Design and Development of Sapling Growth Simulation System

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Abstract

Sapling growth simulation is of great importance to forest management planning, however, few convenient tools were developed for practical use. In order to facilitate simulating sapling growth in uneven-aged spruce (Picea Koraiensis Nakai) and fir (Abies nephrolepis (Trautv.) Maxim.) forest stands in Northeastern China, a simulation system was developed. Firstly, The models for recruitment of established seedlings, and the survival, increment, and diameter at breast height (DBH) of saplings were separately built with the methods of generalized linear models and mixed linear models. Secondly, concept model was constructed by drawing flow chart. Thirdly, the fields and format of the sheets were designed and the codes of the main modules were programmed based on the previous established models. Finally, the system was developed with Excel VBA programming language. Testing results show that the system can precisely predict short-term growth dynamics of saplings.

Keyword: Sapling Growth Simulation System, Generalized Mixed Linear Models, Excel VBA

1. Introduction

Forest management decision making requires various information amongst which prediction for forest dynamics is of most significance [1]. Tree growth models are mostly applied in predicting forest dynamics. They are generally categorized into single tree and stand growth models according to different unit levels [2-4] and from modeling method perspective; they can be classified into empirical and mechanistic models.

Compared to the extensive work on single tree empirical models [5-8], less consideration has been paid to modeling of seedlings (height<0.3m) and saplings (height>0.3m and DBH<5 cm), possibly due to the difficulty in measuring accuracy. However, seedling and sapling dynamic determine the future species composition and need further fine-scale study. Similarly, simulation systems or simulators mostly focus on simulating tree growth and ignore sapling growth modeling. Until now, only a few simulation systems were reported for modeling sapling dynamics. i.e. Eerikäinen et al. [9] have simulated the regeneration establishment, the survival and development of established seedlings by developing a simulator comprised of different modules in uneven-aged, Norway spruce (Picea abies (L.) H. Karst.) and fir (Abies nephrolepis (Trautv.) Maxim.) forest stands in southern Finland. Marks and Lechowicz [10] have simulated the growth process of organ (leaves, shoot and roots) and whole seedling by using the genetic algorithm in TAD.

Generally, the systems or tools constructed with VB, C#, C++ cannot operate directly workbooks of Microsoft Excel and data in Excel need to be imported into the databases of the systems or tools, which result in inconvenience for data analyzing. In contrast, VBA embedded in Excel can manipulate directly workbooks of Microsoft Excel. Besides, three main advantages of VBA have been proposed by Palocsay and collaborators: (1) using Excel as a database; (2) creating PivotTable s (R) and PivotCharts (R) ; (3) importing data using Excel as an automation container. As a result, VBA has been mostly preferred for systems development in recent years [11]. Up to now, some DBMISs (data base management information systems), GISs (geographic information systems) [12], DSSs (decision support systems) [13] and special software in regression analysis [14-17] and charting [18-19] have been developed.

The objectives of this study is to develop a simulator with Excel VBA to simulate recruitment, the survival and growth of saplings, and hence provide decision making for uneven-aged spruce and fir forest management in Changbai Mountains, China.
2. Establishment of sapling growth models

Based on 2-year monitoring period (in 2010 and 2011) of 50 permanent sample plots in uneven-aged spruce and fir forest stands in Northeastern China, we built recruitment models, height distribution models, survival models, increment models with the methods of generalized linear models and mixed linear models.

2.1. Competition index

Competition index was calculated for each sapling using Hegyi’s index.

\[
CI_{ij} = \sum_{t=1}^{N} \left( \frac{CW_{it}}{CW_{ij}} \right) / (DIST_{ij})
\]

where \( CI_{ij} \) is the Hegyi’s index for sapling \( j \) in plot \( i \) with \( N \) surrounding competitors (\( t=1 \) to \( N \)) within the Maximum Competition Distance (MCD). Here, crown width (\( CW_{ij} \) and \( CW_{ijt} \)), instead of diameter at breast height, and the MCD of 5 m yields was selected.

2.2. Recruitment models

Logistic regression model was adopted for estimating recruitment probability \([20-21]\). For recruitment density (individuals per hectare) prediction, conditional Poisson regression model was used.

\[
\text{logit}(\pi_j) = 0.5839 - 0.7598 + 0.0006 - 0.0144 - 0.8547 \times 0.0001
\]

\[
\ln(\mu_j) = 0.6407 - 0.2394 + 0.0001 SD - 0.0276 SE - 0.2280 HC
\]

where \( \pi_j \) is the recruitment probability (0 = absence indicated by probability \( \pi_i \) and 1 = presence indicated by \( 1-\pi_i \)), \( \mu_j \) is the density of established saplings in plot \( j \). CD, SD, SE, HC, SC and CItotal are overstory density, sapling density, slope, herb cover, shrub cover, and plot total competition index of all saplings, respectively.

2.3. Height distribution model

The left-truncated Weibull distribution \([22]\) was used to simulate initial height distribution of saplings assessed at the beginning of one-year period for all species combined as well as individual species.

\[
n_i = N \times W \times 0.811 \times \left( \frac{h_i}{0.126} \right)^{-0.189} \times \exp\left[ \frac{0.3 - \left( \frac{h_i}{0.126} \right)^{0.811}}{0.126} \right]
\]

where \( h_i \) is the mid-value of class \( i \) at an interval of 30 cm, bw is a scale parameter, cw is a form parameter, and tw is a fixed truncation point, typically the smallest height value. Model (4) was built with an Excel VBA algorithm of unitary non-linearity regression equation according to the principle of minimum sum of squared residuals \([23-25]\).

2.4. Survival model

Survival of individual sapling was modeled using Logistic Regression.

\[
\ln\left( \frac{\mu_{ij}}{1-\mu_{ij}} \right) = 7.4708 - 0.3957 \times CD_j + 0.0002 \times SD_j - 0.6246 \times SC_j + 0.3889 \times DBH_j
\]

\[
-0.05715 \times D_j + 0.5118 \times \ln(D_j) + 0.7396 \times H_j - 1.0093 \times \ln(H_j) - 0.3259 \times \sqrt{CI_{ij}} + \mu_{ijj}
\]

\( \mu_{ijj} \sim N(0, 0.4629) \);
where $P_{ij}$ is survival probability of sapling $i$ in plot $j$, and $\mu_0j$ is the residual error at plot level. CD, SD, SC are overstory density, sapling density, shrub cover, respectively.

**2.5. Increment models**

Models were fitted separately for DBH (diameter at breast height) and growth increments of height, ground diameter and crown width using mixed linear models (MLMs).

$$DBH_{ij} = -0.9769 + 0.1220 \times CD_j - 0.2504 \times SC_j + 0.3264 \times H_{ij} + 0.1093 \times CW_{ij} + 0.04969 \times CD_j \times SD_j + 0.00369 \times SC_j \times SD_j + 0.008264 \times CD_j \times SC_j + 0.0581 \times \sqrt{CI_{ij}} + \mu_{ij} + \mu_{0j} \times D_{ij} + e_{ij}$$  \hspace{1cm} (6)

$$\mu_{0j} \sim (0,0.038561) \quad \mu_{ij} \sim (0,0.000047) \quad e_{ij} \sim (0,0.4437)$$

$$\sqrt{ih_{ij}} = 0.1902 - 0.00352 \times CD_j - 0.00000146 \times SD_j + 0.02344 \times DBH_{ij} + 0.09411 \times \sqrt{H_{ij}} + 0.06519 \times CW_{ij} + 0.000264 \times CI_{ij} - 0.00365 \times \sqrt{CI_{ij}} + \mu_{ij} + \mu_{0j} \times SD_j + e_{ij}$$  \hspace{1cm} (7)

$$\mu_{ij} \sim (0,0.000551) \quad \mu_{0j} \sim (0,0.003601) \quad e_{ij} \sim (0,0.04013)$$

$$\sqrt{id_{ij}} = 1.2001 - 0.00003 \times SD_j + 0.008318 \times D_{ij} + 0.1332 \times H_{ij} + 0.1374 \times CW_{ij} + \mu_{ij} + e_{ij}$$  \hspace{1cm} (8)

$$\mu_{0j} \sim (0,0.05861) \quad e_{ij} \sim (0,0.4848)$$

$$\sqrt{iw_{ij}} = 0.3319 + 0.06635 \times H_{ij} + 0.03236 \times CW_{ij} - 0.00035 \times CI_{ij} + \mu_{ij} + e_{ij}$$  \hspace{1cm} (9)

$$\mu_{0j} \sim (0,0.000594) \quad e_{ij} \sim (0,0.02311)$$

where $\mu_0j$ and $\mu_1j$ are the residual errors at plot level and $e_{ij}$ is the residual error at individual tree level. The items, $DBH_{ij}$, $ih_{ij}$, $id_{ij}$ and $iw_{ij}$ represent diameter at breast height, the growth increments of height, ground diameter, and crown width of sapling $j$ in plot $i$.

**3. System design**

Firstly, data at plot level and tree level was inputted into the system, and then competition index of each sapling was calculated. Subsequently, survival probability of each sapling was estimated. When survival probability was more than 0.5, increment of height, ground diameter and crown width of each sapling were separately calculated by relevant models with competition index as one of independent variables. Competition index need to recalculate due to the dynamics of height, ground diameter and crown width. If the height of each sapling was more than 1.3 m, DBH was predicted with the corresponding models. At the end of each simulation time-span, recruitment models were applied to predict recruitment probability and density. Finally, the number of recruited seedlings in each height and ground diameter class was displayed in the form of charts, respectively (Figure 1).

The Sapling Growth Simulation System based on Excel VBA consisted of the user interface, four Excel sheets and abundant program codes embedded in Excel workbook. User interface was convenient for human computer dialogue. Excel sheets were used as database, where initial data at plot and tree level and processed data were stored. In addition, charts were displayed in “Height-density distribution” and “GD-density distribution” sheets, respectively.

The workbook ‘simulator’ included “Primitive data”, “simulation results”, “Height-density distribution” and “GD-density distribution” sheets (Figure 4). The sheets of “Primitive data” and “Simulation results” were used for storing initial data and processed data, respectively. Both of them included “plot number”, “tree species”, “tree number” and “coordinates x and y” fields. However, the field values “the DBH”, “height”, “ground diameter”, “crown width” and “competition index” in “Primitive data” were measured in 2011 and that in sheet “Simulation results” were automatically predicted at specified simulation time (Figure 3). When simulation process ended, the number of saplings in each height class and ground diameter class were automatically counted in “Height-density distribution” and “GD-density distribution” sheets, respectively.
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Firstly, a commandbar was defined and established, then controls commandbarpopup were added with the method “add () “. Finally, dropdown menus were acquired by applying “add () “ method of controls commandbarpopup to msocontrolbutton. The system includes four dropdown menus: “Data management”, “Simulation”, “Statistical analysis” and “Charting” (Figure 2). Part of codes was as flow:

Public Sub addpopupbar ()
Dim cmbnewbar As CommandBar
Dim mbtn As CommandBarPopup
Dim ct1btn As CommandBarButton
Set cmbnewbar = CommandBars.Add (Name: =" Sapling Growth Simulation System")
    With cmbnewbar
        Set mbtn =.Controls.Add (msoControlPopup)
            With mbtn
                .Caption = "Data management"
                Set ct1btn =.Controls.Add
                    With ct1btn
                        .Caption = "Open files"
                        .OnAction = "Open files"
                    End With
                Set ct1btn =.Controls.Add
                    With ct1btn
                        .Caption = "Save files"
                        .OnAction = "Save files"
                    End With
                Set ct1btn =.Controls.Add
                    With ct1btn
                        .Caption = "Delete files"
                        .OnAction = "Delete files"
                    End With
    End With
End Sub
The main modules are used to compute competition index, predict DBH, height, ground diameter and crown width, estimate recruitment probability and density and charting.

A. Design of module of simulation

The integrated module involve process of computing competition index, computing DBH, height, ground diameter and crown width and computing recruitment probability. The main codes were as follow:

```vba
Sub simulation()
    Dim simulation As Integer
    Dim times As Integer
    Dim input As String
    Dim com As Integer
    Dim res As Integer
    Dim simu As Integer
    Dim output As String

    simu = InputBox("Please input simulation time (y) ")
    For times = 1 To simu
        growth
        Next times
        rescruiment
    End Sub
```

B. Design of module of computing competition index

The module was mainly used to compute each sapling competition index. The index was calculated with N surrounding living competitors within 5 m range from the sapling by calling the defined distance function.

C. Design of module of computing DBH, height, ground diameter, crown width and recruitment probability and density

Firstly, height, ground diameter and crown width of each sapling was predicted based on established growth models. Moreover, competition index of each sapling was computed once more. Subsequently, when sapling height reached 1.3m, the DBH of the saplings were calculated. Finally, recruited probability and density were predicted by logistic regression model and conditional Poisson regression model, respectively.
Charts displaying the relation between height or ground diameter classes and sapling density were generated by Chart object in Excel. The codes were acquired by recording a macro, and modified when necessary. Firstly, the type of figure was expressed in broken line chart. Moreover, data of height or ground diameter classes and sapling density in each height or ground diameter classes were added to Series Collection of the active chart. Finally, chart and axis tiles were named.

4. Experimental results

The data of 20 plots measured in 2011 and 2012 was used for system test. The means (Bias) and standard deviations (root mean square error, RMSE) were adopted for validation. The relative formulas are as follows:

\[
Bias = \frac{1}{n} \sum_{i=1}^{n} (w_i - \bar{w}_i)
\]

RMSE = \left( \frac{1}{n} \sum_{i=1}^{n} (w_i - \bar{w}_i)^2 \right)^{\frac{1}{2}}

where \(w_i\) is the observed value in 2011, \(\bar{w}_i\) the predicted value in 2012, and \(n\) the number of observations. Most of the developed models generally had good precision.

<table>
<thead>
<tr>
<th>Models</th>
<th>Number of saplings</th>
<th>Bias</th>
<th>Bias%</th>
<th>RMSE</th>
<th>RMSE%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability models of sapling recruitment</td>
<td>20</td>
<td>0.06</td>
<td>13</td>
<td>0.76</td>
<td>150</td>
</tr>
<tr>
<td>Density models of recruited saplings</td>
<td>15</td>
<td>-0.153</td>
<td>-2.6</td>
<td>1.355</td>
<td>23.1</td>
</tr>
<tr>
<td>survival models</td>
<td>571</td>
<td>-0.058</td>
<td>-6.4</td>
<td>0.281</td>
<td>31.1</td>
</tr>
<tr>
<td>Growth models of height</td>
<td>489</td>
<td>0.039</td>
<td>25.3</td>
<td>0.021</td>
<td>92.8</td>
</tr>
<tr>
<td>Growth models of ground diameter</td>
<td>538</td>
<td>0.69</td>
<td>24.3</td>
<td>2.72</td>
<td>95.7</td>
</tr>
<tr>
<td>Growth models of crown width</td>
<td>538</td>
<td>0.043</td>
<td>18.3</td>
<td>0.178</td>
<td>76.1</td>
</tr>
<tr>
<td>DBH models</td>
<td>192</td>
<td>0.122004</td>
<td>7.7</td>
<td>0.291</td>
<td>34.2</td>
</tr>
</tbody>
</table>

Comparatively, the Biases and RMSEs of recruitment probability models were considerably higher than other models (Table 1).

5. Conclusion

According to the test data most of models for simulation systems were successfully established, though recruitment probability models do not have sound precision.

Therefore, Sapling Growth Simulation System (SGSS) integrated with recruitment models, survival models, increment models can more logically simulate short-term dynamics of saplings in spatially and structurally heterogeneous forest stands.

However, due to lack of long-term continuous observation, long-term prediction results of the Sapling Growth Simulation System (SGSS) cannot be validated. To acquire suitable validation data, an ongoing study is expected to implement within the next year. Moreover, a quantity of variables in certain models, such as canopy density, coverage of herbaceous, coverage of shrub, will change with prediction time. However, the variables were assumed to be constant in all established models. The influence of variables change on the precision of models need to be further explored. If the influence is significant, then the relative models, which express change of the variables, need to be established.

Excel VBA programming language has many advantages. Firstly, it is embedded in Microsoft Excel and its runtime environment and operation object is just Excel workbook. Therefore, it operates directly data in Excel workbook in which most forestry data are. That is to say database is not compulsory for deep data exploration. However, VBA can also simply operate database such as Microsoft Access,
Microsoft SQL Server, Oracle and other databases through ADO module. Hence, workload of programming is greatly reduced. Furthermore, Excel workbook itself has very powerful statistical analysis and charting function. The processes of implement of the functions can be recorded by a new macro and the codes can be modified when necessary. Thus most of functions in Excel workbooks can be implemented by VBA.

Generally, when systems are developed by using VBA, fields and format of sheets and main modules should be separately designed in the framework of the systems flow charts. Sheets are mainly used for storing initial data and processed data. Modules are mainly engaged to implement the all functions of the systems or tools.

On the whole, Sapling Growth Simulation System (SGSS) developed with Excel VBA can easily be operated and precisely predict short-term growth dynamics of saplings and hence provide valuable information for the spruce and fir forest in Northeastern China.

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7. References