sustainability

Article

The Extension and Improvement of the Forest Land Net Present Value Model and Its Application in the Asset Evaluation of *Cunninghamia lanceolata* Forest Land

Weiping Hua [1,2], Tian Qiu [2], Xin Pan [1,3], Chengzhen Wu [1,2], Chongyang Zhuang [1], Shangping Chi [1], Xidian Jiang [1,*] and Jianwei Wu [4,*]

1 Forestry College, Fujian Agriculture and Forestry University, Fuzhou 350002, China
2 Fujian Provincial Key Laboratory of Eco-Industrial Green Technology, Wuyi University, Wuyishan 354300, China
3 Forest Seed and Seedling General Station of Fujian Province, Fuzhou 350003, China
4 Survey Planning and Design Institute, State Forestry and Grassland Administration, Beijing 100714, China
* Correspondence: fujianjxd@163.com (X.J.); wujianwei2018@163.com (J.W.); Tel.: +86-599-5136976 (X.J.)

Abstract: In order to solve the problem in that the classical forest land expectation value method ignores the actual forest stock volume when assessing the income at the end of the current production cycle in the forest, and fill the research gap in this area, the technical system of the forest land asset evaluation was enriched. The forest land returns were divided into two parts, i.e., the segmented forest land return price from the growth of the actual forest stand to the end of the growth cycle (B_{u1}), and the segmented forest land return price for an infinite number of growth cycles after the growth of the actual forest stand to the end of the growth cycle (B_{u2}). Through structure, the forest land gain price expansion model was obtained, and the stand quality including the average diameter at breast height, average height, stock volume, and outturn of stand as dummy variables were used to construct the growth harvest model related to asset evaluation. Taking *Cunninghamia lanceolata* forest land as an example, the traditional asset evaluation methods were comparatively analyzed. The residual standard deviation (RSD) of the growth model was less than 10%, the total relative error (TRE) and mean system error (MSE) were within ±10%, the mean prediction errors (MPE) were less than 5%, and the mean percentage standard errors (MPSE) were less than 10%, respectively. Combining the forest land net present value expansion model with the traditional evaluation method, the evaluation value of the forest land assets was subsequently calculated, and accordingly, the forest land asset evaluation prime stand factors were predicated. It was found that the valuation results of the forest land net present value expansion model were consistent with the actual situation. The forest land net present value expansion model can therefore be used for asset evaluation of tree forest land (including natural uneven-aged forest land), bamboo forest land, shrub forest land, and economic forest land, and provide new technical support for forest land asset evaluation.

Keywords: land net present value expansion model; woodland asset evaluation; *Cunninghamia lanceolata*

Citation: Hua, W.; Qiu, T.; Pan, X.; Wu, C.; Zhuang, C.; Chi, S.; Jiang, X.; Wu, J. The Extension and Improvement of the Forest Land Net Present Value Model and Its Application in the Asset Evaluation of *Cunninghamia lanceolata* Forest Land. *Sustainability* **2023**, *15*, 9096. https://doi.org/10.3390/su15119096

Academic Editor: Tim Ritter

Received: 14 April 2023
Revised: 25 May 2023
Accepted: 31 May 2023
Published: 5 June 2023

1. Introduction

Forest is the largest terrestrial ecosystem on earth, which not only provides abundant timber but is also a valuable natural barrier for human survival and development. It has significant ecological, economic, and social benefits. However, for a long time, the transitional exploitation, depletion, and waste of forest resources have caused a serious deterioration of the ecological environment and affected the sustainable development and utilization of forest resources. The development of forest resource asset evaluation is an important economic activity for forest property transfer, asset mortgage, and forest rights system reform. It is an important means for the rational use and sustainable management of forest resources by realizing the corresponding paid use and curbing their low-cost or free use.

As an important component of forest resources, forest land assets have been studied in depth, mainly focusing on the establishment of the valuation method [1–3], valuation model research [4–6], value valuation influencing factors [4,7–9], and the improvement of the appraisal technology method [10–12]. This forms a forest land asset appraisal technology system, including the market comparison method, income reduction method, residual method, scoring valuation method, forest land expectation value method, annuity capitalization method, base land value correction method, etc. [3]. In the practice of forest land asset evaluation, the expected price method of forest land has often been used to evaluate the right to use forest land assets. Its basic principle is sustainable clear-cutting, which should be dependent on the site qualities, the geographical conditions, and the amount of labor input. Additionally, the evaluation normally starts with the non-forest land afforestation calculation and is mainly based on the suitable tree species standard growth. The net income at the end of infinitely many rotations is all discounted into a present value, and the sum is then used as an appraisal basis for the asset value of forest resources [2,3]. However, this method starts with the calculation of afforestation without the forest land and ignores the income of the actual forest reserve at the end of the current round of logging.

On this basis, aiming to solve the problem that the forest land expectation value method does not take into account the income at the end of the current round of harvesting in forests, and fill the research gap in this area, this study enriched the technical system of forest land asset evaluation. Taking *Cunninghamia lanceolata*, featured with a fast growth, economic value, widespread cultivation, and high regeneration capacity, as a reference species (or benchmark species), a growth model of *Cunninghamia lanceolata* stands was constructed to predict the average diameter at breast height, average timber yield, stock volume related to stand quality, and the number of main harvesting factors for asset assessment. This study divided the forest land income into two parts, i.e., the segmented stand net present value for a real stand growth to the end of the growth cycle, and the segmented stand net present value for an infinite number of growth cycles after the end of the real stand growth cycle. Through structure, a new forest land evaluation method was constructed, i.e., forest land net present value expansion model. The rationality of the stand net present value expansion model was demonstrated by combining the stand net present value expansion model with the traditional assessment methods.

2. Forest Land Net Present Value Expansion Model

The stand net present value consists of two parts, i.e., the segmented stand net present value (B_{u1}) for a real stand growing to the end of its growth cycle, and the segmented stand net present value (B_{u2}) for an infinite number of growth cycles after the real stand grows to the end of its growth cycle. The sum of B_{u1} and B_{u2} is the unlimited year woodland price (B_u) corresponding to the evaluation base date.

2.1. Segmented Forest Land Net Present Value B_{u1}

The forest land expectation value method was implemented under the assumption of sustained yield harvesting, and calculations were conducted from afforestation on non-forested land. However, in general, most forest land has already been afforested, and only some forest land still has a certain amount of standing timber. In this situation, the forest land asset used value calculated using the forest land expectation value method was lower than the actual value. Based on this situation, this study split the forest land asset used value and considered B_{u1} as the portion of use value ignored by the forest land expectation value method. Assuming the actual age of the forest stand is n years, the net income of the forest land in the tth year is Z_t, the net income in the uth year is Z_u, and the discount rate is

p. Then, the present value of the net present value from the forest land in different years from the tth year to the uth year was calculated as follows:

$$\frac{Z_t}{(1+p)^{t-n}}, \ldots\ldots, \frac{Z_u}{(1+p)^{u-n}} \tag{1}$$

When the production cycle is u, the forest land net present value from the nth year to the uth year, with each year's forest land net present value Z_t discounted to present value, totals:

$$B_{u1} = \sum_{t=n}^{u} \frac{Z_t}{(1+p)^{t-n}} \tag{2}$$

In order to maintain consistency with the formula for the segmented forest land revenue value B_{u2}, this study multiplied both the numerator and denominator of Equation (2) by $(1 + p)^{u\text{-}t}$. After organizing these formulas, the expression for the present value of the forest land revenue B_{u1}, from the actual age of the forest stand to the end of the growth cycle, was obtained as follows:

$$B_u = \frac{\sum_{t=n}^{u} Z_t \times (1+p)^{u-t}}{(1+p)^{u-n}} \tag{3}$$

2.2. Segmented Forest Land Net Present Value B_{u2}

B_{u2} is the sum of the present value of the income of the infinite number of growth cycles after the actual forest stand grows to the end of the growth cycle. It was calculated from the reforestation after harvesting, and the net income of the infinite number of production cycles was all converted to the sum of the present value. This was consistent with the traditional formula of the forest land expectation value method [13]. The forest land expectation value method is based on the premise of implementing sustainable management, assuming that the income on the forest land in each growth cycle is the same. The calculation began from the afforestation without forest land, and the net income of infinite growth cycles was converted into the cumulative sum of the present value, and the sum was used as the assessed value of the forest land asset.

When the actual stand age is n years, the time required to start reforestation at the end of the growth cycle is $u - n$, the net income was discounted into the present value B_{u2} corresponding to the actual stand for n years, namely:

$$B_{u2} = \frac{\sum_{t=1}^{u} Z_t \times (1+p)^{u-t}}{(1+p)^{u-n} \times [(1+p)^u - 1]} \tag{4}$$

The segmented forest land price gains B_{u1} formula and the addition of B_{u2} formula corresponds to the infinite on the forest land price appraisal base date (B_u). Therefore, this study started with the non-forest land and forest land under the premise of forest sustainable management. The net income of the forest land at the end of an infinite number of production cycles was then converted into a cumulative sum of the present value to obtain a new valuation method of the present value of the net income of the forest land for an infinite period of time.

In summary, the forest land net present value expansion model can be expressed as follows:

$$B_u = B_{\mathrm{u}1} + B_{u2} = \frac{\sum_{t=n}^{u} Z_t \times (1+p)^{u-t}}{(1+p)^{u-n}} + \frac{\sum_{t=1}^{u} Z_t \times (1+p)^{u-t}}{(1+p)^{u-n} \times [(1+p)^u - 1]} \tag{5}$$

In Equation (5), B_{u1} is the present value of the forest land net income of the actual forest stand to the end of the growth cycle, B_{u2} is the sum of the present value of the forest land income from the infinite number of growth cycles after the actual forest stand grows to the end of the growth cycle, and the sum of the two is the woodland price of the infinite period corresponding to the evaluation base date. The net income is the value of the forest harvesting income after deducting expenses. while the present value is the current value of a future return, usually discounted at a certain interest rate. Therefore, Equation (5) calculates the net income of the forest land in segments. The *Cunninghamia lanceolata*st stage B_{u1} is the net income of the forest land from the actual stand age or initial age to the end of the growth cycle. It corresponds to a finite period, which can either be an incomplete growth period or a complete growth cycle. If the initial age is calculated from 1 year, it is a complete growth cycle. The second stage B_{u2} is an infinite term. Assuming that the net income of the forest land is the same in each complete growth cycle, B_{u2} was discounted to the present value according to the discount rate. The sum of B_{u1} and B_{u2} was the infinite term land price. Equation (5) was used to estimate the annual land rent (B_z) and the limited term land price (B_n), which can be expressed as Equations (6) and (7), respectively:

$$B_z = p \times B_u \tag{6}$$

$$B_n = B_u \times \left[1 - \frac{1}{(1+p)^T}\right] \tag{7}$$

where T is the service life of the forest land.

In the forest land asset evaluation process, the most active asset in the forest land asset market is arbor forest land, and among all arbor forests, *Cunninghamia lanceolata* wood has a high value and is often used as a reference tree species (or benchmark tree species) for evaluation. Therefore, in this study, an empirical analysis of *Cunninghamia lanceolata* forest assets was conducted with an application of a forest land net present value expansion model. In order to calculate the value of *Cunninghamia lanceolata* woodland assets, the growth model of the woodland net present value was needed to determine the stock volume and stand output. Among them, the stock volume can be determined by establishing a stock volume growth prediction model, and the stand output can be determined by a stand output rate model related to the average diameter at breast height.

3. Forest Stand Growth Prediction Model

3.1. Model Construction

The stand growth model is a mathematical model or set of models that is used to describe the relationship between the tree growth and the stand status and site conditions and is used to estimate or simulate the growth and development process of the stand under various specific conditions. The purpose of establishing the stand growth model was to determine the stand factors for the average level of normal growth at various ages. The stand growth model mainly includes the accumulation model, the average diameter at breast height model, and the average height model.

Choosing the appropriate growth equation is an important basis for establishing a stand growth model. Theoretically, an ideal growth equation should have a strong adaptability and high accuracy, and the equation parameters should have a certain biological significance. Among the commonly used growth equations, Richard's equation can meet the above requirements and has been widely used in forest growth harvest modeling [14–16]. Based on Richard's equation, this study constructed a growth prediction model of the stock volume and average diameter at breast height (Equation (8)), which utilized stock volume and average diameter at breast height as variables. In addition, a stand yield model

(Equation (9)) was also established based on Richard's equation, which uses the average diameter at breast height as the independent variable.

$$Y = A \times [1 - \exp(-K \times t)]^C \tag{8}$$

As displayed above Y is the forest stand factor (average diameter at breast height, average height, stock volume, etc.), t is the stand age, and A, K, C are the model parameters.

$$P = A \times [1 - \exp(-K \times D)]^C \tag{9}$$

Here, P is the total yield of the forest stand, and D is the average diameter at breast height of the forest stand.

In order to improve the prediction accuracy and evaluation accuracy of the model so as to be more suitable for forestry production practice and benchmark price evaluation in the Fujian Province, China, we comprehensively considered the meaning of the model parameters. Among them, A and K are the limit parameter and growth rate parameter, respectively; A, K, and C are constructed functions related to the site quality grade (SI) and stand density (SD), respectively; to be specific, $A = f(\mathrm{SI})$, $K = f(\mathrm{SD})$, and $C = f(\mathrm{SI})$ [17–21]. Accordingly, the general expression of the stand growth and the harvest prediction model with the stand age, site, and density as auxiliary variables can be obtained:

$$Y = f(\mathrm{SI}) \times \{1 - \exp[-f(\mathrm{SD}) \times T]\} f(\mathrm{SI}) \tag{10}$$

The parameters of A and C are functions of the site quality grade. In order to ensure the compatibility and logicality of each site quality grade, dummy variables mode was used to construct realistic stand growth models of each site quality grade. Therefore, the parameters of A K, and C can be constructed in the form of dummy variables as follows:

$$A = f(\mathrm{SI}) = X_1 \times a_1 + X_2 \times a_2 + X_3 \times a_3 + X_4 \times a_4 \tag{11}$$

$$K = f(\mathrm{SD}) = k_1 \times N^{k2} \tag{12}$$

$$\mathrm{C} = f(\mathrm{SI}) = X_1 \times c_1 + X_2 \times c_2 + X_3 \times c_3 + X_4 \times c_4 \tag{13}$$

where X_1, X_2, X_3, and X_4 are the dummy variables, and a_1, a_2, a_3, a_4, c_1, c_2, c_3, and c_4 are the equation parameters, corresponding to the site quality grades of 1, 2, 3, and 4, respectively. The value of the dummy variable was set according to the following rules: when the site quality grade was the *Cunninghamia lanceolata* type of land, X_1 = 1, and X_2, X_3, and X_4 were all 0; when the site quality grade was the second type of land, X_2 = 1, and X_1, X_3, and X_4 were all 0; and the rest can be deduced by analogy. The model parameters were solved by Matlab.

3.2. Model Evaluation

The basic principle of the accuracy test is as follows: using another set of test samples not involved in modeling, the theoretical value calculated by the growth model is the independent variable x, and the actual value is the dependent variable y. Then, the one-dimensional linear regression equation $y = a + bx$ was established. If a model fits well, the actual value should be close to the theoretical value. For the one-dimensional linear regression equation, the closer the regression coefficient a is to 0, and the closer b is to 1, the better the model fit. In addition, the evaluation indicators of the quality of the growth model, including the residual standard deviation (RSD), total relative error (TRE), mean system error (MSE), mean percentage standard error (MPSE), and mean prediction error (MPE), were all used to comprehensively evaluate the applicability of the growth model. The evaluation indicators can be calculated as follows:

$$\mathrm{RSD} = \sqrt{\sum(\mathrm{y} - \hat{y})^2 / (n - m - 1)} \tag{14}$$

$$\mathrm{TRE} = \left(\sum \mathrm{y}_i - \sum \hat{y}_i\right) / \sum \hat{y}_i \times 100\% \quad (15)$$

$$\mathrm{MSE} = \frac{1}{n} \sum [(\mathrm{y}_i - \hat{y}_i)/\hat{y}_i] \times 100\% \quad (16)$$

$$\mathrm{MPSE} = \frac{1}{n} \sum |(\mathrm{y}_i - \hat{y}_i)/\hat{y}_i| \times 100\% \quad (17)$$

$$\mathrm{MPE} = \frac{1}{n}\left[1 - t_\alpha \cdot \sqrt{\sum (\mathrm{y}_i - \hat{y}_i)^2} / \left(\hat{\bar{y}} \cdot \sqrt{n \cdot (n-m)}\right)\right] \times 100\% \quad (18)$$

where t_a is the distribution value of t at the confidence level a, S is the remaining standard deviation of the volume, y and $\hat{y}$ are the actual values of the forest stand investigation factor and the theoretical value of the growth model, respectively, $\hat{\bar{y}}$ is the average theoretical value of the forest stand investigation factor, n is the number of samples, and m is the number of variables in the equation.

4. Materials

In this study, the *Cunninghamia lanceolata* timber forest in Nanping City, Fujian Province was taken as the research object. Data was collected from the forest resource fixed sample plot, temporary sample plot, and sample wood timber plot, including the forest site quality grade (SI), average diameter at breast height (D), average height (H), density (SD), stock volume (M), and wood yield (P), etc. Among them, SI contained four grades, i.e., fertile (I), more fertile (II), moderately fertile (III), and barren (IV). According to the statistics, a total of 162 *Cunninghamia lanceolata* sample plots were collected, as shown in Table 1. The plot distribution points are shown in Figure 1.

Table 1. Statistics of the investigation factors for *Cunninghamia lanceolata* stands used in the construction of the stand growth models.

SI	Number of Plots	*D* (cm)	*H* (m)	SD (Strains/hm^2)	*M* (m^3)	*P* (%)
I	39	11.4	11.8	1966	174	72.4
II	48	11	11.2	1933	144	71.1
III	41	10.3	11	1946	130	69.6
IV	34	9.1	9.6	1920	102	67.8

In order to investigate the application of the forest land net present value expansion model, a list of forest resource asset evaluations, as well as the related economic and technical indicators were collected from a forestry enterprise in Fujian, as listed in Table 2. The forest resource asset evaluation list includes the forest site quality grade (SI) and area (S), stand age (t), average diameter at breast height (D), average height (H), density (SD), stock volume (M), timber yield (P), etc. The average wood price of *Cunninghamia lanceolata* was 1050 yuan/m^3, the logging area design fee was 12 yuan/m^3, and the total cost of logging, transportation, and skidding was 200 yuan/m^3. The corresponding sales management and unforeseen fees were 6% of the wood price, and the operating profit was 5% of the wood price.

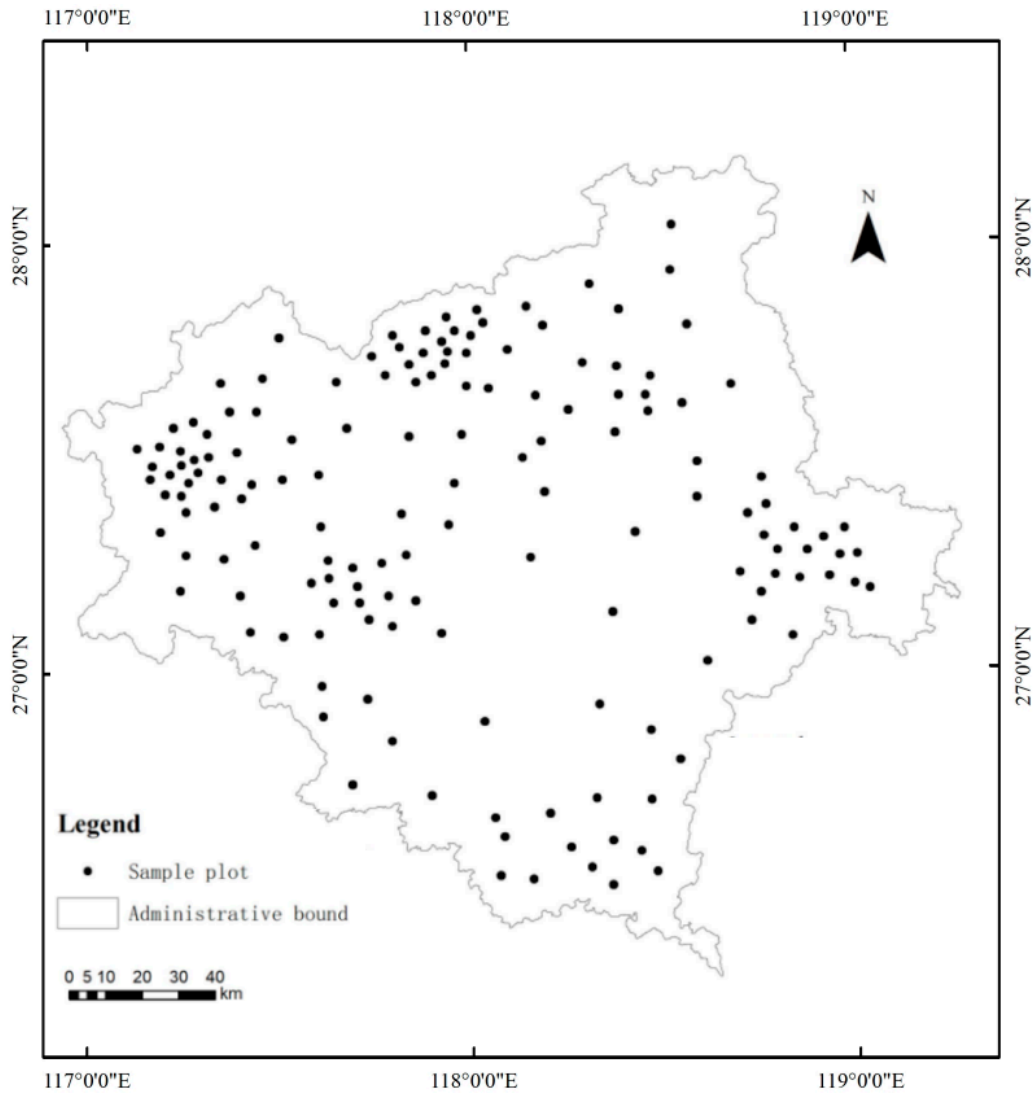

Figure 1. Distribution positions of various *Cunninghamia lanceolata* plots in the study area.

Table 2. List of forest resource asset evaluation for a forestry enterprise in the Fujian Province.

SI	*S* (hm^2)	*t*/a	SD ($Strains/hm^2$)	*D* (cm)	*H* (m)	*P* (%)	*M* (m^3)
I	35	15	2130	8.3	7	69	3836
II	30	14	2085	7.2	6.4	68	2790
III	10	16	2190	8.1	6.8	69	975
IV	25	13	1965	7.5	6.2	67	1725

5. Results

5.1. Cunninghamia lanceolata Stand Growth Prediction Model

Using the data collected from 108 sample plots, the parameters of the forest stand factor estimation model were calculated by Matlab, as listed in Table 3.

Combined with modeling evaluation indicators, after testing, the accumulation volume, average diameter at breast height, mean height, density, and yield regression coefficient values were 1.246, 0.6761, 0.5842, 1.6857, and 0.6782, respectively for *a*, and 0.8922, 0.9356, 0.9471, 0.8784, and 0.9127, respectively for *b*. Other indicators are shown in Table 4.

Table 3. Fitting values of the growth model parameters for *Cunninghamia lanceolata* stands.

Stand Factor	a_1	a_2	a_3	a_4	k_1	k_2	c_1	c_2	c_3	c_4
M	25.9533	24.0910	18.87460	13.4128	0.001060	0.7166	1.4349	1.5139	1.4018	1.3001
D	27.7754	26.3948	25.62740	22.9579	0.000074	0.6894	0.2947	0.2910	0.3037	0.3305
H	17.1375	16.0451	14.46300	11.3020	0.031640	0	0.5824	0.5752	0.5636	0.5201
SD	59.0950	60.7568	79.00500	108.5800	0.006530	0	−0.3927	−0.3714	−0.2478	−0.1308
P	74.7651	73.5431	71.6946	70.2741	5.4764	−0.8346	0.1447	0.1432	0.1389	0.1721

Table 4. Goodness-of-fit value of the *Cunninghamia lanceolata* stand growth model.

Stand Factor	RSD/%	TRE/%	MSE/%	MPE/%	MPSE/%
M	7.47	2.74	7.65	3.15	9.12
D	5.06	1.65	−3.34	1.57	4.25
H	6.62	−1.26	9.12	0.97	5.27
SD	4.79	3.14	−4.96	1.26	5.61
P	6.24	−2.73	5.44	1.27	4.65

It can be seen from Table 4 that the residual standard deviation (RSD) of the established forest factor model was less than 10%, and the total relative error (TRE) and the mean system error (MSE) were both within ±10%. The mean prediction errors (MPE) were less than 5%, and the mean percent standard errors (MPSE) were less than 10%, indicating that the established prediction model of *Cunninghamia lanceolata* growth has a high accuracy. To further verify the applicability of the established model, we calculated the evaluation indicators of RSD, TRE, MSE, MPE, and MPSE using 54 samples that were not involved in the modeling. The model test results are listed in Table 5. From the table, all the factor models had good test results, and all the evaluation indicators of the models were less than 10% or within ±10%, indicating that the growth prediction model established in this paper is applicable and can be used to predict the amount of accumulation, average diameter at breast height, average height, and density in *Cunninghamia lanceolata* stands of different ages and forest land conditions.

Table 5. Precision values for the applicability evaluation of the growth model of the *Cunninghamia lanceolata* stands.

Stand Factor	RSD/%	TRE/%	MSE/%	MPE/%	MPSE/%
M	9.64	3.57	−5.24	4.67	9.66
D	8.23	−3.26	−6.13	3.18	6.74
H	7.16	2.64	8.29	3.22	5.93
N	6.22	−2.99	−5.63	2.14	7.43
P	7.12	2.85	6.17	2.96	5.85

5.2. Prediction of Main Stand Factors of Cunninghamia lanceolata

According to Table 2, the total Chinese *Cunninghamia lanceolata* forest area in this study was 100 hm^2, including four site quality grades. Each grade had the area of 35, 30, 10, and 25 hm^2, respectively, and the age range was 13–16. The forest management type was Chinese *Cunninghamia lanceolata* forest. According to the classification of the age groups of the *Cunninghamia lanceolata* forest in the Fujian Province, the *Cunninghamia lanceolata* forests in this case study was a middle-aged forest, and the production cycle was 26 years. Therefore, combined with the actual stand factors of the case, the traditional evaluation method should adopt the harvest present value method or the forest land expectation value method, and the main stand factors (M, D, H, P, and SD) need to adopt the stand growth prediction model established in this study. The proportional method should be used in the estimation, as shown in Equations (19) and (20):

$$Y_u = \frac{[1 - \exp(-K \times t_u)]^{\,C} \times Y_0}{[1 - \exp(-K \times t_0)]^{\,C}} \tag{19}$$

$$P_u = \frac{[1 - \exp(-K \times D)]^{C} \times P_0}{[1 - \exp(-K \times D_0)]^{C}} \tag{20}$$

where Y_u, t_u, and P_u are predictions of the main forest logging, and Y_0, t_0, P_0 are the realistic forest site factors.

According to Equations (19) and (20), and combined with Tables 2 and 3, the predicted value of main logging factors can be obtained, as listed in Table 6. Since the average diameter at breast height was only used to estimate the average yield rate of the forest stand, the results of this study only listed the density per unit area, the timber yield of the stand, and the stock volume. It can be seen from Tables 2 and 5 that during the main cutting, the average yield rate of forest stand was between 71.1% and 71.8%, and the average stock volume of the stand was in the range of 89 to 152 m^3/hm^2. The density per unit area of each forest quality grade decreased, while the number of other stand factors increased, which was in line with the general law of stand growth. The calculation case and formula are shown in Table A1.

Table 6. Predicted values of *Cunninghamia lanceolata* stand factors during main logging.

SI	S (hm^2)	t/a	SD ($Strains/hm^2$)	P (%)	M (m^3)
I	35	26	1740	71.8	5316
II	30	26	1660	71.4	3830
III	10	26	1833	71.2	1378
IV	25	26	1521	71.1	2219

5.3. Application of the Forest Land Revenue Price Expansion Model

The differences in the evaluation results between the forest land net present value expansion model and the traditional forest land asset evaluation method (forest land expectation value method, hereinafter referred to as the traditional method) were analyzed, which can provide new technical support for forest land asset evaluation. In this study, combined with the predicted results of the primary stand factors and the collected economic and technical indicators, the net benefits of forest land and forest trees were divided in a ratio of 3:7 based on two forest land asset assessment methods. The return rate was 4%, and the evaluation results of the two methods including the indefinite years (B_u), annual rent (B_z), and 30 year land prices (B_n), were obtained, as shown in Figure 2. Among them, B_{ua}, B_{za}, and B_{na} are the calculation results by the forest land net present value expansion model, and B_{ub}, B_{zb}, and B_{nb} are the calculation results by the traditional methods, respectively. Figure 3 shows the assessed values of B_u, B_z, and B_n per unit area, where the results calculated by the forest land net present value expansion model are expressed as B_{uad}, B_{zad}, and B_{nad}, and the results calculated by the traditional methods are expressed as B_{ubd}, B_{zbd}, and B_{nbd}, respectively.

From Figure 2, the assessment values of B_u, B_z, and B_n calculated by the forest land net present value expansion model were found to be larger than those calculated by the traditional method. In particular, the value of B_u for forest site quality level I calculated by the expansion model was greater than 800,000 yuan. However, the value of B_u for forest site quality level I by the traditional method was less than 500,000 yuan. This was mainly due to the fact that the expansion model considered the evaluation value from the actual forest stand to the main cutting. The evaluation result was higher than that of the traditional method, making the evaluation result more realistic and reasonable. From the forest site quality grade, as the forest site quality grade increased from I to II, and then to III, B_u, B_z, and B_n all decreased accordingly, which was mainly due to the fact that as the stand conditions become worse, the stand growth quality became even worse. For example, the stock volume, timber yield, average diameter at breast height, and average height factors were all found to be lower, which was consistent with the general change law of the forest resource asset evaluation results. However, since the area of Site IV was significantly larger than Site III, its total assessment value was found to be higher than that of Site III. Therefore, it was needed to compare the assessment results per unit area, as shown in Figure 3.

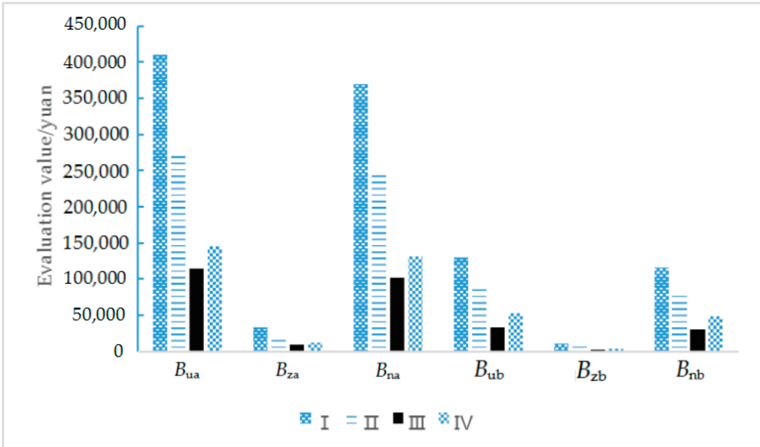

Figure 2. Forest land asset evaluation values calculated by the extended model of forest land net present value and traditional methods.

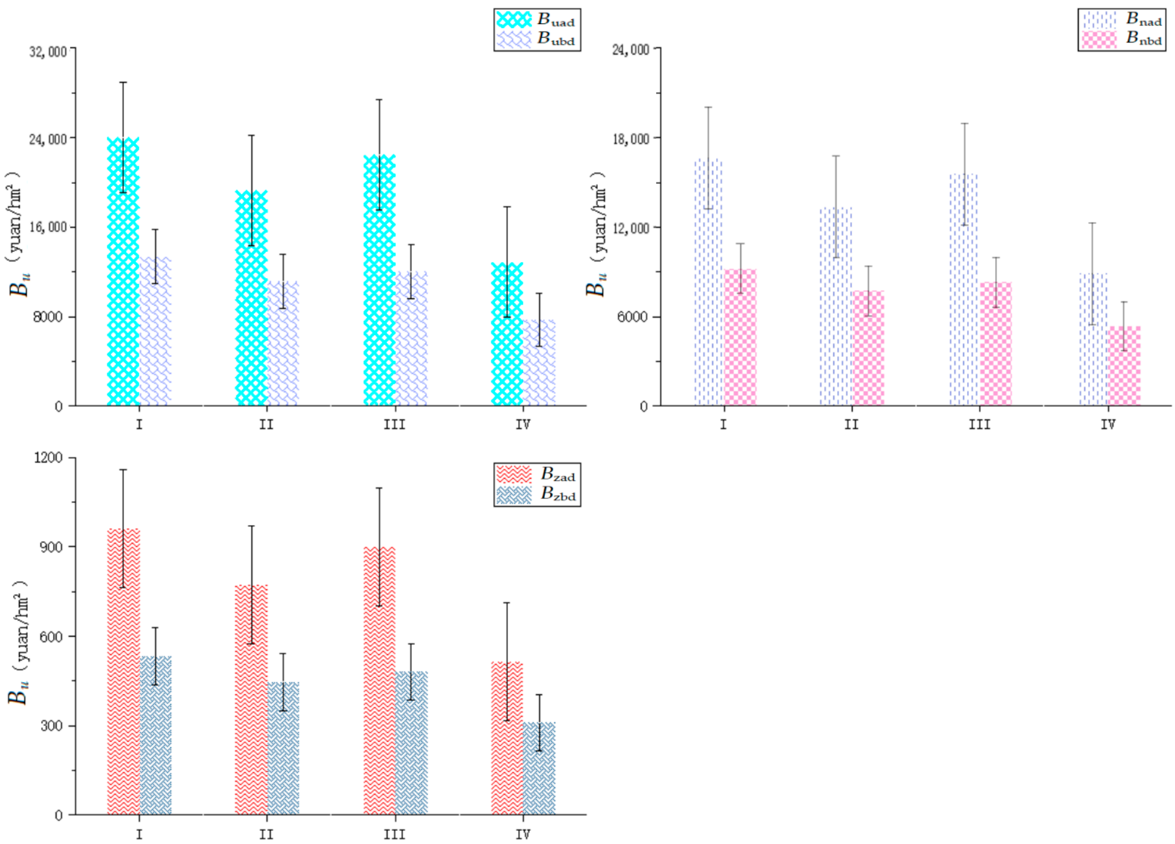

Figure 3. Three unit area evaluation values of forest land assets calculated using the expanded model of forest land net present value and traditional methods, respectively.

Figure 3 shows that the values of B_{uad}, B_{zad}, and B_{nad} were greater than the values of B_{ubd}, B_{zbd}, and B_{nbd}. In addition, the values of B_{uad}, B_{zad}, and B_{nad} increased with the forest site quality grade, which was consistent with the change trend of the total assessment values. As the forest site quality grade increased, the values of B_{u}, B_{z}, and B_n all decreased with the exception for III. This was mainly due to the fact that the factors closely related to forest land evaluation in Site III such as accumulation per unit area and average diameter at breast height were higher than other site quality grades of Sites II and IV, and thus the evaluation results were greater than that of Sites II and IV. However, the change patterns of the results obtained by the two calculation methods were found to be consistent, indicating that the results obtained by the comprehensive mathematics of the forest land net present value are credible in the change trends of the assessment values.

5.4. Response of Forest Land Net Present Value Expansion Model at Different Interest Rates

In order to further analyze the impact of interest rates on the results of the two evaluation methods and the change law, the dynamic variation of forest land asset valuation was analyzed at different interest rate levels. The interest rates of 2.5%, 3%, 4%, 6%, and 8% were used in this analysis as these values have been frequently used in forest resource asset valuation practice. The calculated results of the forest land valuation are shown in Figure 4.

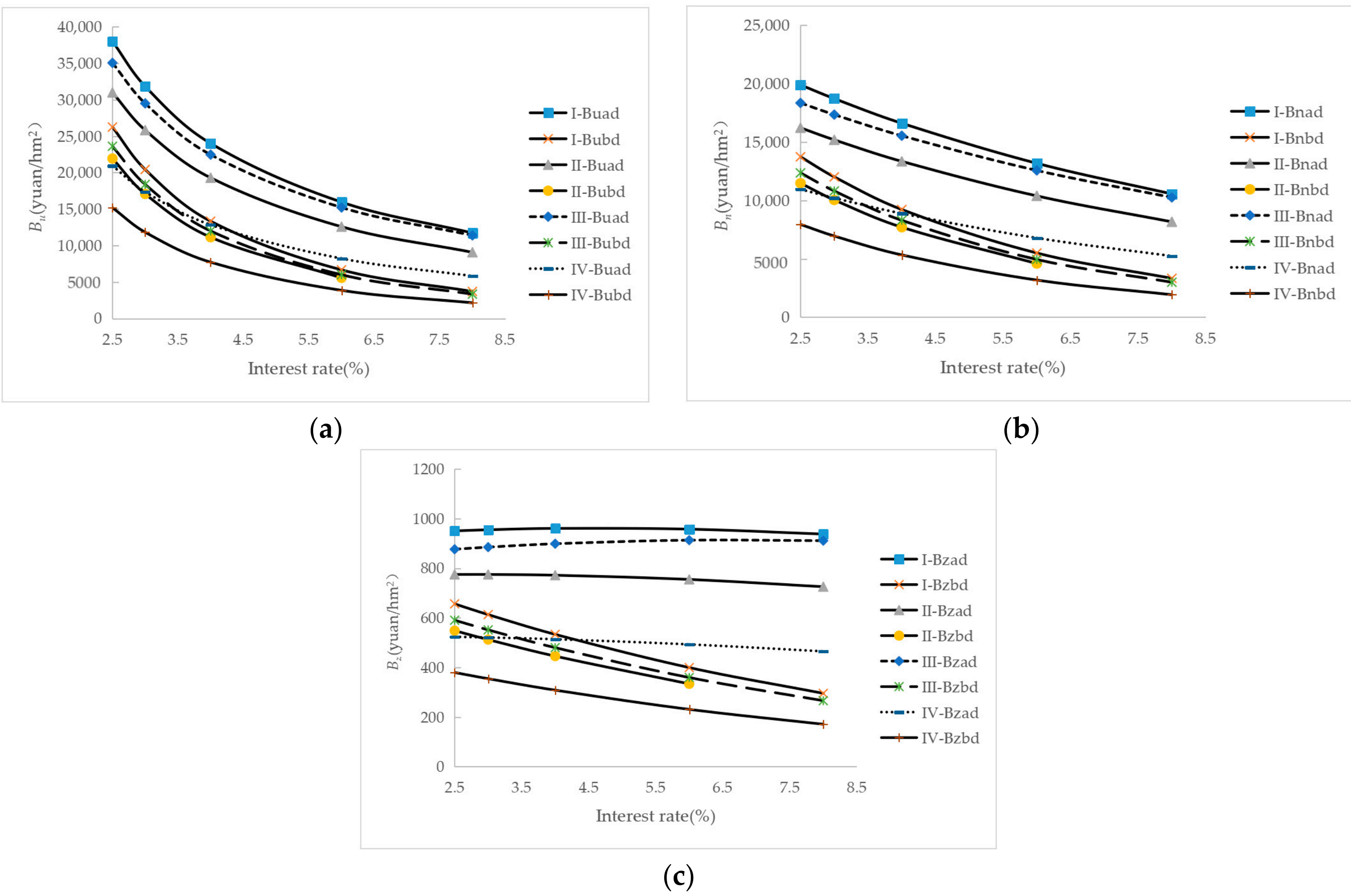

Figure 4. Changes in the evaluation value of the forest land assets calculated by the extended model of forest land return price under different interest rates:(**a**) B_u value; (**b**) B_n value; (**c**) B_z value.

As the interest rate increased, the evaluation value of B_u and B_n per unit area decreased. Under the same stand quality grade, the B_u values calculated by the expansion model were found to be larger than those by the traditional method. The variation curve of the B_u values was steeper when the interest rate increased from 2.5% to 4%, and the B_u value change was flatter when the interest rate increased from 4% to 8%. In addition, under the same stand quality grade, the B_n values calculated by the expansion model were also larger than those by the traditional methods. In terms of the B_z value, there was a certain difference observed between the appraisal value and the B_u value and B_n value as the interest rate changed. Under the same forest site quality, as the interest rate changed, the B_z value from the expansion model *Cunninghamia lanceolatast* first increased and then decreased, and the highest B_z value was obtained at the interest rate of 4%. At the same time, under different interest rates, the curve of the B_z value calculated by the expansion model was relatively flat, while the B_z value calculated by the traditional method decreased with the increase of the interest rate.

The B_z value is the forest land rent in the forest land use right evaluation. Using the forest land net present value expansion model, the minimum land rent was calculated to be 465.10 yuan/hm^2 and the minimum value was 950.48 yuan/hm^2. In contrast, using the traditional method, the minimum land rent was calculated to be 171.02 yuan/hm^2 and the minimum value was 656.28 yuan/hm^2. The minimum value clearly underestimated the current local forest land rent level, and the average land rent obtained from the forest land net present value expansion model (786.20 yuan/hm^2) was in line with the current average rent level. Therefore, this study concluded that the results of the forest land net present value expansion model were in line with the actual situation and can be used to determine the value of forest land asset use rights. In addition, the land rent was found to be higher when the interest rate was 4%.

6. Discussions

6.1. Discussion on the Application of Forest Land Net Present Value Expansion Model in Different Forest Land

According to the specific case analysis results, the evaluation results obtained from the proposed forest land evaluation model were found to be in line with the actual situation and can be used to determine the value of forest land assets. In this method, n is the realistic stand age or the initial age to start the calculation of the forest land revenue. The base date was January (at the beginning of the year), and different initial ages (n) can be used for different forest land asset assessments. When the initial age $n = 1$, i.e., from the beginning of forestation without forest land, the forest land net present value expansion model in Equation (9) can be rewritten as:

$$B_u = \frac{\sum_{t=1}^{u} Z_t \times (1+p)^{u-t}}{[(1+p)^u - 1]} \tag{21}$$

Equation (21) is appliable to the unlimited age land price evaluation of the economic forest calculated from afforestation without forest land. For timber forests, the benefits do not exist every year, but are mainly from the main cutting. When the cost benefits of thinning are not considered (thinning may not always have benefits, and sometimes may even cause losses, and thus we assumed that thinning income and expenditure are offset), and the benefits of each rotation or selective cutting cycle are the same, Equation (21) can be rewritten as:

$$B_u = \frac{Z_u}{[(1+p)^u - 1]} \tag{22}$$

where u is the production cycle, and Z_u is the net income of the forest land at the main logging. Equation (22) is the traditional calculation formula of the forest land expectation price method, which is appliable to the evaluation of the land price starting from the forest afforestation of non-forest land.

When the initial age n is not 1, that is, the timber forest takes the actual stand age as the initial age n, the forest land net present value expansion model can then be simplified as:

$$B_u = \frac{Z_u \times (1+p)^u}{(1+p)^{u-n} \times [(1+p)^u - 1]} \tag{23}$$

Equation (23) is appliable to the woodland price evaluation of timber forest with a forest stand age of n years. When the initial age n = 1, Equation (23) is identical to Equation (22). If the forest is divided into groups with different ages, and benefits are obtained by selective cutting, the u in Equation (5) is the selective cutting period, and Z_u is the net benefits of each selective cutting of forest land, which is applicable to the unlimited land price evaluation of different-aged forests. For the bamboo forest with different stand ages, the growth and harvest cycle can be considered as 1 or 2 years, respectively, and the corresponding initial age can be considered as n = 1. Then, when the harvest cycle is 1 year, Equations (6) and (7) can be rewritten as:

$$B_u = \frac{Z_u}{p} \tag{24}$$

In Equation (24), Z_u is the annual net income of bamboo forest land, which is applicable to the calculation of infinite year land price of bamboo forest. For shrub land assessment, the harvesting cycle can be considered as u years, and the corresponding initial age can be considered as n =1, and Equation (24) can then be used to assess the shrub land value.

In summary, the formula for the established forest land net present value expansion model was not only appliable to the estimation of the price of non-forest land, but also for the estimation of the forest price of the actual forest stand with a stock volume. Meanwhile, when different initial ages and u meanings were adopted, different types of forest land assets were able to be assessed, including arbor forest land (including natural heterogeneous woodland), bamboo woodland, shrub woodland, and economic woodland.

6.2. Application of Assessment Methods Combined with Stand Growth Models in Asset Valuation

The age group of the stand is medium and near-mature forest, and the present value of the harvesting method is generally used to measure its value. This method requires an estimation of the stock volume at the time of main cutting, and therefore, the accuracy of the established stand growth and harvesting model as well as the applicability and practicality issues not only affect the accuracy of the appraisal results, but also affect the operability issues of asset appraisal practice. Until recently, various forms of stand growth and harvest models have been established, such as process growth models, statistical or empirical models based on observation data, and mixed models [22–25]. In particular, the mixed-effect model has been a hot research topic for foresters in recent years; in the mixed-effect model, variables such as topography, landscape, climate, human activities and other factors, as well as many secondary factors contained in the introduced factors are introduced. For example, topography and landscape contain the factors of slope, slope direction, slope position, etc., and climate contains the factors of temperature, humidity, etc. [26–28]. Although the established stand growth harvesting model is highly accurate and can simulate or describe the stand growth pattern well, a large number of basic materials need to be collected in the practice of forest resource asset assessment. Collecting data for several of these mentioned factors are difficult to collect, such as the amount of fertilizer applied in human activities. In particular, in the process of the precise assessment of small classes based on the forest resource asset inventory, some of the inventory may involve more than 100,000. If a high-precision multivariate model is used, the operability of the forest resource asset evaluation will be affected. In this study, based on the theoretical growth equation, the main influencing factors of forest stand growth (stand density) were considered, as the forestry production practice was tightly integrated in a certain area (Fujian Province), and the site quality grades were introduced. On that basis, a forest stand growth prediction model suitable for forest resource asset evaluation was established. According to the four types of stand evaluations, the main stock volume can be easily estimated without affecting the accuracy, which can be popularized and applied in the forest resource asset evaluation.

7. Conclusions

Since the forest land expectation value method does not consider the forest income with the actual forest reserves at the end of the current production cycle, a forest land net present value expansion model was established according to the structure of segmented forest land income. Taking Chinese *Cunninghamia lanceolata*, a dominant tree species in Fujian Province as an example, the forest land net present value expansion model and traditional evaluation methods were evaluated and applied by establishing a prediction model of forest stand growth related to asset valuation, including the average diameter at breast height, average height, average stock volume, and average yield. This study found that the assessment results obtained from the expansion model were consistent with the variation pattern formed by the forest resource asset assessment values with changes in observed in the stand factors, which were also consistent with the actual situation. Therefore, the developed expansion model can be used in forest land asset evaluation. When different initial ages and u meanings were adopted, different types of forest land assets were able to be assessed, including the tree woodland (including natural, heterogeneous woodland), bamboo woodland, shrub woodland, and economic woodland, which can thereby provide new techniques for forest land asset evaluation.

Author Contributions: W.H.: conceptualization, methodology, investigation, data, curation, writing—original draft. T.Q.: conceptualization, methodology, formal analysis, investigation, writing—review and editing. X.P.: methodology, formal analysis, investigation, writing—review and editing. C.W.: conceptualization, writing—review and editing, supervision. C.Z.: writing—original draft, writing—review and editing. S.C.: writing—original draft, writing–review and editing. X.J.: conceptualization, methodology, writing—original draft, writing—review and editing, validation. J.W.: methodology, writing—original draft, writing—review and editing, validation. X.P., C.Z., S.C. contributed equally to this work and should be considered co-first author. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Fujian Natural Science Foundation (2021J011141), the Fujian Forestry Science and Technology Project (2022FKJ08), the Open Project of Fujian Provincial Key Laboratory of Ecological Industry Green Technology (WYKF-EIGT2021-4), and the Innovation training program (S202210397048).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

When the site quality level was I, the models for stand density (N), average diameter at breast height (D), average height (H), timber yield (P), and volume (M) were as follows:

$$N = 59.0950 \times [1 - \exp(-0.006530 \times t)]^{-0.3927} \tag{A1}$$

$$D = 27.7754 \times [1 - \exp(-0.000074 \times N^{0.6894} \times t)]^{0.2947} \tag{A2}$$

$$H = 17.1375 \times [1 - \exp(-0.031640 \times N^{0.6894} \times t)]^{0.5824} \tag{A3}$$

$$P = 74.7651 \times \left[1 - \exp\left(-5.4764 \times N^{-0.8346} \times D\right)\right]^{0.1447} \quad \text{(A4)}$$

$$M = 25.9533 \times [1 - \exp(-0.001060 \times N^{0.7166} \times t)]^{1.4349} \quad \text{(A5)}$$

According to the above formula, the forest stand factor values predicted by the model during final cutting with site quality level I could be calculated, and then combined with the current stand factor values, while the estimated values of the stand factors during main logging could be determined through the proportional method.

Table A1. Calculated values of forest stand factors for each site quality grade.

SI	S (hm^2)	Current Stand Factor Values					
		t/a	SD (Strains/hm^2)	D (cm)	H (m)	P (%)	M (m^3)
I	35	15	2130	8.3	7	69	3832.5
II	30	14	2085	7.2	6.4	68	2790
III	10	16	2190	8.1	6.8	69	975
IV	25	13	1965	7.5	6.2	67	1725
SI	**S (hm^2)**	**Forest stand factor values predicted by the model during final cutting**					
		t/a	**SD (strains/hm^2)**	**D (cm)**	**H (m)**	**P (%)**	**M (m^3)**
I	35	26	2250	10.3	9.7	71	4169
II	30	26	2309	10.1	9.4	71	3386
III	10	26	2196	10.4	10.0	72	1252
IV	25	26	2374	10.0	9.1	70	2660
SI	**S (hm^2)**	**Estimated values of stand factors during main logging**					
		t/a	**SD (strains/hm^2)**	**D (cm)**	**H (m)**	**P (%)**	**M (m^3)**
I	35	26	1740	9.2	8.8	71.8	5316
II	30	26	1660	8.1	8.3	71.4	3830
III	10	26	1833	9.0	8.3	71.2	1378
IV	25	26	1521	8.4	8.3	71.1	2219

References

1. Morck, R.; Schwartz, E.; Stangeland, D. The valuation of forestry resources under stochastic prices and inventories. *J. Financ. Quant. Anal.* **1989**, *24*, 473–487. [CrossRef]
2. Chen, P.L.; Liu, J. *Operational Skills of Forest Resource Asset Assessment*; China Forestry Press: Beijing, China, 2002.
3. Chen, P.L.; Liu, J.; Chen, C.X. *Forest Resource Asset Evaluation*; Higher Education Press: Beijing, China, 2010.
4. Alig, R.J.; Adams, D.M.; Chmelik, J.T. Private forest investment and long-run sustainable harvest volumes. *Springer Neth.* **1999**, *17*, 307–327.
5. Qian, T. Study on land rent of plantation and its quantification. *J. Nanjing For. Univ. (Nat. Sci. Ed.)* **2010**, *34*, 125–128.
6. Li, Y.; Yang, X.; Lang, P. ArcGis-based assets assessment method for tree and woodland. *J. Northeast For. Univ.* **2013**, *41*, 123–127.
7. Goebel, A.; Campbell, B.; Mukamuri, B. People, values, and woodlands: A field report of emergent themes in interdisciplinary research in Zimbabwe. *Agric. Hum. Values* **2000**, *17*, 385–396. [CrossRef]
8. Commission, F. The natural environment framework: Estimating the value of new woodland. *For. Comm.* **2004**, *1*, 341–353.
9. Li, X.W. Asset Grading and Evaluation Technology Of Commercial Forest Land. Master's Thesis, Fujian Agriculture and Forestry University, Fujian, China, 2014.
10. Chi, S.P.; Jiang, X.D.; Hua, W.P. Application of analytic hierarchy process in forest land asset evaluation market method. *For. Econ. Issues* **2014**, *34*, 149–153.
11. Liu, Y. Application of forest land income method to forest land asset evaluation. *China Agric. Account.* **2016**, *6*, 44–46.
12. Zhang, N.; Ning, Z.; Yang, H.Q. Forsmann model and its generalized improvement: Evolution of evaluation methodology based on forest land expectation. *For. Econ.* **2020**, *42*, 3–15.
13. Liu, J.; Chen, P.L. The Expected price correction method for forest land: A practical method for evaluating timber forest land assets. *For. Econ.* **2003**, *3*, 45–46.

14. Tian, Y.; Wu, H.W.; Zhang, W.Z. Study on compatibility DBH growth model and tree height curve model of Castanopsis carlesii stand in Fuzhou. *For. Resour. Manag.* **2020**, *4*, 44–49.
15. Wang, S.L.; Long, S.S.; Zeng, S.Q. Growth model of basal area of oak secondary forest in Hunan. *J. Cent. South Univ. For. Sci. Technol.* **2021**, *41*, 84–91.
16. Wu, H.W.; Zhang, W.Z.; Tian, Y. Sectional area growth model of Pinus elliottii forest based on dummy variable. *J. Cent. South Univ. For. Sci. Technol.* **2021**, *41*, 117–123.
17. Zeng, W.S.; Zhang, H.R.; Tang, S.Z. Using the dummy variable model approach to construct compatible single-tree biomass equations at different scales—A case study for masson pine (pinus massoniana) in Southern China. *Can. J. For. Res.* **2011**, *41*, 1547–1554. [CrossRef]
18. Gao, D.Q.; Deng, H.F.; Wang, H.B.; Cheng, Z.C. A growth model of Mongolian oak forest based on dummy variables. *J. Northeast For. Univ.* **2014**, *42*, 61–64.
19. Cao, M.; Pan, P.; Ouyang, X.Z.; Zang, H.; Wu, Z.R.; Yang, Y.; Zhan, C.Y. A study on the growth model of single tree diameter at breast height and tree height in natural secondary forests of Minnan based on dummy variables. *J. Beijing For. Univ.* **2019**, *41*, 88–96.
20. Min, Z.Q.; Hu, Y.Y.; Wang, D.J.; Sun, J.M.; Li, H.T.; Li, W.Z. A study on the growth model of natural oak forests at breast height and tree height in the Qinba Mountains based on dummy variables. *For. Resour. Manag.* **2020**, *5*, 89–99.
21. Zhu, G.Y.; Hu, S.; Fu, L.Y. A growth model for the cross-sectional area of natural oak forests in Hunan based on dummy variable. *J. Nanjing For. Univ. (Nat. Sci. Ed.)* **2018**, *42*, 155–162.
22. Tang, S.Z.; Li, X.F.; Meng, Z.H. Research progress of stand growth model. *For. Sci. Res.* **1993**, *6*, 672–679.
23. Peng, C.H. Growth and yield models for uneven-aged stands:past, present and future. *For. Ecol. Manag.* **2000**, *132*, 259–279. [CrossRef]
24. Huang, S.L.; Ramirez, C.; McElhaney, M. F3: Simulating spatiotemporal forest change from field inventory, remote sensing, growth modeling, and management actions. *For. Ecol. Manag.* **2018**, *415−416*, 26–37. [CrossRef]
25. Lei, X.D. Application of machine learning algorithm in forest growth and harvest prediction. *J. Beijing For. Univ.* **2019**, *41*, 23–36.
26. Guillermo, T.; Curtis, L.V.; Harold, E.B. Regional mixed-effects height–diameter models for loblolly pine (*Pinus taeda* L.) plantations. *Eur. J. For. Res.* **2007**, *126*, 253–262.
27. Wang, Z.; Lu, L.L.; Zhang, X.Q. Construction of stand volume growth model of Chinese *Cunninghamia lanceolata* based on Bayesian model average method. *For. Sci. Res.* **2021**, *34*, 64–71.
28. He, J.; Zhu, G.Y.; Zhang, X.Y. Average DBH growth model of oak natural forest in Hunan Province Based on site and density effects. *J. Cent. South Univ. For. Sci. Technol.* **2021**, *41*, 75–82.