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# The Characteristics and Biomass Distribution in Crown of *Larix olgensis* in Northeastern China

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**Abstract :** This study was performed in 22 unthinned *Larix olgensis* plantations in northeast China. Data were collected on 95 sample trees of different canopy positions and the diameter at breast height ($d_{1.3}$) ranged from 5.7 cm to 40.2 cm. The individual tree models for the prediction of vertical distribution of live crown, branch and needle biomass were built. Our study showed that the crown, branch and needle biomass distributions were most in the location of 60% crown length. These results were also parallel to previous crown studies. The cumulative relative biomass of live crown, branch and needle were fitted by the sigmoid shape curve and the fitting results were quite well. Meanwhile, we developed the crown ratio and width models. Tree height was the most important predictor for crown ratio model. A negative competition factor, *ccf* and *bas* which reflected the effect of suppression on a tree, reduced the crown ratio estimates. The height–diameter ratio was a significant predictor. The higher the height–diameter ratio, the higher crown ratio is. Diameter at breast height is the strongest predictor in crown width model. The models can be used for the planning of harvesting operations, for the selection of feasible harvesting methods, and for the estimation of nutrient removals of different harvesting practices.

***Key words* :** *Larix olgensis plantations Crown ratio Crown width Crown biomass*

## Introduction

*Larix olgensis* is one of three main coniferous timber species in northwestern China. The area of *Larix olgensis* plantation is about four million ha and occupies 70% of the plantation in northeastern China. The understanding of dynamics of *Larix olgensis* is important for forest conservation, management and timber yield in these regions.

Tree crown plays an essential role in tree productivity because crown is the location of many physiological processes such as principal photosynthesis, respiration and transpiration which are related to growth and development of the tree. Crown dimensions have an effect on physiological processes (Jahnke and Lawrence, 1965), seed production and forest regeneration (Hale, 2004), stem form (Larson, 1963), wildlife use potential (Mohren *et al.*, 1987), behavior under wind stress (Moore, 2002), and wood quality (Maguire *et al.*, 1991). Therefore, crown dimension is an important component of forest growth and yield models and is used in many tree and crown level growth modeling systems (Cole and Lorimer, 1994; Valentine *et al.*, 1994). Monserud and Sterba (1996) applied tree crown as one of the predictors in diameter and height growth equations, and Vanclay (1994) showed that tree crown can be considered when simple competition indices are not able to adequately predict recovery from competition when a competitor is removed such as by thinning.

Crown size is usually described as crown length and crown width. Crown length is the difference between total height and the height to the crown base. Crown size has been considered related to tree vigor and is a measure of photosynthetic potential (Daniels and Burkhart, 1975). A dimensionless measure of crown size is crown ratio, which is defined as crown length divided by total tree height. Monserud (1975) found that crown ratio is a good indicator of the ability of a tree to utilize available resources for growth. Daniels *et al.* (1979) considered both crown length and crown ratio to reflect the potential of a released tree to utilize available resources such as increased growing space. When total tree height is measured, it is very easy to obtain the height to the crown base. Crown length and crown ratio have become widely measured tree characteristics in forest inventories in the past. Monserud and Sterba (1996) found that the logarithm of crown ratio is highly significant for predicting the basal area increment of all Austrian forest species.

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Crown width has been used in calculating distance dependent competition indices such as area overlap index (Biging and Dobbertin, 1992). There are two kinds of crown width models-models for open-grown trees and models for stand-grown trees. Equations for predicting the dimensions of crowns in open locations consider maximum biological potential, while those for stand-grown trees which generally have a smaller crown due to competition are called LCW (Largest Crown Width) equations (Hann, 1997). LCW models predict the actual size of tree crowns in forest stands, and have many applications including estimations of crown surface area and volume in order to assess forest health (Zarnoch *et al*., 2004), tree-crown profiles and canopy architecture (Hann, 1999; Marshall *et al*., 2003), forest canopy cover (Gill *et al*., 2000) and the arrangement of trees in forest visualization programs (Habus and Hann, 1998). When modeling crown diameter relationship, many techniques such as simple linear model (Paulo *et al*., 2002; Benítez *et al*., 2003), linear models with quadratic terms (Bechtold, 2003) as well as non-linear models using power function and monomolecular function (Bragg, 2001; Tomén *et al*., 2001) have been used.

The complex structure and irregular distribution of foliage and branch made it difficult to predict the crown related biomass. Although some studies on crown biomass distribution have been published (Gillespie *et al*., 1994; Baldwin and Peterson, 1997; Timo and Eero, 2008), the estimation of foliage and branch biomass remains one of the least understood aspects of forest growth and yield modeling. The breast height diameter, tree height and diameter-height ratio were used as predictors in biomass models because these are commonly available in forest inventory (Marklund, 1988; Korhonen and Maltamo, 1990; Hakkila, 1991).

In order to predict the harvested branches and needles above the delimbed pulpwood section, the vertical distribution of biomass components within one tree has to be known. This requires tree-level information on the length of the living crown and on the way in which the biomass has accumulated along the whole crown length. Therefore, the purpose of this study is to produce crown characters and biomass distribution models for *Larix olgensis*, that can be applied to estimate the total amounts and share of total branch and needle biomasses along any given stem section of an individual tree. These models consist of the following individual tree models: crown ratio model, crown width model, and the relative accumulation of living crown biomass, branch biomass and needle biomass models. The developed models in this study may be applied for the prediction of biomass under different silviculture conditions, and for the simulation of various thinning procedures and harvesting methods.

## Materials and Method

### 1. Data collection

Sample trees were collected in 22 unthinned *Larix olgensis* plots with different age and density from MengJiaGang forest farm, which is located in Jiamusi city of Heilongjang province, northeastern China, ranging across 130° 33′~130° 53′ E and 46° 20′~46° 31′ N. The size for each plot is 0.1 ha. Stem diameter at breast height (DBH), total height (HT), height to crown base (HCB), crown width (CW), and the coordinate of x and y were recorded for each tree in the plots. The definition of crown base is the lowest living branch which has one green leaf at least. The cumulative basal area distribution of the trees on the plot was divided into five equal size strata, and the average diameter at breast height and total height of each stratum was calculated. Based on the calculated average diameter at breast height and total height for each stratum, one sample tree was randomly chosen outside the plot in the stand. The total of 95 trees was selected as sample trees for stem analysis. However, none of sample trees were selected in three plots because of their poor situations.

The sample trees were felled as carefully as possible to minimize damage to their crowns. The discs were taken from the stem at a height of 1.3 m, stump, and then at 1.0 m interval above stump following Smalian's method of stem analysis. Each section at 1.0 m interval

**Table 1. Description of variables.**

| Variable | Definition |
|---|---|
| bas | Stand basal area (at breast height level) ($m^2 ha^{-1}$) |
| ccf | Crown competition factor |
| $d_{1.3}$ | Tree diameter at breast height (1.3 m from ground level) (cm) |
| h | Total tree height (m) |
| hcb | height of the first live branch (m) |
| cl | Crown length (*h-hcb*) (m) |
| cr | Crown ratio (CL/*h*) |
| cw | Crown width (m) |
| hd | Tree height (m) and diameter (cm) ratio |
| dinc | The height of branch in tree (m) |
| hrel | Relative height of the branch in crown (*h-dinc*) /*cl* 0, ..., 1 |
| mcrown | Total dry mass of living crown (kg) |
| mbranch | Total dry mass of living branch (kg) |
| mneedle | Total dry mass of needle (kg) |
| mcum(crown) | Cumulative relative biomass of live crown 0, ..., 1 |
| mcum(branch) | Cumulative relative biomass of live branches 0, ..., 1 |
| mcum(needle) | Cumulative relative biomass of needles 0, ..., 1 |

**Table 2. Mean, standard deviation and range of stand and tree variables.**

| Variables | Units | Modeling data | | | Validation data | | |
|---|---|---|---|---|---|---|---|
| | | N | Mean (S.D.) | Min-max | N | Mean (S.D.) | Min-max |
| Plot(n=22) | | | N=17 | | | N=5 | |
| bas | $m^2ha^{-1}$ | 17 | 30.73(7.07) | 17.7-47.9 | 5 | 32.91(6.21) | 26.0-44.0 |
| ccf | | 17 | 74.66(32.11) | 18.5-142.6 | 5 | 70.96(25.72) | 35.3-104.6 |
| Tree(n=1595) | | | N=1248 | | | N=347 | |
| $d_{1.3}$ | cm | 1248 | 22.2(3.5) | 5.7-34.9 | 347 | 23.88(4.7) | 14.6-40.2 |
| h | m | 1248 | 21.2(2.1) | 6.7-29.4 | 347 | 22.7(2.32) | 16.5-29.8 |
| hd | % | 1248 | 0.97(0.1) | 0.61-1.75 | 347 | 0.97(0.15) | 0.52-1.39 |
| hcb | m | 1248 | 10.6(3.2) | 2.0-19.9 | 347 | 9.61(3.65) | 2.5-18.3 |
| cr | % | 1248 | 0.5(0.2) | 0.14-0.91 | 347 | 0.58(0.15) | 0.21-0.88 |
| cl | m | 1248 | 10.6(3.4) | 2.0-21.7 | 347 | 13.09(3.73) | 4.4-24.4 |
| cw | m | 1248 | 3.8 (0.9) | 1.6-7.8 | 347 | 3.701.12) | 1.7-8.85 |
| Branch(n=5325) | | | N=3897 | | | N=1428 | |
| mneedle | kg | 3897 | 0.2(0.2) | 0.002-5.47 | 1428 | 0.13(0.3) | 0.001-4.61 |
| mbanch | kg | 3897 | 0.1(0.1) | 0.002-3.80 | 1428 | 0.25(0.46) | 0.001-5.41 |
| mcrown | kg | 3897 | 0.3(0.3) | 0.004-6.19 | 1428 | 0.39(0.6) | 0.003-6.39 |

within the live crown is called "Layer". Every branch in each crown layer was numbered and surveyed. Crown biomass mainly included branch biomass and needle biomass. A standard branch selected for each layer was a branch that was growing very well within each layer. The standard branch was used to determine the crown biomass. The weight of standard branches were measured and the needles were removed from the standard branches, and then branches and leaves were taken samples. To estimate the biomass of crown, the samples were dried, and moisture content was measured in the laboratory. The variables used in this study were described in Table 1. The stand and tree data were summarized in Table 2.

## 2. Crown ratio model

The crown size was determined by crown length and width. Thus, the crown length and width models were needed to be constructed to estimate crown dimension. The crown ratio instead of crown length was used in this paper.

The crown ratio will reflect tree competition and size in stand. Generally, the tree had higher crown ratio in low density stand, but with increasing density, crown recession increases. As the live crown diminished, the relation of crown ratio and competition showed random variation. Although the relationships were distinct between species, the similar tendency of these relationships could be described by a saturation curve. Hasenauer and Monserud (1996) applied Logistic function to predict the crown ratio.

$$cr = \frac{1}{1+e^{-x\beta}} \quad (1)$$

where *cr* is the crown ratio and $x\beta$ is a linear combination of independent variables and unknown coefficients.

The basic tree size variables (tree height and $d_{1.3}$) were applied. The tree height and diameter ratio(*hd*) are an important variable of the taper of a tree and are related to crown ratio. The competition of trees are reflected by the basal area (*bas*) and crown competition factor(*ccf*). The advantage of *ccf* is that it is independent of stand age and site, and the advantage of *bas* is that it can be used to measure the competition under diversified thinning treatments(Hasenauer and Monserud, 1996; Timo and Eero, 2008). From above, the function used in this study is expressed as:

$$cr = \frac{1}{1+e^{a_0+a_1\times h+a_2\times ccf+a_3\times \log(bas)+a_4\times hd}} \quad (2)$$

where $a_0$, $a_1$, $a_2$, $a_3$ and $a_4$ are unknown coefficients and *h*, *ccf*, *bas* and *hd* are showed as in Table 1.

## 3. Crown width model

Since the crown width (*cw*) of each tree was obtained by measuring crown radius of two directions such as north to south and east to west, the mean radius of twice measurements was used in this study. We considered linear regression model predicting the mean crown radius as a function of $d_{1.3}$, *h* and *hd*.

The form of the model is as follows (Pretzsch *et al*., 2002):

$$\ln(cw) = a_0 + a_1\times\ln(d_{1.3}) + a_2\times(h) + a_3\times\ln(nd) + \varepsilon \quad (3)$$

where $a_0$, $a_1$, $a_2$ and $a_3$ are unknown coefficients, $d_{1.3}$, *h* and *hd* are showed as in Table 1 and ε is the random error term.

### 4. Crown biomass models

The cumulative distribution of total living crown mass and needle mass was found to follow a sigmoid shape from the crown base to the top of the tree. To describe the mass distributions, the flexible three-parameter Chapman–Richards function was used in this study. This model has been commonly used for the description of stand development (Timo and Eero, 2008). The transformed form of the model was applied in the study and was developed for live crown mass, branch mass and needle mass. We assumed that the relative distribution of the crown mass components was the same for different stands as well as for trees with different sizes. The form of the mode using in this study is showed as follow:

$$f(x) = a_0 + \frac{a_1}{(1 + e^{-(h_{rel} - a_2)/a_3})} \quad (4)$$

where $f(x)$ is cumulative relative biomass of live crown, branch and needle, $a_0$, $a_1$, $a_2$ and $a_3$ are unknown coefficients and $h_{rel}$ is showed as in Table 1.

The model (2) and (4) were fitted by applying the STATISTICA procedure "NLIN" using the Gauss–Newton method. Root mean square error (RMSE) and coefficient of determination ($R^2$) were used to evaluate model fittings.

### 5. Validation

The validation date set includes 25 sample trees of 5 sample plots (Table 2). The independent validation procedures for each model in the validation data were performed using the following statistical measures: Mean Error (ME), Mean Absolute Error (MAE), Relative Mean Error (RME), Relative Mean Absolute Error (RMAE), and Precision Estimation (Li *et al.*, 2001).

## Results

### 1. Crown ratio model

The fitted results of crown ratio model (Eq. (2)) were showed in Table 3. The estimated parameters all passed t-test if we set significant level at 0.05, $R^2$ is 0.45 and RMSE is 0.093 (Table 3). Based on the sign of estimated coefficients, the higher the stand basal area or more suppressed the status of the tree (negative height competition index) may correspond to the lower crown ratio. The plot of residuals showed no obvious trend (Figure 1).

### 2. Crown width model

The diameter at breast height ($d_{1.3}$) was used in crown width model because previous studies have showed that $d_{1.3}$ was the most important variable to predict width of crown radius. The regression equations (3) were fitted

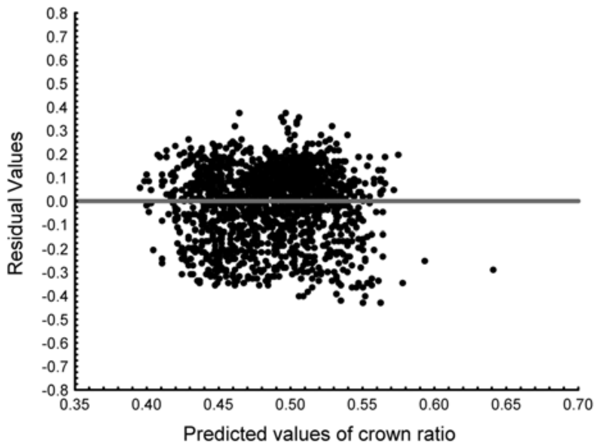


**Figure 1. Residuals for model estimating crown ratio.**

**Table 3. Parameter estimates and fit statistics of equation (2).**

| Parameters | Estimate | Standard Error | t-value | p-value | Fit statistics | | |
|---|---|---|---|---|---|---|---|
| | | | | | n | RMSE | $R^2$ |
| $a_0$ | -0.4275 | 0.154129 | -0.94141 | 0.046638 | 1248 | 0.093 | 0.45 |
| $a_1$ | 0.0348 | 0.007605 | 4.58252 | 0.000005 | | | |
| $a_2$ | -0.0029 | 0.001244 | -2.40682 | 0.016205 | | | |
| $a_3$ | -0.0712 | 0.005210 | -0.40626 | 0.024606 | | | |
| $a_4$ | 0.1898 | 0.014071 | 1.66426 | 0.026257 | | | |

**Table 4. Parameter estimates and fit statistics of equation (3).**

| Parameters | Estimate | Standard Error | t-value | p-value | Fit statistics | | |
|---|---|---|---|---|---|---|---|
| | | | | | n | RMSE | $R^2$ |
| $a_0$ | 1.114574 | 0.528376 | 1.773736 | 0.046298 | 1248 | 0.074 | 0.69 |
| $a_1$ | -0.266649 | 0.108075 | -0.865533 | 0.046877 | | | |
| $a_2$ | 0.044589 | 0.014884 | 2.995808 | 0.002779 | | | |
| $a_3$ | 1.442424 | 0.308863 | 4.670108 | 0.000003 | | | |

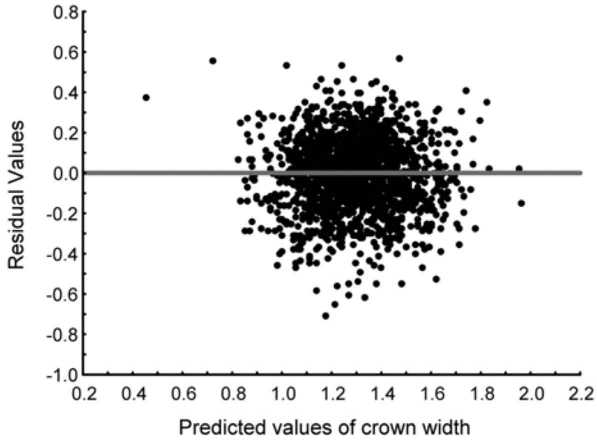


**Figure 2. Residuals for model estimating crown width.**

and $R^2$ and root mean square error (RMSE) were calculated. In Table 4, $R^2$ is 0.69 and RMSE is 0.074. The fitted model was logical and significant at the 0.05 level. The relation between crown width and $d_{1.3}$ is negative and this result of study was consistent with former research (Pretzsch *et al*., 2002). The plot of residuals showed no obvious trend (Figure 2).

### 3. Biomass distribution models in crown

The function (4) fitted the sigmoid shape of the cumulative relative biomasses of living crown, branch and needle quite well (Table 5). For the cumulative relative biomass of living crown (*mcum(crown)*), $R^2$ is 0.96 and RSME is 0.047, For the cumulative relative biomass of living branch (*mcum(branch)*), $R^2$ is 0.95 and RSME is 0.052, For the cumulative relative biomass of living needle (*mcum(needle)*), $R^2$ is 0.94 and RSME is 0.054. The plots of residuals showed no obvious trend (Figure 3), but in the upper quarter of the canopy, the model was slightly rigid (Figure 4).

The study showed that the percentage of needle biomass was scanty within the height of 0.2*cl* and the value of cumulative needle biomass was less than 10% of the total needle biomass. When the relative distance from crown base achieved 0.4*cl*, the value of cumulative needle biomass was about 20% of the total needle biomass. When relative distance from crown base achieved 0.5*cl* (the location was the half distance of crown), the percentage of needle biomass gradually increased and the value of cumulative needle biomass was about 30% of the total needle biomass. With the relative height increasing, the percentage of needle biomass achieved the largest value in 0.6-0.7*cl*, but the increasing rate of percentage of needle biomass was slow in 0.9*cl*. So the photosynthesis was stronger in middle location of the crown, and the distribution of total dry mass of branch, needle and crown were uniform (Figure 4). These characters were consistent with biology character of the *Larix olgensis*.

### 4. Model validation

For the validation purpose, the fitted models of crown ratio, crown width, and cumulative relative biomass of crown, branch and needle were applied to the validation data set and then several evaluation statistics including ME, MAE, M%E/%, MA%E/% and Precision/% were computed, The result of validation statistics was summarized in Table 6.

The validation results indicated that deviance measures were all fairly low. The fitted crown width model was slightly underestimated the validation data, but the mean absolute errors (MAE) and the mean percent errors (M%E) are 0.18 and -23.91% respectively. Thus the predictions for crown width are reasonably precise, but slightly biased.

**Table 5. Parameter estimates and fit statistics of equation (4).**

| Attribute | Parameters | Estimate | Standard Error | t-value | p-value | Fit statistics | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | n | RMSE | $R^2$ |
| Crown mass | $a_0$ | -0.0473 | 0.0143 | -7.387 | 0.0000 | 3897 | 0.047 | 0.958 |
| | $a_1$ | 1.1723 | 0.0466 | 26.968 | 0.0000 | | | |
| | $a_2$ | 0.6685 | 0.0117 | 54.163 | 0.0000 | | | |
| | $a_3$ | 0.1914 | 0.0115 | 20.470 | 0.0000 | | | |
| Branch mass | $a_0$ | -0.0652 | 0.0163 | -7.544 | 0.0000 | 3897 | 0.052 | 0.945 |
| | $a_1$ | 1.1615 | 0.0444 | 27.871 | 0.0000 | | | |
| | $a_2$ | 0.6218 | 0.0100 | 58.619 | 0.0000 | | | |
| | $a_3$ | 0.1957 | 0.0116 | 20.107 | 0.0000 | | | |
| Needle mass | $a_0$ | -0.0673 | 0.0151 | -7.162 | 0.0000 | 3897 | 0.054 | 0.935 |
| | $a_1$ | 1.2649 | 0.0484 | 25.967 | 0.0000 | | | |
| | $a_2$ | 0.6899 | 0.0121 | 52.282 | 0.0000 | | | |
| | $a_3$ | 0.2164 | 0.0120 | 19.693 | 0.0000 | | | |

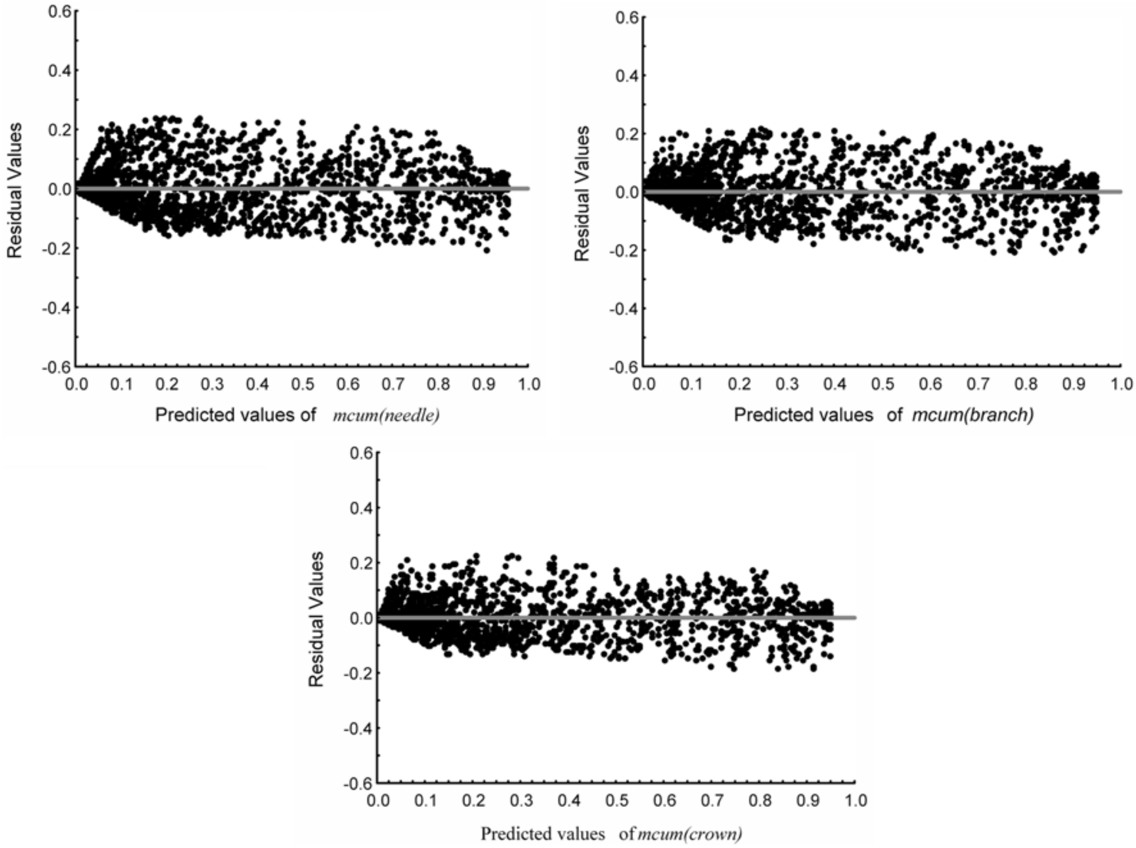


**Figure 3. Residuals for Eq. (4) estimating the cumulative relative biomass of live crown, branch and needle.**

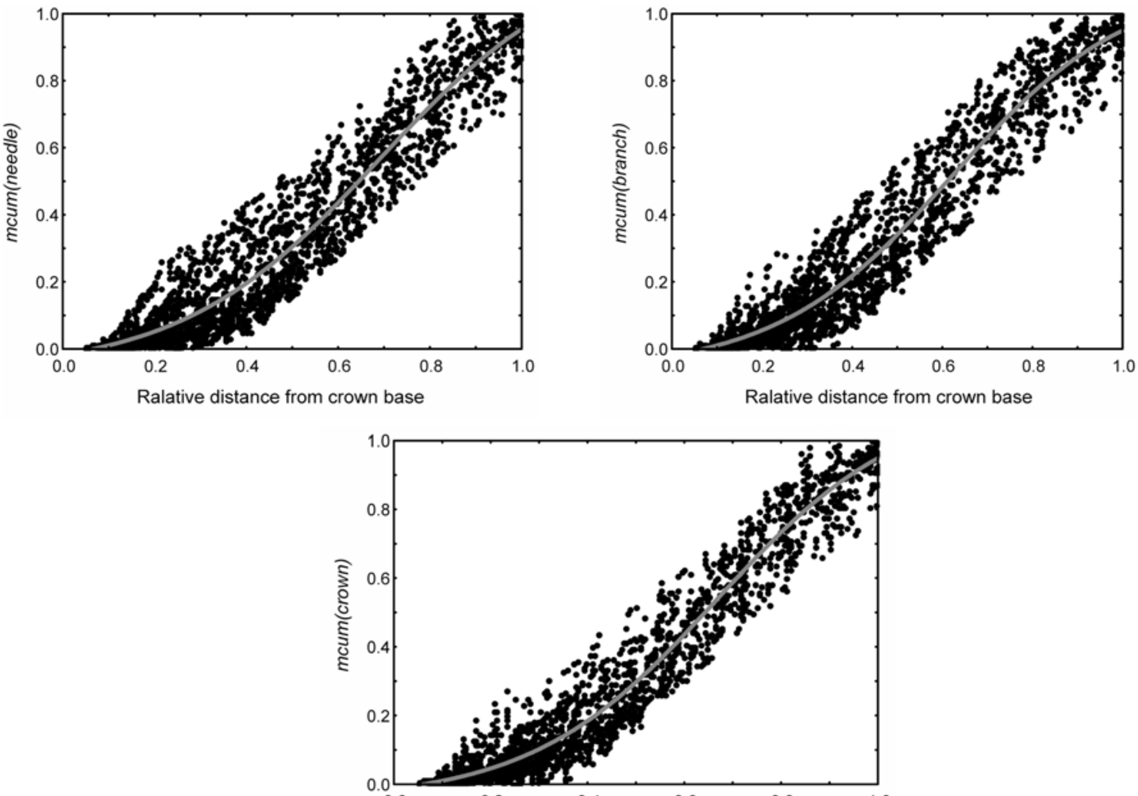


**Figure 4. The predicted and observed cumulative relative biomass of live crown, branch and needle.**

**Table 6. Validation results of equation (2), (3), and (4).**

| Model | ME | MAE | M%E /% | MA%E /% | Precision /% |
|---|---|---|---|---|---|
| Crown ratio | 0.1351 | 0.1715 | 16.6177 | 27.7988 | 96.1718 |
| Crown width | 0.1572 | 0.1889 | -23.9105 | 52.9105 | 90.6969 |
| Cumulative relative biomass of crown | 0.07300 | 0.1211 | -2.1451 | 53.8168 | 97.2234 |
| Cumulative relative biomass of branch | 0.0425 | 0.0933 | -7.2846 | 42.7102 | 97.5084 |
| Cumulative relative biomass of needle | 0.0658 | 0.1073 | 4.2400 | 43.0966 | 97.2571 |

## Discussion

### 1. Crown models

The stand's and tree's growth history, like earlier thinnings, Competition effects were estimated by crown competition factor (*ccf*) and stand basal area (*bas*) in Eq. (2). The *ccf* and logarithmic *bas* were significant for the crown ratio model, resulting in decreasing crown ratio as competition increases. Hasenauer and Monserud (1996) developed a crown ratio model for all major tree species in Austria. Timo and Eero (2008) found that a negative sign of *hd* ratio in crown ratio model indicated that the living crown may decrease as *hd* ratio increases. A negative competition factor, *ccf* and *bas,* which reacted the effect of suppression on a tree, reduced the crown length estimates.

Tree crown width is an important measure for several key factors in stand management (Pretzsch *et al*., 2002). On an individual tree basis, it helps to describe competition between trees and by being related to branch thickness, it also indirectly affects timber quality (Van Laar, 1973), and thus the economic value of a tree. On a stand basis, it is a general competition measure and an important measure of habitat quality, and also can evaluate crown closure. The crown width model provides adequate crown diameter predictions for China *Larix olgensis* plantations. The selected model, like the rest of the functions tested, uses diameter at breast height as predictor variable because it is by far the most common variable used in crown diameter prediction models (Bechtold, 2003). Diameter at breast height is the strongest predictor of crown diameter. Many researchers used diameter at breast height as predictor variable. For example, Paulo *et al*. (2002) reported an improvement in a model to relate crown diameter to diameter at breast height in open cork oak woodlands by including a crown shape parameter and distance to the nearest tree.

### 2. The distribution of biomass in crown

In closed-canopy plantation of larch pine, crown, branch and needle biomass were largely correlated with relative distance from crown base. The relationship of crown, branch and needle biomass to relative distance from crown base was known to vary by species. The maximum values of branch, needle and crown biomass occurred near sixty percent of the relative distance from crown base for larch. The branch, needle and crown biomass were distinct with tree size, and the crown biomass of dominant tree was greater than the suppressed tree. The results were similar to the past researches (Figure 4). The maximum values of crown, branch and needle biomass occurred near the midpoint of the crown for western hemlock, two-thirds up the crown for Douglas-fir, and gradually increases up the crown for grand fir (Kershaw and Maguire, 1995). The crown, branch and needle biomass does not differ significantly among upper crown levels, but it is lower at the crown bottom (Horntvedt, 1993). At the crown base, although branches diameter are larger, less foliages on them are sustained probably because of the limitation of light availability (Valentine *et al*., 1994).

The models of the cumulative relative biomass of live crown, branch and needle were fitted quite well in this study. The relative height at which the needle biomass reached its maximum point was 60% for larch pine. The needle biomass reached its maximum point was 47% for pine and 52% for spruce (Timo and Eero, 2008). In pine stands of various ages, the vertical foliage density peaked at about 50% relative height (Makela and Vanninen, 2001). These results showed that the height of efficiency crown was in location of 60% crown.

## Conclusion

The crown ratio and width models built in this study can be utilized for the thinning system to analyze the transformation of crown. The distribution model of crown biomass may be applied to analyze the physiological processes, such as photosynthesis, respiration, transpiration, to estimate the light interception within the canopy in crown on different treatments, and to explain the transformation of crown (crown length and width) and tree growth situation. These models can be applied to improve the current forest management modeling system.

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