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# New Height Growth Models for Western Larch in British Columbia 

## Introduction

Western larch (Larix occidentalis Nutt.) is a locally important species in the Nelson Forest Region, and to a lesser extent, in the Kamloops Forest Region. Its range extends from west of the Rockies to Okanagan Lake, and north to Salmon Arm, in the IDF, ICH, MS, and ESSF biogeoclimatic zones. Prior to this study, the site index curves developed for western larch in western Montana were used to model height and estimate site index in British Columbia. It has been suggested that these curves may not adequately reflect the height growth patterns of western larch in BC. Differences could arise from genetics, different methods of selecting sample trees, or climatic differences. The objective of this project was to produce accurate height growth models for western larch in BC.

## Study Stands and Methods

Study plots ( $20 \mathrm{~m} \times 20 \mathrm{~m}, 0.04 \mathrm{ha}$ ) were deliberately installed in western larch leading ( $>70 \%$ larch) stands to cover the geographical and biogeoclimatic range of larch in southeastern British Columbia. These stands were naturally established, unmanaged, even-aged, and usually the result of fire. The plots were uniform in soil, understory composition, and stand characteristics. The three largest diameter dominant or co-dominant, healthy larch trees free of suppression and damage in the plot were the sample trees. These trees were destructively sampled for stem analysis: stem sections were taken at $0.3 \mathrm{~m}, 0.8 \mathrm{~m}, 1.3 \mathrm{~m}$, and then at 1 m intervals for the remainder of the bole. The annual growth rings on each section were counted. 108 plots were suitable for height growth modelling. The data were split into a calibration data set ( 72 plots) and a test data set ( 36 plots). Four height growth models (conditioned logistic, Chapman-Richards, conditioned ChapmanRichards, and conditioned Weibull) were fit to the calibration data. These models predict height as a function of breast height age and site index (top height @ 1.3m age 50). The models were tested by estimating heights in the test data set, calculating the errors in the estimates, and analyzing the errors. The best model was selected based on the mean squared error and test results. The best model was then re-fit to the combined (calibration and test) data set.

## Results and Discussion

The Chapman-Richards model had the lowest error, and is recommended for use in British Columbia. This model is:

$$
H=1.3+3.785 \times(S-1.3)^{0.7850} \times\left(1-e^{-0.01497 \times(A-0.5)}\right)^{2.193 \times(S-1.3)^{-0.02314}}
$$

where $\mathrm{H}=$ top height $(\mathrm{m}), \mathrm{S}=$ site index ( m at breast height age 50 ), $\mathrm{A}=$ breast height age (yrs), and $\mathrm{e}=$ base of natural logarithms.

All the models fit the data quite well; there was not much difference between the four models. The testing of the Montana model also indicated that it is satisfactory for estimating height of western larch in British Columbia, although the fitted Chapman-Richards model is slightly better. Therefore, the use of the Montana model in the past has been expedient, but the new Chapman-Richards model should be used in the future.

| Age @ bh (years) | Site index (m@ 1.3m age 50) |  |  |  |  |  |  |  |  |  |  |  |  |  | Age @ bh (years) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 |  |
| 12 | 1.6 | 2.1 | 2.6 | 3.1 | 3.7 | 4.3 | 5.0 | 5.6 | 6.3 | 6.9 | 7.6 | 8.3 | 9.0 | 9.7 | 12 |
| 14 | 1.7 | 2.3 | 2.9 | 3.5 | 4.2 | 4.9 | 5.6 | 6.4 | 7.1 | 7.9 | 8.7 | 9.5 | 10.3 | 11.1 | 14 |
| 16 | 1.8 | 2.5 | 3.2 | 3.9 | 4.7 | 5.5 | 6.3 | 7.2 | 8.0 | 8.9 | 9.7 | 10.6 | 11.5 | 12.4 | 16 |
| 18 | 2.0 | 2.7 | 3.5 | 4.3 | 5.2 | 6.1 | 7.0 | 7.9 | 8.8 | 9.8 | 10.7 | 11.7 | 12.7 | 13.6 | 18 |
| 20 | 2.1 | 2.9 | 3.8 | 4.7 | 5.7 | 6.7 | 7.7 | 8.7 | 9.7 | 10.7 | 11.7 | 12.8 | 13.8 | 14.8 | 20 |
| 22 | 2.2 | 3.1 | 4.1 | 5.1 | 6.2 | 7.2 | 8.3 | 9.4 | 10.5 | 11.6 | 12.7 | 13.8 | 14.9 | 16.0 | 22 |
| 24 | 2.3 | 3.3 | 4.4 | 5.5 | 6.6 | 7.8 | 9.0 | 10.1 | 11.3 | 12.5 | 13.6 | 14.8 | 16.0 | 17.2 | 24 |
| 26 | 2.4 | 3.6 | 4.7 | 5.9 | 7.1 | 8.4 | 9.6 | 10.8 | 12.1 | 13.3 | 14.6 | 15.8 | 17.1 | 18.3 | 26 |
| 28 | 2.6 | 3.8 | 5.0 | 6.3 | 7.6 | 8.9 | 10.2 | 11.5 | 12.8 | 14.1 | 15.5 | 16.8 | 18.1 | 19.4 | 28 |
| 30 | 2.7 | 4.0 | 5.3 | 6.7 | 8.1 | 9.4 | 10.8 | 12.2 | 13.6 | 15.0 | 16.3 | 17.7 | 19.1 | 20.5 | 30 |
| 32 | 2.8 | 4.2 | 5.6 | 7.1 | 8.5 | 10.0 | 11.4 | 12.9 | 14.3 | 15.7 | 17.2 | 18.6 | 20.0 | 21.5 | 32 |
| 34 | 3.0 | 4.4 | 5.9 | 7.5 | 9.0 | 10.5 | 12.0 | 13.5 | 15.0 | 16.5 | 18.0 | 19.5 | 21.0 | 22.5 | 34 |
| 36 | 3.1 | 4.7 | 6.2 | 7.8 | 9.4 | 11.0 | 12.6 | 14.1 | 15.7 | 17.3 | 18.8 | 20.4 | 21.9 | 23.4 | 36 |
| 38 | 3.2 | 4.9 | 6.5 | 8.2 | 9.8 | 11.5 | 13.1 | 14.8 | 16.4 | 18.0 | 19.6 | 21.2 | 22.8 | 24.4 | 38 |
| 40 | 3.4 | 5.1 | 6.8 | 8.6 | 10.3 | 12.0 | 13.7 | 15.4 | 17.0 | 18.7 | 20.4 | 22.0 | 23.7 | 25.3 | 40 |
| 42 | 3.5 | 5.3 | 7.1 | 8.9 | 10.7 | 12.5 | 14.2 | 16.0 | 17.7 | 19.4 | 21.1 | 22.8 | 24.5 | 26.2 | 42 |
| 44 | 3.6 | 5.5 | 7.4 | 9.3 | 11.1 | 12.9 | 14.7 | 16.5 | 18.3 | 20.1 | 21.8 | 23.6 | 25.3 | 27.0 | 44 |
| 46 | 3.8 | 5.7 | 7.7 | 9.6 | 11.5 | 13.4 | 15.2 | 17.1 | 18.9 | 20.7 | 22.5 | 24.3 | 26.1 | 27.9 | 46 |
| 48 | 3.9 | 5.9 | 7.9 | 9.9 | 11.9 | 13.8 | 15.7 | 17.6 | 19.5 | 21.4 | 23.2 | 25.0 | 26.9 | 28.7 | 48 |
| 50 | 4.0 | 6.1 | 8.2 | 10.3 | 12.3 | 14.3 | 16.2 | 18.2 | 20.1 | 22.0 | 23.9 | 25.8 | 27.6 | 29.5 | 50 |
| 52 | 4.2 | 6.3 | 8.5 | 10.6 | 12.6 | 14.7 | 16.7 | 18.7 | 20.7 | 22.6 | 24.5 | 26.4 | 28.3 | 30.2 | 52 |
| 54 | 4.3 | 6.5 | 8.7 | 10.9 | 13.0 | 15.1 | 17.2 | 19.2 | 21.2 | 23.2 | 25.2 | 27.1 | 29.0 | 31.0 | 54 |
| 56 | 4.4 | 6.7 | 9.0 | 11.2 | 13.4 | 15.5 | 17.6 | 19.7 | 21.7 | 23.8 | 25.8 | 27.7 | 29.7 | 31.7 | 56 |
| 58 | 4.5 | 6.9 | 9.2 | 11.5 | 13.7 | 15.9 | 18.0 | 20.2 | 22.2 | 24.3 | 26.4 | 28.4 | 30.4 | 32.4 | 58 |
| 60 | 4.7 | 7.1 | 9.5 | 11.8 | 14.1 | 16.3 | 18.5 | 20.6 | 22.8 | 24.9 | 26.9 | 29.0 | 31.0 | 33.0 | 60 |
| 62 | 4.8 | 7.3 | 9.7 | 12.1 | 14.4 | 16.7 | 18.9 | 21.1 | 23.2 | 25.4 | 27.5 | 29.6 | 31.7 | 33.7 | 62 |
| 64 | 4.9 | 7.5 | 10.0 | 12.4 | 14.7 | 17.0 | 19.3 | 21.5 | 23.7 | 25.9 | 28.0 | 30.2 | 32.3 | 34.3 | 64 |
| 66 | 5.0 | 7.7 | 10.2 | 12.6 | 15.0 | 17.4 | 19.7 | 22.0 | 24.2 | 26.4 | 28.6 | 30.7 | 32.8 | 35.0 | 66 |
| 68 | 5.1 | 7.8 | 10.4 | 12.9 | 15.3 | 17.7 | 20.1 | 22.4 | 24.6 | 26.9 | 29.1 | 31.3 | 33.4 | 35.6 | 68 |
| 70 | 5.3 | 8.0 | 10.6 | 13.2 | 15.6 | 18.1 | 20.4 | 22.8 | 25.1 | 27.3 | 29.6 | 31.8 | 34.0 | 36.1 | 70 |
| 72 | 5.4 | 8.2 | 10.8 | 13.4 | 15.9 | 18.4 | 20.8 | 23.2 | 25.5 | 27.8 | 30.1 | 32.3 | 34.5 | 36.7 | 72 |
| 74 | 5.5 | 8.3 | 11.0 | 13.7 | 16.2 | 18.7 | 21.2 | 23.6 | 25.9 | 28.2 | 30.5 | 32.8 | 35.0 | 37.3 | 74 |
| 76 | 5.6 | 8.5 | 11.2 | 13.9 | 16.5 | 19.0 | 21.5 | 23.9 | 26.3 | 28.7 | 31.0 | 33.3 | 35.5 | 37.8 | 76 |
| 78 | 5.7 | 8.6 | 11.4 | 14.1 | 16.8 | 19.3 | 21.8 | 24.3 | 26.7 | 29.1 | 31.4 | 33.8 | 36.0 | 38.3 | 78 |
| 80 | 5.8 | 8.8 | 11.6 | 14.4 | 17.0 | 19.6 | 22.2 | 24.6 | 27.1 | 29.5 | 31.9 | 34.2 | 36.5 | 38.8 | 80 |
| 82 | 5.9 | 8.9 | 11.8 | 14.6 | 17.3 | 19.9 | 22.5 | 25.0 | 27.5 | 29.9 | 32.3 | 34.6 | 37.0 | 39.3 | 82 |
| 84 | 6.0 | 9.1 | 12.0 | 14.8 | 17.5 | 20.2 | 22.8 | 25.3 | 27.8 | 30.3 | 32.7 | 35.1 | 37.4 | 39.8 | 84 |
| 86 | 6.1 | 9.2 | 12.2 | 15.0 | 17.8 | 20.5 | 23.1 | 25.7 | 28.2 | 30.6 | 33.1 | 35.5 | 37.9 | 40.2 | 86 |
| 88 | 6.2 | 9.4 | 12.4 | 15.2 | 18.0 | 20.7 | 23.4 | 26.0 | 28.5 | 31.0 | 33.5 | 35.9 | 38.3 | 40.7 | 88 |
| 90 | 6.3 | 9.5 | 12.5 | 15.4 | 18.3 | 21.0 | 23.7 | 26.3 | 28.8 | 31.4 | 33.8 | 36.3 | 38.7 | 41.1 | 90 |
| 92 | 6.4 | 9.6 | 12.7 | 15.6 | 18.5 | 21.2 | 23.9 | 26.6 | 29.2 | 31.7 | 34.2 | 36.7 | 39.1 | 41.5 | 92 |
| 94 | 6.5 | 9.8 | 12.9 | 15.8 | 18.7 | 21.5 | 24.2 | 26.9 | 29.5 | 32.0 | 34.6 | 37.0 | 39.5 | 41.9 | 94 |
| 96 | 6.5 | 9.9 | 13.0 | 16.0 | 18.9 | 21.7 | 24.5 | 27.1 | 29.8 | 32.4 | 34.9 | 37.4 | 39.9 | 42.3 | 96 |
| 98 | 6.6 | 10.0 | 13.2 | 16.2 | 19.1 | 22.0 | 24.7 | 27.4 | 30.1 | 32.7 | 35.2 | 37.8 | 40.2 | 42.7 | 98 |
| 100 | 6.7 | 10.1 | 13.3 | 16.4 | 19.3 | 22.2 | 25.0 | 27.7 | 30.4 | 33.0 | 35.6 | 38.1 | 40.6 | 43.1 | 100 |
| 102 | 6.8 | 10.2 | 13.5 | 16.6 | 19.5 | 22.4 | 25.2 | 27.9 | 30.6 | 33.3 | 35.9 | 38.4 | 40.9 | 43.4 | 102 |
| 104 | 6.9 | 10.4 | 13.6 | 16.7 | 19.7 | 22.6 | 25.4 | 28.2 | 30.9 | 33.6 | 36.2 | 38.7 | 41.3 | 43.8 | 104 |
| 106 | 7.0 | 10.5 | 13.8 | 16.9 | 19.9 | 22.8 | 25.7 | 28.4 | 31.2 | 33.8 | 36.5 | 39.1 | 41.6 | 44.1 | 106 |
| 108 | 7.0 | 10.6 | 13.9 | 17.0 | 20.1 | 23.0 | 25.9 | 28.7 | 31.4 | 34.1 | 36.8 | 39.4 | 41.9 | 44.5 | 108 |
| 110 | 7.1 | 10.7 | 14.0 | 17.2 | 20.3 | 23.2 | 26.1 | 28.9 | 31.7 | 34.4 | 37.0 | 39.7 | 42.2 | 44.8 | 110 |
| 112 | 7.2 | 10.8 | 14.1 | 17.3 | 20.4 | 23.4 | 26.3 | 29.1 | 31.9 | 34.6 | 37.3 | 39.9 | 42.5 | 45.1 | 112 |
| 114 | 7.2 | 10.9 | 14.3 | 17.5 | 20.6 | 23.6 | 26.5 | 29.4 | 32.1 | 34.9 | 37.6 | 40.2 | 42.8 | 45.4 | 114 |
| 116 | 7.3 | 11.0 | 14.4 | 17.6 | 20.8 | 23.8 | 26.7 | 29.6 | 32.4 | 35.1 | 37.8 | 40.5 | 43.1 | 45.7 | 116 |
| 118 | 7.4 | 11.1 | 14.5 | 17.8 | 20.9 | 23.9 | 26.9 | 29.8 | 32.6 | 35.4 | 38.1 | 40.7 | 43.4 | 46.0 | 118 |
| 120 | 7.4 | 11.2 | 14.6 | 17.9 | 21.1 | 24.1 | 27.1 | 30.0 | 32.8 | 35.6 | 38.3 | 41.0 | 43.6 | 46.2 | 120 |
| 122 | 7.5 | 11.3 | 14.7 | 18.0 | 21.2 | 24.3 | 27.3 | 30.2 | 33.0 | 35.8 | 38.5 | 41.2 | 43.9 | 46.5 | 122 |
| 124 | 7.6 | 11.3 | 14.8 | 18.2 | 21.4 | 24.4 | 27.4 | 30.4 | 33.2 | 36.0 | 38.8 | 41.5 | 44.1 | 46.8 | 124 |
| 126 | 7.6 | 11.4 | 15.0 | 18.3 | 21.5 | 24.6 | 27.6 | 30.5 | 33.4 | 36.2 | 39.0 | 41.7 | 44.4 | 47.0 | 126 |
| 128 | 7.7 | 11.5 | 15.1 | 18.4 | 21.6 | 24.7 | 27.8 | 30.7 | 33.6 | 36.4 | 39.2 | 41.9 | 44.6 | 47.3 | 128 |
| 130 | 7.7 | 11.6 | 15.2 | 18.5 | 21.8 | 24.9 | 27.9 | 30.9 | 33.8 | 36.6 | 39.4 | 42.1 | 44.8 | 47.5 | 130 |
| 132 | 7.8 | 11.7 | 15.2 | 18.6 | 21.9 | 25.0 | 28.1 | 31.1 | 34.0 | 36.8 | 39.6 | 42.4 | 45.1 | 47.7 | 132 |
| 134 | 7.9 | 11.7 | 15.3 | 18.7 | 22.0 | 25.2 | 28.2 | 31.2 | 34.1 | 37.0 | 39.8 | 42.6 | 45.3 | 48.0 | 134 |
| 136 | 7.9 | 11.8 | 15.4 | 18.9 | 22.1 | 25.3 | 28.4 | 31.4 | 34.3 | 37.2 | 40.0 | 42.8 | 45.5 | 48.2 | 136 |
| 138 | 8.0 | 11.9 | 15.5 | 19.0 | 22.3 | 25.4 | 28.5 | 31.5 | 34.5 | 37.3 | 40.2 | 43.0 | 45.7 | 48.4 | 138 |
| 140 | 8.0 | 12.0 | 15.6 | 19.1 | 22.4 | 25.6 | 28.7 | 31.7 | 34.6 | 37.5 | 40.4 | 43.1 | 45.9 | 48.6 | 140 |
| 142 | 8.1 | 12.0 | 15.7 | 19.2 | 22.5 | 25.7 | 28.8 | 31.8 | 34.8 | 37.7 | 40.5 | 43.3 | 46.1 | 48.8 | 142 |
| 144 | 8.1 | 12.1 | 15.8 | 19.3 | 22.6 | 25.8 | 28.9 | 32.0 | 34.9 | 37.8 | 40.7 | 43.5 | 46.3 | 49.0 | 144 |
| 146 | 8.2 | 12.2 | 15.9 | 19.3 | 22.7 | 25.9 | 29.0 | 32.1 | 35.1 | 38.0 | 40.9 | 43.7 | 46.4 | 49.2 | 146 |
| 148 | 8.2 | 12.2 | 15.9 | 19.4 | 22.8 | 26.0 | 29.2 | 32.2 | 35.2 | 38.1 | 41.0 | 43.8 | 46.6 | 49.4 | 148 |
| 150 | 8.2 | 12.3 | 16.0 | 19.5 | 22.9 | 26.1 | 29.3 | 32.4 | 35.4 | 38.3 | 41.2 | 44.0 | 46.8 | 49.5 | 150 |
| 152 | 8.3 | 12.3 | 16.1 | 19.6 | 23.0 | 26.2 | 29.4 | 32.5 | 35.5 | 38.4 | 41.3 | 44.2 | 47.0 | 49.7 | 152 |
| 154 | 8.3 | 12.4 | 16.2 | 19.7 | 23.1 | 26.4 | 29.5 | 32.6 | 35.6 | 38.6 | 41.5 | 44.3 | 47.1 | 49.9 | 154 |
| 156 | 8.4 | 12.5 | 16.2 | 19.8 | 23.2 | 26.5 | 29.6 | 32.7 | 35.7 | 38.7 | 41.6 | 44.5 | 47.3 | 50.0 | 156 |
| 158 | 8.4 | 12.5 | 16.3 | 19.9 | 23.3 | 26.5 | 29.7 | 32.8 | 35.9 | 38.8 | 41.7 | 44.6 | 47.4 | 50.2 | 158 |
| 160 | 8.4 | 12.6 | 16.4 | 19.9 | 23.3 | 26.6 | 29.8 | 32.9 | 36.0 | 39.0 | 41.9 | 44.7 | 47.6 | 50.3 | 160 |



## Reference

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