Research paper

Modeling and Comparing Height Growth of Larch Plantations in Different Land Types in Eastern Liaoning Province, Northeast China

Hui-Yan Gu[1,2)]

【Summary】

This study compared the growth of 2 larch plantations located in different land types in eastern Liaoning Province, China based on forest inventory data and mathematical models. Results demonstrated that the Chapman-Richards function was the most suitable model for the study site. The ecological land type (ELT) classification system is an effective tool for larch plantation zoning. Gentle slopes, including ELT2 and ELT3, were the best sites for larch plantations. *Larix kaempferi* showed greater growth than did *L. olgensis*. This research also indicated that species selection, such as *L. kaempferi*, was a key for forest plantation establishment and future stand development. Thus, species and site selections are key components for consideration in forest management practices.

Key words: Chapman-Richards function, forest inventory data, *Larix kaempferi*, *Larix olgensis*, mathematical models.

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[1)] School of Forestry, Northeast Forestry Univ., Harbin 150040, China. 東北林業大學林學院，150040 黑龍江省哈爾濱市和興路26號。

[2)] Corresponding author, e-mail:ghuiyan@nefu.edu.cn 通訊作者。

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研究報告

中國遼寧東部不同土地類型落葉松人工林高生長比較

谷會岩[1,2)]

摘 要

本文依據林業的二類調查數據，結合數學模型，比較了遼寧東部不同土地類型落葉松人工林的高生長狀況，研究結果表明：Chapman-Richards function適合比較落葉松人工林高生長狀況，土地的ELT分類系統適合落葉松人工林的立地區劃，緩坡最適合落葉松人工林高生長，日本落葉松比長白落葉松高生長好，是更適合發展落葉松人工林的樹種。

關鍵詞：Chapman-Richards function、林葉二類調查數據、日本落葉松、長白落葉松、數學模型。

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INTRODUCTION

Larch plantations have been developed throughout Northeast China, with a total area of 313 x 10^6 m^2 based on a 1994~1998 forest inventory. Larch trees grow quickly and have relatively high economic value. Over the last few decades, many studies focused on the biology, physiology, and ecology of larch plantations in China (e.g., Wang and Zhang 1992, Li and Zhou 2000, Wang et al. 2000, Wu and Wang 2000, Wang et al. 2001, Sun et al. 2005). Among them, site productivity has been a central topic (Li et al. 1992, Liu 1995, Liu et al. 1998, Chen 2003, Weng and Chen 2004). Biological growth coupled with site quality has very rarely been considered (Hägglund 1981, Avery and Burkhart 1994). Thus, we attempted to evaluate plantation tree growth under different site productivity conditions to provide further information for managing larch plantations in Northeast China. *Larix olgensis*, native to Liaoning, China, and *L. kaempferi*, introduced from Japan, are 2 common plantation species in the study region. Such regionally focused species-level comparative studies exploring the genetic growth potentials of these 2 species and relations to site productivity are rare in the literature. Therefore, this study may provide new information on the productivities of these 2 commercial species in various ecological land types (ELTs) across the region.

MATERIALS AND METHODS

Study area

The study sites were located in Benxi City in eastern Liaoning Province, China. Benxi City is located at 123°34′~125°46′E and 40°49′~41°35′N, and occupies an approximate area of 8420 km^2 (Fig. 1). This region is in the transition zone from mountains to hills, and features a temperate continental climate with long, cold winters and short, warm summers. The annual mean temperature is 7~8℃. The average annual precipitation is 750 mm, mainly falling in July and August. The vegetation types are pine and larch plantations and secondary-growth forests.

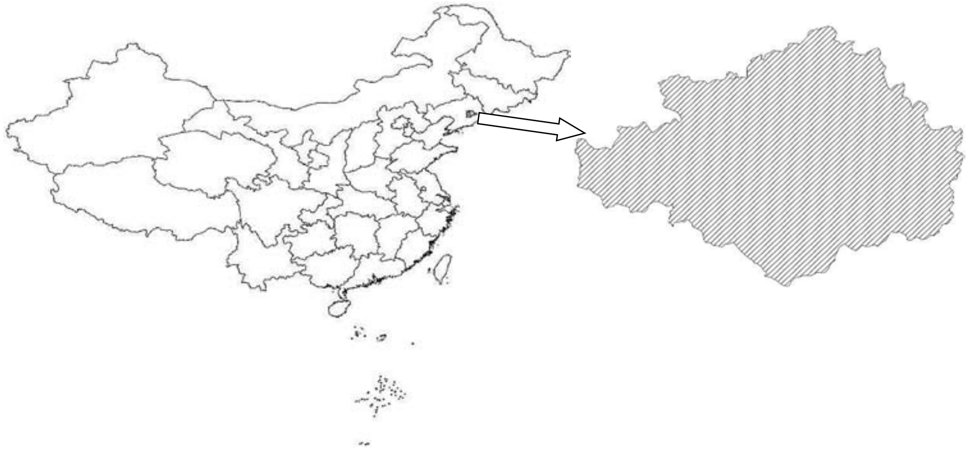


Fig. 1. Map of the study area showing the location of the study.

ELTs

Ecological classification of forestlands has become an important step toward ecological management of forests. In North America, ecological classification has been widely used to pursue sustainable forest management (Hall 2001, Hirvonen 2001, Abella et al. 2003). In Northeast China, ecological classification has been studied for mountain forest sustainability (Dai et al. 2003, Tang et al. 2006). ELTs are a basic component of the ecological classification system and can be used in forest management planning. In this study, we adopted this classification system to divide our study into 5 ELTs: bottomlands, dry-gentle slopes, mesic-gentle slopes, dry-steep slopes, and mesic-steep slopes (Table 1).

Data

Forest inventory data were provided by the Benxi Forestry Bureau. In summary, the forest inventory plots were surveyed in May~September 1990 and 1991 on 1773 ha of larch plantations. Table 2 shows selected data from larch plantations, and Figs. 2 and 3 plot height vs. age of larch trees. These data were used for initial model selection and parameter estimation for all ELTs and study areas.

Growth model candidates

Three mathematical functions were chosen to model tree growth: the Chapman-Richards function, the Lundqvist-Korf function, and the logistic function. All 3 are S-shaped curves and are widely used to model dominant height growth (Bertalanffy 1949, 1957, Lundqvist 1957, Richard 1959, Rennolls 1995, Amaro 1998, Duan and Zhang 2004). They have the following forms:

Table 1. Ecological land type (ELT) classification system in eastern Liaoning Province, China

Aspect (Azimuth)	Slope (°)	ELT no.	Description
-	≤ 5	1	Bottomlands
135~315	5~25	2	Dry-gentle slopes
≤ 135 or ≥ 315	5~25	3	Mesic-gentle slopes
135~315	≥ 25	4	Dry-steep slopes
≤ 135 or ≥ 315	≥ 25	5	Mesic-steep slopes

Table 2. Characteristics of *Larix olgensis* (a) and *L. kaempferi* (b) based on forest inventory data used in the model selection and parameter estimation procedures

(a)

ELT	Number of plots	Measured variable	Average (minimum~maximum)	Standard deviation
1	285	Stand age (yr)	21.55 (4~49)	10.21
		Dominant height (m)	9.72 (0.4~22.3)	4.52
2	4195	Stand age (yr)	22.98 (3~65)	11.45
		Dominant height (m)	9.69 (0.3~24.8)	4.49
3	6257	Stand age (yr)	23.91 (3~65)	11.71
		Dominant height (m)	10.04 (0.3~27.3)	4.56
4	749	Stand age (yr)	24.80 (4~65)	12.69
		Dominant height (m)	10.27 (0.3~27.1)	4.97
5	990	Stand age (yr)	24.49 (4~65)	12.13
		Dominant height (m)	10.26 (0.4~24.5)	4.70
Total	12,476	Stand age (yr)	23.64 (3~65)	11.71
		Dominant height (m)	9.94 (0.3~27.3)	4.58

(b)

ELT	Number of plots	Measured variable	Average (minimum~maximum)	Standard deviation
1	368	Stand age (yr)	20.00 (4~63)	11.37
		Dominant height (m)	9.31 (0.5~24.4)	5.27
2	7266	Stand age (yr)	18.21 (3~65)	12.42
		Dominant height (m)	8.02 (0.2~29.2)	5.61
3	10243	Stand age (yr)	19.44 (3~65)	12.90
		Dominant height (m)	8.57 (0.3~29.3)	5.77
4	1199	Stand age (yr)	17.79 (3~63)	12.76
		Dominant height (m)	7.71 (0.3~27.1)	5.80
5	1559	Stand age (yr)	19.16 (3~63)	12.53
		Dominant height (m)	8.10 (0.4~28.4)	5.68
Total	20,635	Stand age (yr)	18.90 (3~65)	12.69
		Dominant height (m)	8.30 (0.2~29.3)	5.71

ELT, ecological land type.

Chapman-Richards function

$$H = A(1 - e^{-kt})^m; \quad (1)$$

Lundqvist-Korf function

$$H = Ae^{-\frac{k}{t^m}}; \text{ and} \quad (2)$$

Logistic function

$$H = A/[1 + e^{(k - mt)}]; \quad (3)$$

where A is the asymptote of the height, k is a measure of the growth rate, m is a shape parameter, and t is the age of the stand of trees (yr).

Growth in different ELTs of the study area was modeled using these functions. All parameters in Eqs. 1~3 were estimated by a least-squares technique in SPSS 10.0 (SPSS, Chicago, IL, USA). A number of graphical and statistical methods are used to perform model validation (Reynolds et al. 1988, Mayer and Butler 1993, Janssen 1995, Soares et al. 1995). The mean residual (Mres), variance ratio (VR), residual sum of squares (RSS), absolute mean residual (AMRes), and

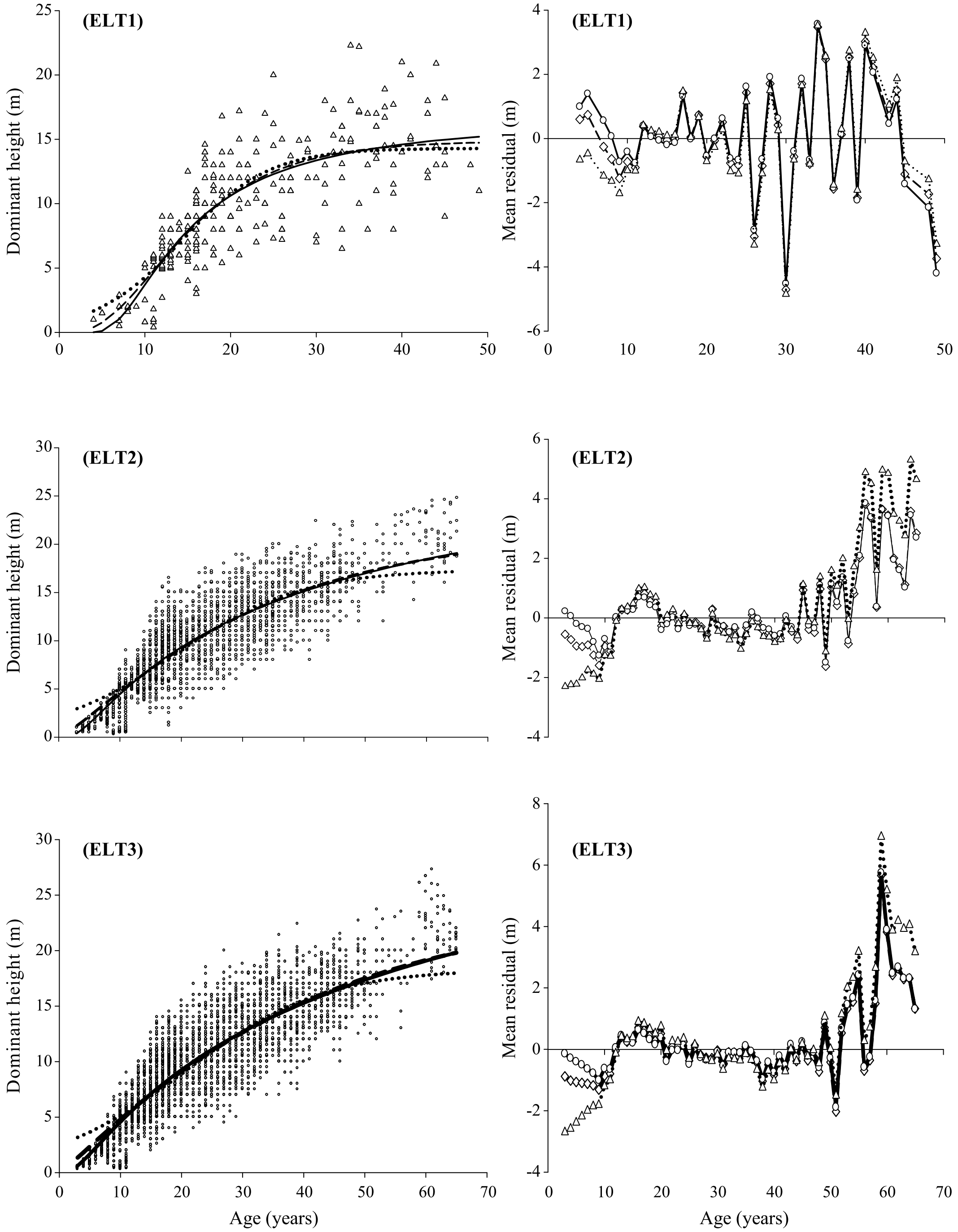
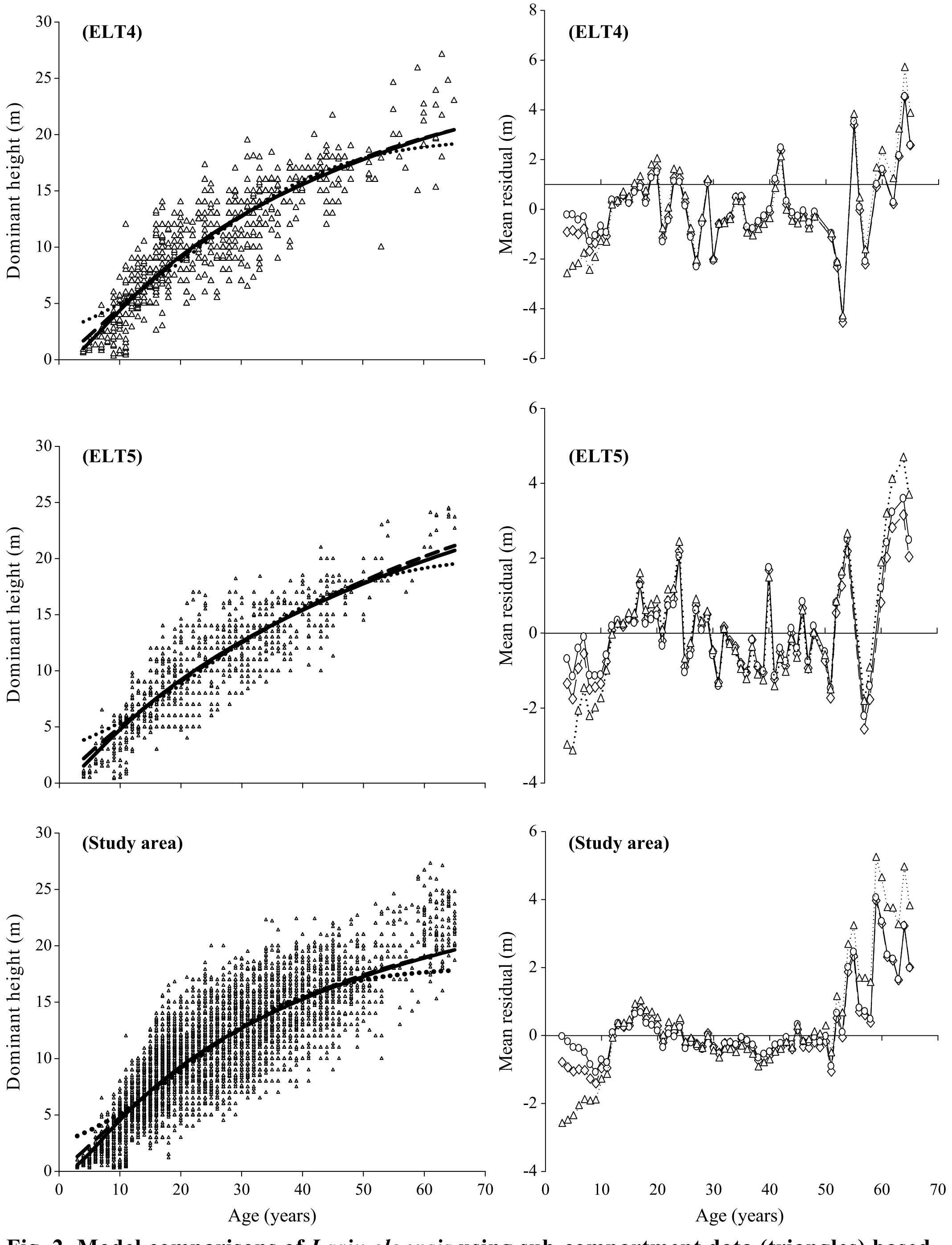


Fig. 2. Model comparisons of *Larix olgensis* using sub-compartment data (triangles) based on the Chapman-Richards function (long dashed line), Lundqvist-Korf function (solid line), logistic line (dotted line), and mean residuals (short dashed line with diamonds for the Chapman-Richards function, solid line with circles for the Lundqvist-Korf function, and dotted line with triangles for the logistic line).



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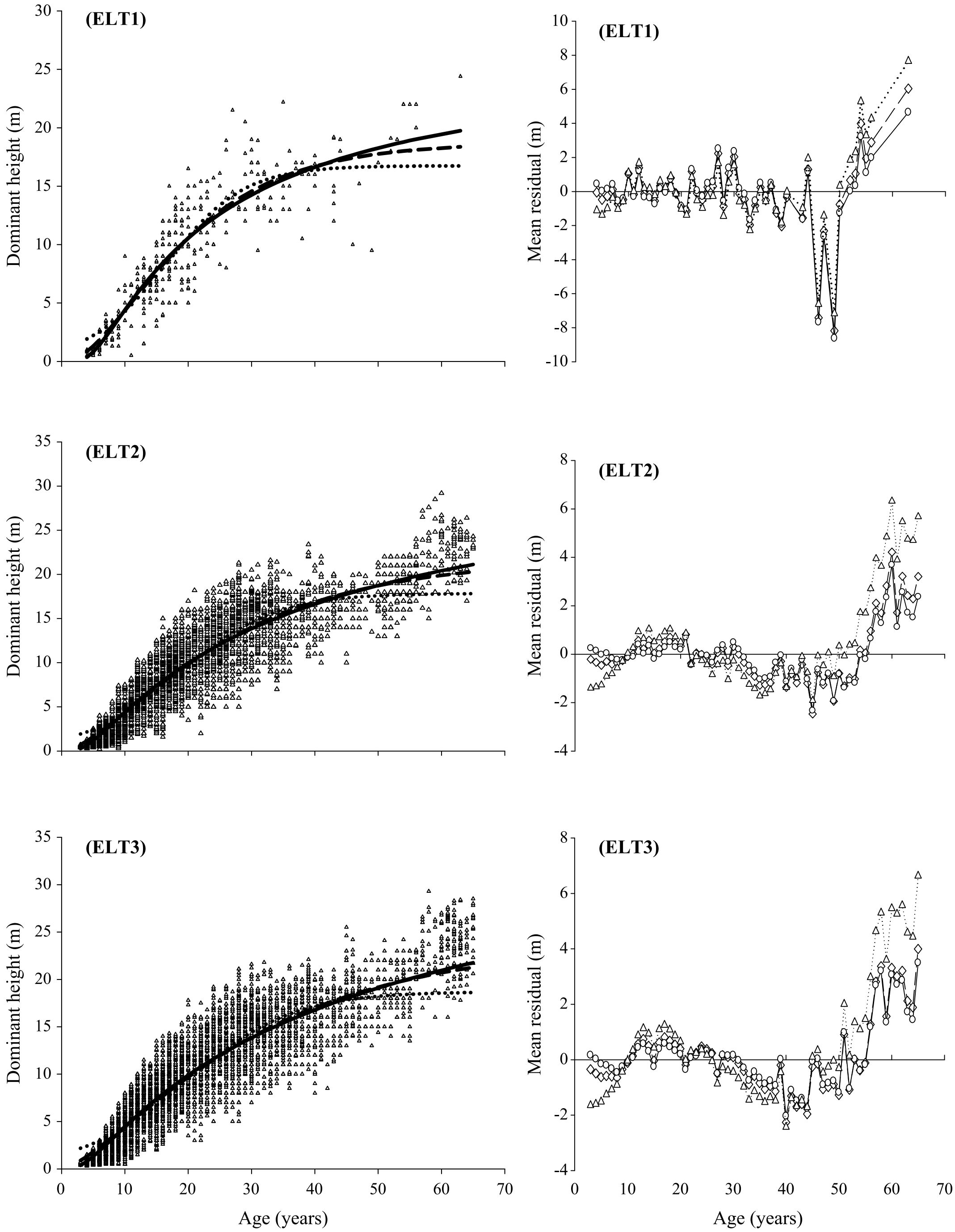

Fig. 3. Model comparisons of *Larix kaempferi* using sub-compartment data (triangles) based on the Chapman-Richards function (long dashed line), Lundqvist-Korf function (solid line), logistic line (dotted line), and mean residuals (short dashed line with diamonds for the Chapman-Richards function, solid line with circles for the Lundqvist-Korf function, and dotted line with triangles for the logistic line).

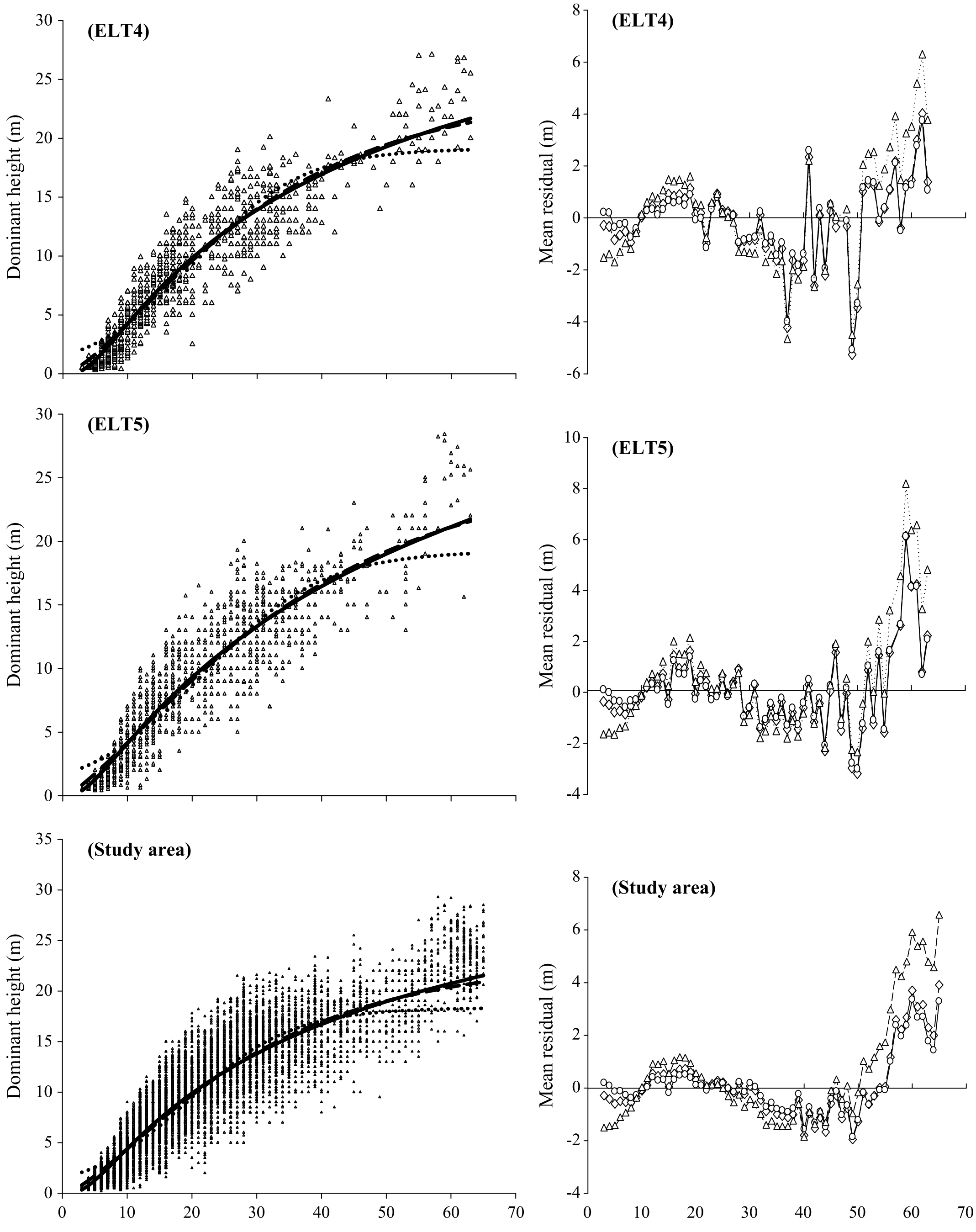

Fig. 3. Model comparisons of *Larix kaempferi* using sub-compartment data (triangles) based on the Chapman-Richards function (long dashed line), Lundqvist-Korf function (solid line), logistic line (dotted line), and mean residuals (short dashed line with diamonds for the Chapman-Richards function, solid line with circles for the Lundqvist-Korf function, and dotted line with triangles for the logistic line).

coefficient of determination (R^2) were computed (Amaro et al. 1998). These are all based on a comparison of observed and estimated values.

RESULTS AND DISCUSSION

Model comparison and selection

Table 3 shows estimates of all of the parameters, and computations of Mres, VR, RSS, AMRes and R^2 are given in Table 4. Parameter k in the Lundqvist-Korf function for *L. olgensis* in ELT1 was designated the origin. The asymptote of the Lundqvist-Korf function ranged 16.74~107.82 and was the largest of the 3 functions for the same species cultivated in the same ELT. Growth curves of these 3 functions showed similar trends, except for differences in the young (< 10 yr) and old (> 40 yr) plantations. Also, the mean residual increased as the age increased (Figs. 2, 3). All R^2 values of these functions for the 2 larch plantations were > 0.6.

Based on R^2 values, the Lundqvist-Korf function gave the best fit, and the logistic function gave the worst fit of the 3 functions. There was no inflection point of the Chapman-Richards function for *L. olgensis* in ELT5, because the shape parameter was < 1 (Liu and Li 2003). The high accuracy of the Lundquist-Korf function was related to the relatively low inflection point (Duan and Zhang 2004). The observed respective maximum heights of *L. olgensis* and *L. kaempferi* were 27.3 and 29.3 m (Table 1). Although the Lundquist-Korf function gave the best overall fit, the estimated asymptote was too large to agree with the observed data. Model selection is a compromise between biological and statistical considerations (Amaro et al. 1998, Anta and Aranda 2005). The Chapman-Richards function was chosen to describe the growth of the 2 larch plantations.

Height growth comparisons of different species

In all ELTs and in the entire study area, *L. kaempferi* showed greater growth than *L. olgensis* (Fig. 4). This result is consistent with findings of Yao et al. (1989), whose study was also based on a young larch plantation. Although *L. kaempferi*'s height growth was faster than the native species, determining whether to choose this species for a widespread plantation species in this region depends on its ecological impacts, which need further study.

Height growth comparisons of differing ELTs

Upon comparing the growth between different ELTs (Fig. 5), there was only a significant difference for ELT1. According to Li et al. (1992), the steepness of the slope of the land has the greatest effect on the growth of *L. olgensis*, at least in Liaoning Province, China. No significant difference between mesic and dry slopes of the same gradient is built into the ELT classification scheme. An azimuth of 135°~315° is considered a dry slope; a dry-mesic slope was not considered, according to the ELT classification system. The average height after 40 yr of growth was also computed, since most larch plantations are logged at this age. Heights after 40 yr did not significantly differ among ELT2, ELT3, ELT4, and ELT5 (Table 3). The study area can therefore be divided into 2 zones: a low-productivity zone of ELT1, and a high-productivity zone composed of ELT2, ELT3, ELT4, and ELT5. Based on these results, all of the study zone is suitable for larch plantations, except for bottomlands. Steep slopes, including ELT4 and ELT5, tend to suffer water and soil loss and should be designated an ecological forest zone (Zhang et al. 2006). Gentle slopes, including ELT2 and ELT3, should be used as the main larch plantation zone.

Table 3. Estimated parameters, inflection points, and SI (40) (height of larch at age 40) of *Larix olgensis* (a) and *L. kaempferi* (b) in the model functions

(a)

ELT	Model	Parameters			Inflection points		SI (22)
		A	k	m	Abscissa	Ordinate	
1	Chapman-Richards	14.8722	0.1244	3.8581	10.8535	4.6739	14.4801
	Lundqvist-Korf	16.7405	81.4256	1.7317	9.7518	3.4569	14.5984
	Logistic	14.3031	2.8206	0.1969	14.3250	7.1516	14.2125
2	Chapman-Richards	21.6800	0.0352	1.2591	6.5453	2.9619	15.2282
	Lundqvist-Korf	37.4877	8.7523	0.6141	7.0913	2.7064	15.1132
	Logistic	17.3438	1.8795	0.0978	19.2178	8.6719	15.3348
3	Chapman-Richards	24.4769	0.0273	1.1404	4.8124	2.2457	15.3567
	Lundqvist-Korf	51.3790	7.6298	0.4985	6.4785	2.5427	15.2741
	Logistic	18.3260	1.8298	0.0886	20.6524	9.1630	15.5291
4	Chapman-Richards	25.4717	0.0275	1.2033	6.7297	2.9980	15.6506
	Lundqvist-Korf	54.7418	8.0683	0.5036	7.1994	2.7647	15.5451
	Logistic	19.7272	1.9161	0.0837	22.8925	9.8636	15.9237
5	Chapman-Richards	34.2718	0.0142	0.9515			15.4661
	Lundqvist-Korf	107.8221	6.8217	0.3401	7.8663	2.0963	11.1804
	Logistic	20.4721	1.7625	0.0738	23.8821	10.2361	15.6950
Total	Chapman-Richards	23.6633	0.0294	1.7112	18.2719	5.2672	12.5868
	Lundqvist-Korf	45.9369	7.9466	0.5355	6.7095	2.6113	15.2568
	Logistic	18.1376	1.8396	0.0904	20.3496	9.0688	15.5122

(b)

ELT	Model	Parameters			Inflection points		SI (22)
		A	k	M	Abscissa	Ordinate	
1	Chapman-Richards	18.7286	0.0755	2.3020	11.0434	5.0440	16.6911
	Lundqvist-Korf	27.2725	15.9740	0.9418	8.7926	3.4697	16.6247
	Logistic	16.7451	2.7007	0.1633	16.5383	8.3726	16.3898
2	Chapman-Richards	21.7726	0.0494	1.7070	10.8246	4.8356	16.8766
	Lundqvist-Korf	39.1313	10.3568	0.6759	8.2903	3.2786	16.6279
	Logistic	17.8541	2.5106	0.1338	18.7638	8.9271	16.8699
3	Chapman-Richards	23.8747	0.0402	1.5184	10.3895	4.6695	17.0041
	Lundqvist-Korf	47.1709	9.3280	0.5964	8.1114	3.2448	16.7811
	Logistic	18.6977	2.3865	0.1202	19.8544	9.3489	17.1729
4	Chapman-Richards	24.1577	0.0413	1.6004	11.3863	5.0307	17.1856
	Lundqvist-Korf	45.7125	10.0910	0.6287	8.6956	3.4274	16.9437
	Logistic	19.1366	2.4717	0.1205	20.5120	9.5683	17.4679
5	Chapman-Richards	26.3845	0.0323	1.4351	11.1837	4.7593	16.6403
	Lundqvist-Korf	62.2537	8.8777	0.5145	8.6469	3.2791	16.4552
	Logistic	19.2481	2.3816	0.1090	21.8495	9.6241	16.9097
Total	Chapman-Richards	23.0420	0.0434	1.5900	10.6851	4.7638	16.9300
	Lundqvist-Korf	43.8316	9.7440	0.6271	8.2485	3.2730	16.7155
	Logistic	18.3395	2.4380	0.1253	19.4573	9.1698	17.0405

ELT, ecological land type; A, asymptote of the height; k, measure of the growth rate; m, slope parameter.

Table 4. Evaluation of the functions from statistics for *Larix olgensis* (a) and *L. kaempferi* (b). The underlined data are the best value based on the statistical analysis

(a)

ELT	Model	Mres	VR	RSS	AMRes	R^2
1	Chapman-Richards	0.0073	0.6403	2047.09	2.0596	0.6470
	Lundqvist-Korf	-0.0133	0.6617	2029.69	2.0564	0.6499
	Logistic	0.0294	0.6096	2099.06	2.0873	0.6379
2	Chapman-Richards	0.0247	0.7198	21688.97	1.7943	0.7438
	Lundqvist-Korf	0.0111	0.7386	21194.57	1.7568	0.7495
	Logistic	0.0422	0.6797	23651.65	1.8951	0.7206
3	Chapman-Richards	0.0219	0.7372	31495.88	1.7887	0.7583
	Lundqvist-Korf	0.0109	0.7520	30905.31	1.7580	0.7625
	Logistic	0.0363	0.7017	34166.92	1.8795	0.7374
4	Chapman-Richards	0.0247	0.7680	3891.76	1.7903	0.7890
	Lundqvist-Korf	0.0128	0.7823	3819.68	1.7613	0.7930
	Logistic	0.0430	0.7329	4257.73	1.8764	0.7692
5	Chapman-Richards	0.0228	0.7419	5153.57	1.8351	0.7638
	Lundqvist-Korf	0.0125	0.7554	5084.12	1.8186	0.7671
	Logistic	0.0396	0.7028	5677.59	1.9265	0.7399
Total	Chapman-Richards	0.0228	0.7305	64642.59	1.8065	0.7527
	Lundqvist-Korf	0.0112	0.7470	63385.14	1.7741	0.7575
	Logistic	0.0399	0.6930	70381.14	1.9004	0.7307

(b)

ELT	Model	Mres	VR	RSS	AMRes	R^2
1	Chapman-Richards	0.0170	0.7896	2033.89	1.7630	0.8003
	Lundqvist-Korf	-0.0073	0.8073	2014.49	1.7315	0.8022
	Logistic	0.0512	0.7546	2144.92	1.8923	0.7894
2	Chapman-Richards	0.0424	0.8396	31787.78	1.5468	0.8612
	Lundqvist-Korf	0.0040	0.8636	30796.33	1.5077	0.8656
	Logistic	0.1010	0.7863	37058.26	1.7280	0.8381
3	Chapman-Richards	0.0533	0.8350	46957.63	1.6178	0.8625
	Lundqvist-Korf	0.0171	0.8590	45068.94	1.5554	0.8680
	Logistic	0.1094	0.7790	56246.04	1.8351	0.8353
4	Chapman-Richards	0.0738	0.8563	4435.42	1.4795	0.8901
	Lundqvist-Korf	0.0237	0.8857	4161.75	1.4028	0.8969
	Logistic	0.1477	0.7883	5795.05	1.7654	0.8565
5	Chapman-Richards	0.0618	0.8295	7005.25	1.6038	0.8608
	Lundqvist-Korf	0.0257	0.8530	6742.12	1.5330	0.8660
	Logistic	0.1198	0.7703	8509.23	1.8488	0.8309
Total	Chapman-Richards	0.0509	0.8360	92797.26	1.5902	0.8622
	Lundqvist-Korf	0.0140	0.8605	89197.37	1.5341	0.8676
	Logistic	0.1091	0.7799	110547.99	1.7984	0.8359

ELT, ecological land type; Mres, mean residual; VR, variance ratio; RSS, residual sum of squares; AMRes, absolute mean residual.

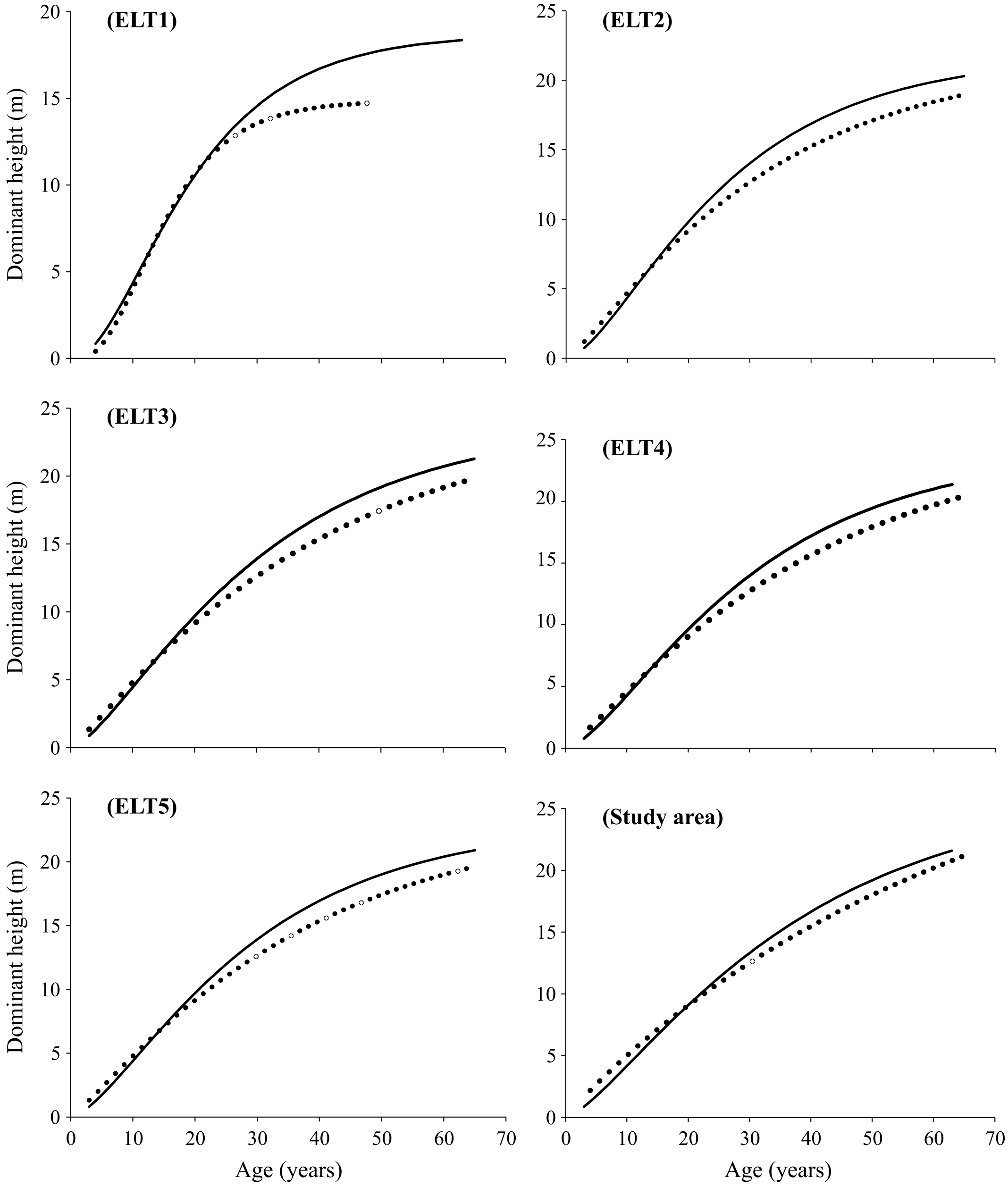

Fig. 4. Height growth comparisons of *Larix olgensis* (dotted line) and *L. kaempferi* (solid line) in different ecological land types (ELTs).

CONCLUSIONS

Based on both biological and statistical considerations, the Chapman-Richards function was most suitable for describing the height growth of both *L. kaempferi* and *L. olgensis*. The ELT classification system is a useful tool for deciding where to set up larch plantations. In the present case, gentle slopes, including ELT2 and ELT3, should be used

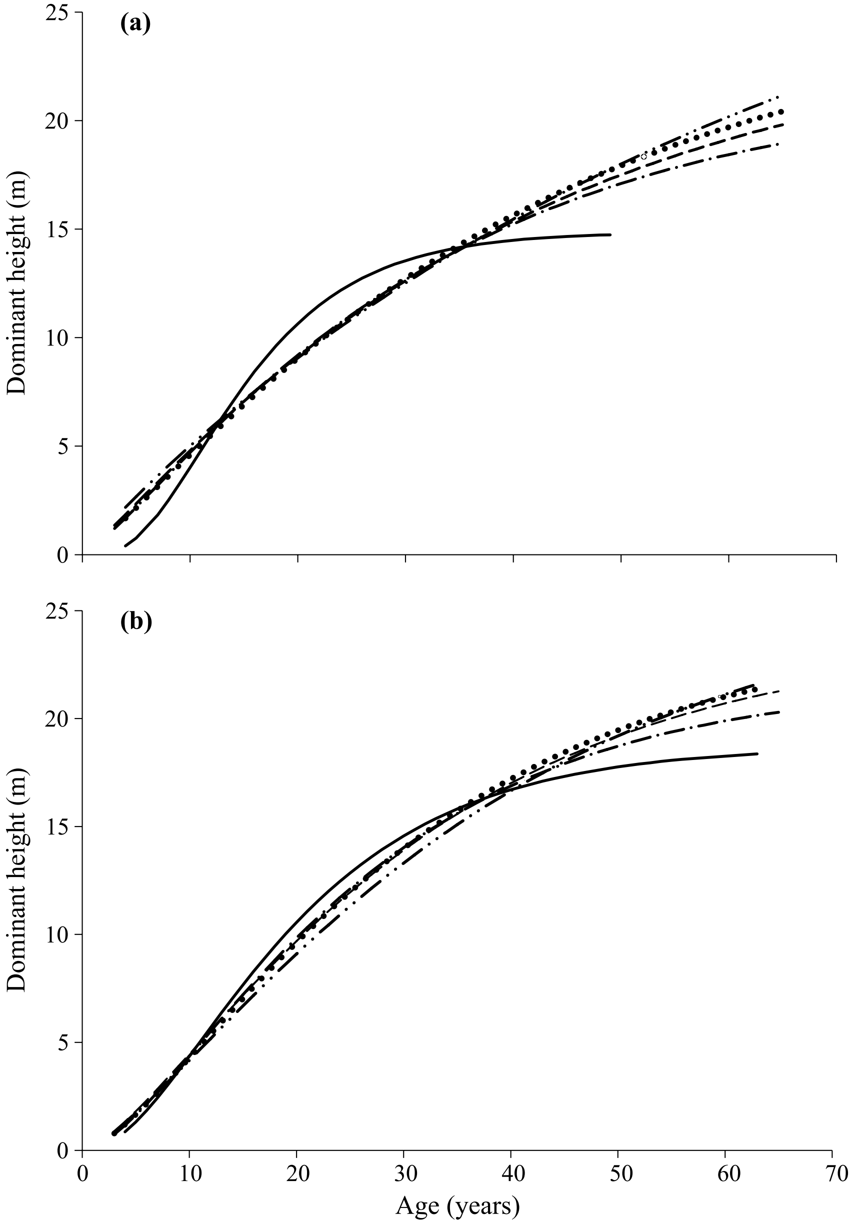

Fig. 5. Height growth comparisons for *L. olgensis* (a) and *L. kaempferi* (b) in the different ELTs (solid line for ELT1, dash-dot line for ELT2, long dash line for ELT3, dotted line for ELT4, dash-dot-dot line for ELT5).

as primary larch plantation areas. In all ELTs and in the overall study area, *L. kaempferi* showed greater growth than *L. olgensis*. *Larix kaempferi* should be widely planted according to the present growth analysis.

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