 1998). In terms of SIBEC sampling, this means that samples for the target site series and species are not selected based on the site index (the Y value) of the sample plot—typically, the site index is unknown until the sample has been collected and compiled. Bias in model-based inference arises from model mis-specification, whereas in the design-based approach, the estimators are considered biased if the expected value of the estimator over all possible samples does not equal the population parameter (Gregoire 1998). At present, there is no compelling evidence to suggest that the SIBEC model is mis-specified. However, preliminary work, pending further data collection and analysis, indicates that elevation and latitude may need to be added to the model for high-elevation ESSF sites.

APPENDIX 2 Biogeoclimatic units for which data are sparse in the first approximation SIBEC estimates

BWBSvk	ESSFmm1	ESSFwk2	IDFdw
BWBSwk1	ESSFmv1	ESSFwm	PPdh1
BWBSwk2	ESSFmv2	ESSFxv1	PPdh2
BWBSwk3	ESSFmv3	ESSFxv2	SBPSxc
ESSFmk	ESSFmv4	ICHxw	

FIGURE A2.1 *Shaded areas indicate the location and extent of the BEC subzones and variants for which data are sparse (listed above). Estimates exist for the remaining BEC subzones and variants, from either the first or second approximation SIBEC estimates.*

APPENDIX 3 Biogeoclimatic units and their upper elevation limits for applying SIBEC estimates (B.C. Ministry of Forests 1997)

ESSFdc1 – 1850 m (Kamloops)	ESSFmw – 1550 m	ESSFwc4 – 1800 m
ESSFwc2 – 1600 m (Nelson)	ESSFmv1 – 1300 m	ESSFwk2 – 1150 m
ESSFdc2 – 1750 m	ESSFmv2 – 1250 m	ESSFwm – 1750 m
ESSFdv – 1750 m	ESSFmv3 – 1300 m	ESSFwv – 1300 m
ESSFdk – 1850 m	ESSFmv4 – 1250 m	ESSFvc – 1550 m
ESSFmc – 1400 m	ESSFwc2 – 1500 m (Prince George)	ESSFxc – 1950 m
ESSFmk – 1400 m	ESSFdc1 – 1800 m (Nelson)	
ESSFmm1 – 1400 m	ESSFwc3 – 1450 m	

British Columbia Ministry of Forests. 1997. Site index estimates by site series for coniferous tree species in British Columbia. Res. Br., Victoria, B.C.

———. 2001. SIBEC sampling and data standards. Vers. 5.1. B.C. Min. For., Res. Br., Victoria, B.C.

Carmean, W.H. 1975. Forest site quality evaluation in the United States. Adv. Agron. 27:209–69.

Clutter, J.L., J.C. Fortson, L.V. Pienaar, G.H. Brister, and R.L. Bailey. 1983. Timber management: a quantitative approach. John Wiley & Sons, Toronto, Ont.

Demaerschalk, J.P. and A. Kozak. 1974. Suggestions and criteria for more effective regression sampling. Can. J. For. Res. 4: 341–8.

Goudie, J.W. 1996. The effects of stocking on estimated site index in the Morice, Lakes and Vanderhoof timber supply areas in central British Columbia. *In* Proc.: Northern Interior Vegetation Management Assoc. Annual General Meeting. P. Tollestrup (editor). Smithers, B.C.

Green, R.N., P.L. Marshall, and K. Klinka. 1989. Estimating site index of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) from ecological variables in southwestern British Columbia. For. Sci. 35:50–63.

Gregoire, T.G. 1998. Design-based and model-based inference in survey sampling: appreciating the difference. Can. J. For. Res. 28:1429–47.

Hagglund, B. 1981. Evaluation of forest site productivity. For. Abst. 42(11): 515–27.

J.S. Thrower & Associates Ltd. 1997. Second growth site index on Western Forest Products' TFL 6. Report to Western Forest Products Ltd.

———.2002. Site index adjustment for the wet-belt portion of the Okanagan TSA. Final Report to the Okanagan Innovative Forestry Society.

Klinka, K. and R.E. Carter. 1990. Relationships between site index and synoptic environmental factors in immature coastal Douglas-fir stands. For. Sci. 36: 815–30.

Meidinger, D. 2001. Ecosystem mapping accuracy and timber supply applications. Pdf file, B.C. Min. For., Res. Br. www.for.gov.bc.ca/research/becweb/pdf/PEM_accuracy_statement_3.pdf

Meidinger, D., B. Enns, S. Reed, and G. Olivotto. 2001. Pilot to develop a methodology for ecologically based yield analysis. Final Report. B.C. Min. For., Res. Br., Victoria, B.C.

Mitchell, K.J., M. Stone, S.E. Grout, C.M. Di Lucca, G.D. Nigh, J.W. Goudie, J.N. Stone, A.J. Nussbaum, A. Yanchuk, S. Stearns-Smith, and R. Brockley. 2002. TIPSY. Vers. 3.06. File, B.C. Min. For., Res. Br. <www.for.gov.bc.ca/research/gymodels/tipsy/>

Nigh, G.D., D. Meidinger, and A. Mirza. 1997. SIBEC sampling and data standards. Vers. 4.0. B.C. Min. For., Res. Br., Victoria, B.C. Misc. Rep. 075.

Nussbaum, A.F. 1998. Site index adjustments for old-growth stands based on paired plots. B.C. Min. For., Res. Br., Victoria, B.C. Work. Pap. 37. www.for.gov.bc.ca/hfd/pubs/Docs/Wp/Wp37.htm

Särndal, C.-E. 1978. Design-based and model-based inference in survey sampling. Scand. J. Stat. 5:27–52.

Smith, N.J. 1995. Estimating site index in TFL 39 and TFL 44. Report to B.C. Min. For. MacMillan Bloedel Ltd., Nanaimo, B.C.

Thompson, S.K. 1992. Sampling. John Wiley & Sons, New York, N.Y., Chap. 10, p. 94.