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CONTRIBUTION FACTOR OF WOOD PROPERTIES OF THREE POPLAR CLONES TO STRENGTH OF LAMINATED VENEER LUMBER

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ABSTRACT

The term "Contribution Factor" (C_f) was introduced in this paper to indicate the contribution ratio of solid wood properties to laminated veneer lumber (LVL) strength. Three poplar (*Populus* sp.) clones were studied, and the results showed that poplar with good solid wood properties has high Contribution Factor. The average Contribution Factor of Poplar 69 (*Populus deltoides* cv. I-69/55), Poplar 72 (*P. euramericana* cv. I-72/58), and Poplar 63 (*P. deltoides* cv.I-63-51) was 76.2%, 68.6%, and 66.1%, respectively. The average Contribution Factor of the three clones for shear strength, modulus of elasticity (MOE), and impact toughness was approximately 80%, which is higher than that for modulus of rupture (MOR), compressive strength, and hardness. The average Contribution Factor of the six properties tested was highest in Poplar 69 (76.2%) and the lowest in Poplar 63 (66.1%), indicating that the Contribution Factor is positively affected by solid wood properties. Densification also significantly affects LVL MOE in Poplar 72, as compared to that of Poplar 69. Poplar 63, however, showed highest improvement in MOR strength from solid wood to LVL and also highest specific LVL MOR, even though it has the lowest solid wood MOR among the three clones.

Keywords: Contribution factor, *Populus* sp., solid wood, laminated veneer lumber, wood properties, strength, plantation.

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INTRODUCTION

Plantation forests are important for the sustainable development of forestry. China has more than 33 million hectares of planted forests to increase its fiber resource and improve its ecosystem, and is now a world leader in afforestation programs (Wang 1995). Efficient use of this resource, however, requires comprehensive understanding of the relationship between wood properties and processing of plantation-grown wood for end-use products. There is voluminous information in the literature on the growth-quality relations of Poplar (*Populus* sp.) wood, which Hu (1988) has compiled, but only a few studies have been conducted addressing the effects of silvicultural treatments and/or juvenile wood on properties of wood composites (Pugel et al. 1989a,b; Wasniewski 1989; Kretschmann et al. 1993). Recent research has focused on the silvicultural effects of specific products, i.e., laminated veneer lumber (Shupe et al. 1997a), plywood (Shupe et al. 1997b; Bao and Jiang 1998), and fiberboard (Shupe et al. 1998). These investigations, however, were performed mainly on the southern pines (*Pinus* spp.), and did not address the effects of plantation-grown genetically engineered species on the performance of specific end-use products. With regard to poplar plantation wood, preliminary studies have been done to determine the relationships between wood properties and end-uses (Fu and Bao 1999; Bao et al. 2000); however, these studies did not identify the "Contribution Factor" of properties other then the inherent solid wood strength.

This study was undertaken to investigate the contribution ratio of solid wood (SWD) properties to laminated veneer lumber (LVL) strength. The objective was to determine the relationship between SWD and LVL properties as observed in poplar clones and to provide a scientific basis for better utilization of poplar plantation resources. Among the various types of wood composites, LVL has more structural similarities to natural wood because it is a wood-matrix laminated assembly with all veneers glued parallel to the longitudinal axis of the billet; therefore, LVL was chosen as the end-use product, whose properties are usually superior to those of solid wood.

MATERIALS AND METHODS

Three clones of a poplar plantation, i.e., *Populus deltoides* cv. I-63/51 (Poplar 63), *P. deltoides* cv. I-69/55 (Poplar 69), and *P. euramericana* cv. I-72/58 (Poplar 72), were selected. Two 11-year-old trees were obtained for each of the three clones from a plantation forest having a stand density of 270 trees per ha growing in a sandy soil site and located at 117° E longitude and 38° N latitude near the Yangtze River at Ann Qing, Anhui Province. Logs 3.5 m in length with base diameter from 24 to 26 cm were cut from each tree. To minimize variability, test samples for determinations of wood and LVL properties were obtained from the same log. Each log was crosscut into two parts—the lower part (1.3 m) was used to manufacture into LVL, and the upper part (2.1 m) was used to determine solid wood properties. The LVL in this study were made from 2.61-mm-thick veneers.

LVL manufacture

The veneers used in the manufacture of LVL were peeled with a laboratory peeler. After peeling, the veneers were clipped to 50–60-cm size and dried to a moisture content below 6% in a "roller" dryer. LVL was prepared at the Research Institute of Wood Industry Laboratory in Beijing, China, using a 600- × 600-mm plywood press. The plies consisted of thirteen layers of 2.61-mm-thick veneer. The resin spread was 300 g/m^2 (liquid basis) of unextended phenol-formaldehyde adhesive (52.7% solid content, 700 MPa viscosity, 10~12 pH). The press temperature, pressure, time, and spacer were 160°C, 1.5 MPa, 20 min, and 25 mm thick, respectively.

Specimen preparation and testing

The various SWD and LVL properties tested are shown in Table 1. In loading direction, TABLE *Testing methods for poplar solid wood (SWD) and laminated veneer lumber (LVL) properties.*

Properties					
Absolute Density	/	5050 × 25	16	16	GB 1993–91
Moisture Content (MC)	/	50 × 50 × 25	16	16	JAS "Structural LVL"
Shear Strength	R25	150 × 25 ×	16	16	JAS "Structural LVL"
Modulus of Rupture (MOR)	R90	575 × 90 × 25	16	16	JAS "Structural LVL"
Modulus of Elasticity (MOE)	R90	575 × 90 × 25	16	16	JAS "Structural LVL"
Compressive Strength	L	50 × 25 × 25	16	16	JAS "Structural plywood'
Impact Toughness	R	300 × 25 × 25	16	16	GB 1940–91
Hardness	R	50 × 50 × 25	16	16	GB 1941–91

R, T, and L refer to radial, tangential, and longitudinal, respectively, and the number after them (e.g., 90, 25) refers to specimen width in mm. With respect to specimen dimensions: for SWD-L refers to longitudinal length, T to tangential width, and R to radial thickness; for LVL-L refers to length parallel to grain, T to width perpendicular to grain, and R to thickness. The letters GB refer to Chinese national standards (National Technique Monitoring Bureau of PRC 1991) and JAS to Japanese agricultural standards (Japanese Agric-For-Aquatic Ministry 1989; 1991).

To measure the effect of wood properties on LVL strength, the term "Contribution Factor" (C_f) was applied. Since the mechanical properties of wood structural composites are usually better than those of solid wood, we assumed that the strength of LVL would be better than that of solid wood. Accordingly, the Contribution Factor C_f, as an indication of the proportion (%) of LVL strength that originated from solid wood properties, can be expressed as:

$$C_f(\%) = (P_s/P_L)100 \quad (1)$$

where P_S is SWD strength and P_L is LVL strength. A high C_f indicates a large effect of solid wood properties on LVL strength, i.e., a large portion of the LVL strength originated from solid wood properties, and only a small portion from processing variables (e.g., adhesive and hot panel assembly, etc). Conversely, a low C_f has a small effect of solid wood properties, and any improvement in LVL strength is mainly due to the contribution of adhesive and processing technique.

RESULTS AND DISCUSSION

The various properties of solid wood and LVL for different clones are shown in Table 2. In solid wood, the highest density was found in Poplar 69 (0.39 g/cm³) and the lowest in Poplar 63 (0.33 g/cm³). By analysis of variance, all the five strength properties [i.e., shear, modulus of rupture (MOR), modulus of elasticity (MOE), compressive strength, and hardness] of Poplar 69 were significantly greater than those of Poplar 63, with the corresponding values for Poplar 79 between the two other clones. Impact toughness, however, showed higher value in Poplar 72 than in Poplar 69, with Poplar 63 still exhibiting the lowest value. It is noted that the variability of the data, as expressed by coefficient of variation, indicated that most of the coefficients in the solid wood properties were higher than those of LVL. The variability of LVL is reduced through the additive effect of LVL strength and the defect dispersion from the assembled veneers (Ambrose 1994).

As shown in Table 2, LVL density was higher than SWD density due to densification effect during hot-pressing, but the order of LVL density with respect to the clone factor was the same as that of solid wood, i.e., densities of LVL 69, LVL 72, and LVL 63 were 0.52, 0.49, and 0.43 g/cm³, respectively. On the average, all LVL strength properties, with the exception of impact toughness, exhibited

TABLE 2. *Properties of poplar SWD and LVL from different clones.*

Wood and clones	Density	MC	Shear strength R25	Shear strength T25	MOR R90	MOR T25	MOE R90	MOE T25	Compressive strength L	Compressive strength T	Impact toughness L	Impact toughness T	Hardness R
	(g/cm^3)	(%)	(MPa)		(MPa)		(GPa)		(MPa)		(KJ/m^2)		(N)
SWD63	0.33 A (10.9)[a]	7.02 A (6.3)	5.57 D (13.6)	6.34 C (21.4)	44.78 C (18.5)	41.05 D (30.3)	7.00 D (12.3)	7.62 C (13.6)	38.37 C (10.8)	4.18 D (3.5)	19.33 D (34.6)	22.05 D (31.2)	1820 D (21.9)
SWD69	0.39 A (5.4)	7.01 A (6.4)	8.72 B (8.9)	8.70 A (24.5)	67.17 A (25.7)	70.48 BC (15.6)	10.49 B (20.7)	11.13 B (17.5)	53.82 B (10.0)	5.96 C (6.7)	28.25 C (17.1)	33.44 A (38.2)	2550 C (12.7)
SWD72	0.35 A (5.5)	6.88 A (8.5)	6.90 C (7.7)	8.49 B (12.8)	57.20 B (12)	60.97 C (9.1)	9.16 C (11.5)	10.68 B (7.8)	45.94 C (11.0)	4.93 CD (13.0)	32.60 BC (22.0)	39.60 A (24.7)	2144 C (20.2)
LVL63	0.43 B (1.9)	5.43 B (1.0)	8.82 B (12.7)	8.82 A (8.1)	67.86 A (20.0)	77.54 A (11.4)	9.15 C (5.4)	9.86 B (5.3)	64.05 A (7.5)	11.99 B (14.2)	22.42 D (12.2)	19.80 C (11.1)	3130 B (10.9)
LVL69	0.52 B (3.7)	5.69 B (1.2)	10.32 A (9.3)	10.14 A (20.1)	78.37 A (15.2)	80.71 A (14.5)	12.38 A (12.8)	13.44 A (18.1)	66.54 A (6.2)	13.9 A (14.6)	35.66 B (19.4)	28.00 BC (14.5)	4175 A (18.3)
LVL72	0.49 B (2.2)	5.45 B (1.9)	8.82 B (3.1)	10.18 A (9.1)	75.11 A (5.8)	87.89 A (16.6)	13.05 A (5.0)	14.16 A (15.3)	67.36 A (5.2)	11.53 B (8.2)	44.97 A (8.7)	36.97 A (12.0)	3325 B (19.4)

[a] Number in parenthesis refers to coefficient of variation (%

higher values than those of SWD of the same poplar clone. In impact toughness, the LVL was better than that of SWD wood in the radial direction, but not in the tangential direction. It is further noticed that the impact toughness is greater in the tangential than the radial direction in SWD, but it is the reverse in LVL. Radial toughness was higher than tangential toughness due mainly to the LVL structure of multiple gluelines. When LVL was impacted radially, the gluelines were in series with one another; thus only the wood veneer in the contacted LVL surface absorbed or buffered the impact energy. On the other hand, when LVL was impacted tangentially, the alternate veneers and adhesive films were in parallel with one another, therefore, the adhesive restricted the absorbing action of contiguous veneers to reduce the impact toughness.

A comparison of the Contribution Factors of SWD strength to those of LVL strength in different clones is shown in Table 3. Among individual properties, the average C_f of the three clones for shear strength, MOE, and impact toughness were near 80%, whereas those of the other strength properties were much lower (i.e., 72.9% for MOR, 54.9% for compressive strength, and 61.2% for hardness). The differences in C_f in individual clones are summarized as follows:

1. In shear strength and MOR, the C_f in both tangential and radial directions were highest in Poplar 69, and lowest in Poplar 63.
2. In compressive strength, the C_f showed the same trends as in shear strength, and the average C_f in the longitudinal direction was almost 30% higher than in the tangential direction.
3. In MOE, the C_f of Poplar 69 were highest, but those of Poplar 72 were the lowest.
4. In impact toughness, the C_fs were calculated only in the radial direction but not in the tangential direction because the tangential toughness of solid wood was greater than that of LVL. When LVL was impacted in the radial direction, the C_f was highest in Poplar 63 and least in Poplar 72.

TABLE 3. *Contribution factors of poplar SWD properties to LVL strength in different clones.*

Wood and clone	Compaction ratio	Shear strength R25	Shear strength T25	MOR R90	MOR T25	MOE R90	MOE T25	Compressive strength L	Compressive strength T	Impact toughness R	Impact toughness T	Hardness R	Ave. C_f (%)
SWD63 vs. LVL63	1.30	63.15	71.88	65.99	52.94	76.50	77.28	59.91	34.86	86.22	111.3	65.24	65.24
SWD69 vs. LVL69	1.33	84.50	85.80	85.70	87.32	84.73	82.81	80.88	42.88	79.22	119.4	77.49	77.49
SWD72 vs. LVL72	1.43	78.23	83.40	76.15	69.37	70.19	75.42	68.20	42.76	72.49	107.1	70.08	70.08
Ave. C_f (%)		78.75		72.91		77.83		54.92		79.31		61.24	

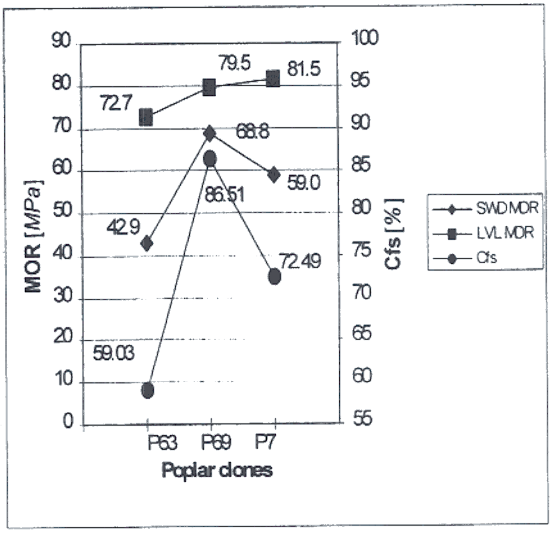

FIG. 1. Effects of Poplar clones and C_f on modulus of rupture of laminate veneer lumber.

5. In hardness, Poplar 72 had the highest C_f, and Poplar 63 the least.

The Contribution Factors in individual properties varied greatly among the clones. Even though a large portion of the LVL strength originated from solid wood properties, the differences in C_f that existed among the various mechanical properties cannot be explained entirely by the effect of wood properties alone. An improvement in LVL strength is also due to the contributory effect of several variables, such as adhesive and manufacture technique. Consequently, the C_f were further evaluated to identify the most probable cause of the LVL performance. Since the bending strength is considered most critical to LVL's structural performance, MOE and MOR were chosen for the analysis. The relationships between C_f and average MOE for the three clones are shown in Fig. 1, and the relationships between C_f and average MOR are shown in Fig. 2.

A comparison of the strength properties among the poplar clones shows three types of relationship:

Case 1 Lower SWD strength and smaller C_f value with lower LVL strength (e.g.,

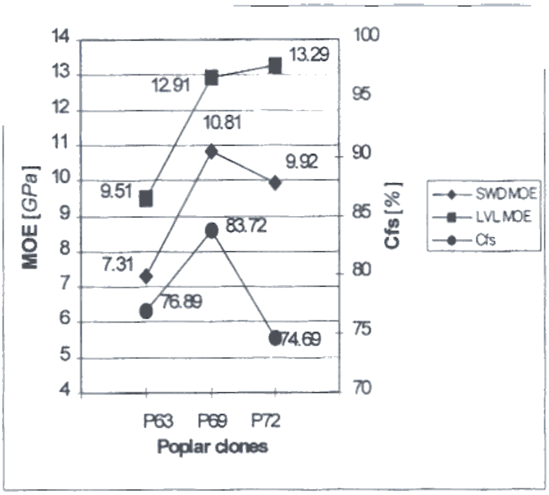

FIG. 2. Effects of poplar clones and C_f on the modulus of rupture of laminate veneer lumbber.

Poplar 63 vs. Poplar 69 or Poplar 63 vs. Poplar 72).

Case 2 Higher SWD strength and larger C_f value with higher LVL strength (e.g., Poplar 69 vs. Poplar 63, or Poplar 72 vs. Poplar 63).

Case 3 Lower SWD strength and smaller C_f value associated with higher LVL strength (e.g., MOE and MOR of Poplar 72 vs. Poplar 69).

An interesting result is found in Case 3. The MOE of solid wood in Poplar 72 was 8.2% lower than that in Poplar 69. However, the MOE of LVL in Poplar 72 was 5.3% greater than that in Poplar 69 even though the Contribution Factor of Poplar 72 was more than 12% smaller than that of Poplar 69. These results indicate that factors other than the inherent solid wood strength also affect LVL MOE; therefore, a further examination was necessary. The improvement in MOE of LVL (E_{lvl}) over MOE of SWD (E_{swd}) [i.e., $(E_{lvl} - E_{swd})/E_{swd}$] and compaction ratio [i.e., ratio of LVL density to SWD density] were calculated from the average data of Poplar 63, Poplar 72, and Poplar 69. The results, summarized in Table 4, indicate that Poplar 72 had a higher compaction ratio (i.e., 1.43) and higher improvement of LVL MOE (37.73%). Since veneer thickness was not significantly different, and resin application rate and LVL thickness were controlled in the same manner during hot-pressing, the high compaction ratio of Poplar 72 was most likely due to veneer densification on the LVL surface, resulting in a high MOE value. A significant improvement in MOE by surface densification of panel products has been documented by Hse (1975) on flakeboard and Suchsland and Woodson (1986) on fiberboard. It should be noted, however, that the effect of density in composite materials is often evaluated also based on specific strength properties (i.e., ratio of strength to density). Such calculation for the average specific MOE and MOR together with Tukey's range test is

TABLE 5. *Mean specific bending strength of SWD and LVL for different clones.*

Wood/Clone	MOE (GPa*cm³/g)	MOR (MPa*cm³/g)
SWD63	22.41 (13.3)[a] C	132.13 (24.3) C
SWD69	27.83 (13.5) A	177.17 (13.5) A
SWD72	28.86 (8.7) A	171.66 (8.7) AB
LVL63	22.14 (3.7) C	169.27 (11.5) AB
LVL69	24.81 (10.9) BC	153.07 (14.6) BC
LVL72	26.92 (9.1) AB	165.28 (10.4) AB

[a] Number in parenthesis refers to coefficient of variation (%). Means with the same capital letter are not significantly different by Tukey's test at 0.05 level.

TABLE 4. *The improvement in bending strength from SWD to LVL for different clones.*

		Strength improvement (%)					
		R90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Poplar 63	1.30	30.71	29.40	30.06	51.54	88.89	70.22
Poplar 69	1.33	18.02	20.75	19.39	16.67	14.56	15.62
Poplar 72	1.43	42.47	32.58	37.53	31.31	44.15	37.73

summarized in Table 5. An analysis of variance indicated that the differences in specific MOE of solid wood between Poplar 69 and Poplar 72 were not significant. However, the LVL's specific MOE (24.81) of Poplar 69 was significantly lower than that of SWD wood specific MOE (27.83), indicating that the density of LVL from Poplar 69 had the least effect on LVL MOE. This phenomenon supports Case 3, i.e., the higher compaction ratio of Poplar 72 resulted in higher improvement of LVL strength. The analysis of variance also showed that the specific LVL MOR (153.07) of Poplar 69 was significantly lower than the specific SWD MOR (177.17), but the differences in specific MOR between LVL and solid wood of Poplar 72 were not significant, indicating again that the density effects on LVL MOR were less in Poplar 69 than Poplar 72. The most surprising results on MOR, however, were in Poplar 63. Even though the SWD specific MOR had the lowest value (132.13 in Table 5), Poplar 63 yielded the largest improvement in LVL MOR (70.22% in Table 4), and resulted in the highest specific LVL MOR (169.27). The reason for the high specific LVL MOR of Poplar 63 is not clear in this study; nevertheless, the potential of improving LVL property with poplar clone needs further investigation.

CONCLUSIONS

The term "Contribution Factor" can be used as an index to evaluate the contribution of solid wood strength to LVL strength. It is directly related to the inherent properties of wood. A genetically good poplar tree had high contribution factors, and vice versa. The Contribution Factors in shear strength, modulus of elasticity, and impact toughness were near 80%, and higher than those in modulus of rupture, compressive strength, and hardness. The average Contribution Factors of the six properties tested were highest in Poplar 69, and lowest on Poplar 63, indicating that the Contribution Factor is positively affected by solid wood properties.

Densification effect on LVL MOE was significant in Poplar 72, as compared to Poplar 69. The most surprising results on MOR, however, were in Poplar 63. With the lowest SWD specific MOR, Poplar 63 yielded the largest improvement in LVL MOR and resulted in the highest specific LVL MOR.

REFERENCES

AMBROSE, J. 1994. Simplified design of wood structure. 5th ed. John Wiley & Sons, Inc., New York, pp. 213–218.

BAO, F. C., AND Z. H. JIANG. 1998. Wood properties of main species from plantation in China. China Forestry Publ. House, Beijing, PRC pp. 525–575.

———, ———, AND S. LIU. 2000. A modeling approach to the relationship between plantation poplar properties and qualities of veneer and plywood. Scientia Silvae Sinicae 36(1):91–96.

FU, F., AND F. C. BAO. 1999. End-use selection of plantation poplar: Solid wood or laminated veneer lumber. Scientia Silvae Sinicae 35(4):64–72.

HSE, C. Y. 1975. Properties of flakeboards from hardwoods growing on southern pine sites. Forest Prod. J. 25(3):48–53.

HU, S. C. 1988. Cottonwood (*Populus deltoides* Bart.)–A bibliography 1987–1986. Bulletin 794, La. Agric. Exp. Sta., Louisiana State Univ. Agric. Center, Baton Rouge, LA.

JAPANESE AGRIC-FOR-AQUATIC MINISTRY. 1989. Structural plywood. JAS (Japanese Agricultural Standard), Tokyo, Japan.

———, 1991 Structural laminated lumber. JAS (Japanese Agricultural Standard), Tokyo, Japan.

KRETSCHMAN, D. E., R. C. MOODY, R. F. PELLERIN, B. A. BENDTSEN, J. M. CAHILL, R. H. MCALISTER, AND D. W. SHARP. 1993. Effect of various proportions of juvenile wood on laminated veneer lumber. Res. Pap. FPL-RP-521. USDA Forest Service, Forest Prod. Lab., Madison, WI. 31 pp.

NATIONAL TECHNIQUE MONITORING BUREAU OF PRC. 1991. Test methods for wood physical and mechanical properties. GB 1927-1943-91 (Chinese National Standard), Beijing PRC.

PUGEL, A. D., E. W. PRICE AND C. Y. HSE. 1989a. Composites from southern pine juvenile wood. Part 1. Panel fabrication and initial properties. Forest Prod. J. 40(1): 29–33.

———, ———, ———. 1989b. Composites from southern pine juvenile wood. Part 2. Durability and dimensional stability. Forest Prod. J. 40(3):57–61.

SHUPE, T. F., C. Y. HSE, L. H. GROOM, AND E. T. CHOONG. 1997a. Effect of silvicultural practice and veneer layup on some mechanical properties of loblolly pine LVL. Forest Prod. J. 47(9):63–69.

———, ———, ———, AND ———. 1997b. Effect of silvicultural practice and veneer layup on some mechanical properties of loblolly pine plywood. Forest Prod. J. 47(10):101–106.

———, ———, E. T. CHOONG, AND L. H. GROOM. 1998. Effect of silviculture practice and wood type on loblolly pine particleboard and medium density fiberboard properties. Holzforschung 53:215–222.

SUCHSLAND, O., AND G. E. WOODSON. 1986. Fiberboard manufacturing practices in the United States. USDA Forest Service Agric. Handbook 640, Washington, DC, p. 30.

WASNIEWSKI, J. L. 1989. Evaluation of juvenile wood and its effects on Douglas-fir structural composite panels. pages 159–173 *in* T. M. Maloney, ed. Proc. 23rd Washington State Univ. Intern. Particleboard/Composite Materials Symposium, Pullman, WA.

WANG, S. J. 1995. Recent research on Poplar. Chinese Forestry Publ. House, Beijing PRC. pp. 1–2.