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Computing the Bucking Rate of Japanese Larch Logs for Timber Harvesting

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Abstract

The Japanese larch (*Larix kaempferi* [Lamb.] Carrière) is a major timber species in Korea. However, studies on bucking rates and merchantable logs of this species are insufficient in South Korea. To bridge these gaps, in this study, the bucking rate of Japanese larch (*Larix kaempferi* [Lamb.] Carrière) was computed and the number of long logs and merchantable log volumes were analyzed. Sample trees were bucked according to the log grade for trading, and collected from a forest field in Gangwon Province. The bucking rate of all Japanese larch logs was >89%. The highly profitable 2-4 logs of 3.6 m length from trees with ≤30 cm diameter at breast height (DBH) and 5-6 logs with ≥34 cm DBH were produced. The bucking rate of long logs was >84%; thus, Japanese larch was found to be suitable for the supply of high-grade timber. Additionally, to follow reasonable wood supply plans, merchantable volume tables were offered based on 3.6 m-long number of logs and small-end diameter classes. Understanding the proportion of merchantable log volumes, bucking rates, and the number of long and short logs has large-scale applications in practical forestry.

Key Words: bucking rate, long-length logs, log grade, merchantable volume, *Larix kaempferi*

Introduction

Standing trees harvested from a forest are used according to different commercial applications. For utilization for timber, only woody parts of a tree, which exclude the top part of a stem, except twigs, leaves, and root, are used (Son et al. 2016). Bucking rate is the utilization rate of wood as timber for use in construction applications or production of furniture, such as board lumbar and rectangular lumber. It is calculated as a percentage of the standing tree to the practical merchantable production volume (National Institute of Forest Science 2016). The bucking rate is an important criterion while considering the sale of standing trees, as it can be used to estimate the amount of unsawn timber production; therefore, the demand for research on bucking rate is consistently increasing to acquire accurate information (National Institute of Forest Science 2016).

The first study on the merchantable volume of a standing tree was conducted by Kim (1963). Since then, relevant research in South Korea has been conducted on bucking and bark rates (Kim and Park 1969; Park and Kim 1978; Park and Chae 1979; Woo et al. 1987). Lee et al. (2000) reported an equation for estimating the bucking rate based on the minimum top diameter by analyzing the stem data of Korean red pine tree in the Gangwon region. Kwon et al. (2007) estimated the merchantable volume and yield percentage of timber by simulating the stem form. Further, Kwon et al. (2013) developed a merchantable-volume com-

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putation model based on the standard size of boards and squared timber. Recently, Son et al. (2016) analyzed the bucking rates of species using stem taper functions. Even today, there are many complaints or opinions from stakeholders, including the National Forest Management Offices, that merchantable volume is underestimated when the existing bucking rate is applied during the sale of standing trees. Therefore, the National Institute of Forest Science has proposed newly updated bucking rate tables based on the frequent demands for practical bucking rates (National Institute of Forest Science 2016).

The bucked lumber is used as raw material for buildings, structure development, interiors, decks, and pulp, and thus, the prices of unsawn logs vary according to the grade classified by criteria, such as diameter, log length, knot, cleavage, curvature, and decay; particularly, good-quality long-length logs are traded at high prices and classified as excellent grade (National Institute of Forest Science 2013; Korea Forestry Promotion Institute 2023). The merchantable logs and bucking rates have been assessed in previous studies, but they were discussed based only on the simulation results using stem taper functions and log standards. Comparisons with merchantable logs and long logs from wood samples from forest sites were not examined (Kwon et al. 2007; Kwon et al. 2013; Son et al. 2016). In this context, the bucking rate and number of logs were studied because of the importance of merchantable long logs using field data (Lee et al. 2017).

In countries with advanced forestry, bucking rates have been estimated, and merchantable volume tables by type have been provided based on merchantable volume using field data (Spurr 1952; Honer 1967; Edminster et al. 1980; Van Deusen et al. 1981). In particular, practical forestry-oriented research has actively progressed, as it provides tables for the number of logs and merchantable volume consistent with the grades, by developing a stem form factor, which estimates merchantable logs, considering the taperness of a standing tree (Mesavage and Girard 1956; Mawson and Conners 1987; Scrivani 1989; Wiant 1986). However, studies on bucking rates and merchantable logs are insufficient in South Korea; therefore, continuous research is necessary.

Thus, this study aimed to bridge this gap in research by providing the merchantable volume, bucking rate, and number of logs of Japanese larch (*Larix kaempferi* [Lamb.] Carrière), a major commercial tree species in South Korea, by analyzing log samples of standing trees that were cut on-site for sale, computing the total merchantable volume and bucking rates, and examining the production of long-length logs, which are economically more feasible than short-length logs.

Materials and Methods

Study site

The study was conducted in forestry fields located in Hongchecon, Hoengseong, and Hwacheon counties in Gangwon Province, where the Japanese larch is most widely distributed across 105,164 ha in South Korea (Korea Forest Service 2023). Japanese larches were felled and cut for sale from forest stands in these fields. The logs in the field were investigated between July and September 2011 at eight sites and between February and April 2019 at three sites. The sample logs varied in diameter and height, from small to large trees with diameter greater than 30 cm, and were collected from forest sites (Lee 2018).

Field measurement method

In the field, basic site and stand information, including address, stand type, aspect, slope, and location, were first recorded to identify the overall condition of the forest stand. Subsequently, according to criteria, such as diameter, log length, knot, cleavage, curvature, and wood cavity, Japanese larch logs, which are traded for sale, cut into round wood by length from a felled tree were investigated (National Institute of Forest Science 2013). Felled trees in the forestry field were chopped to maximize the number of 3.6 m-long logs to provide maximum high-quality sawtimber. When the 3.6 m-long logs could no longer be chopped further, 2.7 m-long logs were produced. Short-length logs (1.8 m) were produced from the residue of a stem after 3.6 m and 2.7 m-long logs were chopped.

The following measurement factors of a sample tree were measured: diameter at breast height (DBH) at 1.2 m height above ground, stump diameter (at approximately 0.2 m height), log length, large-end diameter, and small-end diameter of all logs. In addition, the length from the top stem to the end of the tree height after the last chopped log was measured, and the height of a standing tree was calculated (Lee 2018). The lengths of the logs were measured using a measuring tape, and the diameters outside and inside the bark were measured using calipers. The diameters were measured twice, perpendicularly. Subsequently, the final large- and small-end diameters of all logs were calculated by averaging the two respective aforementioned measurements.

Sample trees and analysis method

The number of collected Japanese larch trees was 320 trees, with their DBH ranging from 11.2 cm to 66.0 cm (mean: 24.5 cm) and height ranging from 12.0 m to 35.1 m (mean: 23.3 m). Among these, some very large and small sample trees, with extreme diameter values, were excluded from the analysis because the number of sample trees was small in these diameter classes. The chopped logs included 3.6 m and 2.7 m long-length logs for high quality timber, and 1.8 short-length logs for pulpwood. Nevertheless, only 17 trees produced 2.7 m-long logs because the chopping process was conducted to retain economic feasibility by maximizing the number of long-length logs.

In this study, the bucking rate, ratio of merchantable volume to standing tree volume, and corresponding merchantable volume were compared using DBH and height classes. Moreover, the merchantable volume, bucking rate, and number of long-length logs were analyzed to determine the amount of timber production for high-quality sawtimber. The log volumes of a felled tree were computed using Smalian’s equation, and the volume of a standing tree was computed by adding the sum of the log volumes, stump volume using a cylindrical formula, and tree top-end volume using a conical formula (Lee et al. 2017; Lee 2018). Merchantable volume was defined as the volume of logs inside the bark and the bucking rate as the ratio of merchantable volume inside the bark calculated by the above process to a standing tree volume outside the bark (Son et al. 2016).

Using the analysis described above, the volumes and bucking rate of logs of all lengths (3.6, 2.7, and 1.8 m) and long-length logs (3.6 and 2.7 m) were provided with tables wherein the values were sorted at an interval of 4 cm DBH and 2 m height considering the established classification method and the number of sample trees in this study. The number of long-length logs was analyzed for only 3.6 m-long logs, and the corresponding results have been presented to provide information on related economical productivity.

Table 1. Merchantable volume and bucking rate for long- and short-length logs (3.6, 2.7, and 1.8 m) of *Larix kaempferi*

Measurement factor		DBH class (cm)										Total	No. of sample trees
		14	18	22	26	30	34	38	42	46	50		
Height class (m)	14	0.092 (89)	0.075 (68)	0.136 (86)								0.101 (81)	6
	16	0.106 (90)	0.146 (90)	0.181 (88)	0.311 (90)							0.146 (90)	16
	18	0.134 (86)	0.163 (89)	0.216 (91)	0.378 (97)		0.607 (91)					0.203 (90)	25
	20	0.168 (88)	0.208 (93)	0.275 (88)	0.391 (94)	0.463 (96)	0.78 (91)			1.609 (98)		0.320 (91)	41
	22	0.199 (93)	0.211 (93)	0.340 (93)	0.420 (94)	0.606 (95)	0.793 (96)	0.537 (96)				0.354 (94)	48
	24		0.198 (91)	0.337 (94)	0.602 (91)	0.611 (96)	0.853 (95)	1.252 (94)	1.565 (97)	1.355 (94)		0.576 (93)	61
	26		0.295 (91)	0.392 (93)	0.886 (89)	0.800 (95)	0.892 (97)	1.344 (96)	1.605 (94)	1.808 (95)		0.732 (93)	56
	28		0.368 (91)	0.369 (93)	0.696 (96)	1.220 (82)		1.415 (97)	2.095 (98)	2.067 (95)	2.218 (97)	0.979 (90)	39
	30			0.534 (94)	0.720 (97)	0.843 (86)		1.421 (98)	1.796 (98)	2.445 (98)		0.971 (92)	18
	32				0.817 (96)		2.026 (81)		2.052 (98)			1.730 (89)	4
	Total	0.132 (89)	0.204 (90)	0.337 (92)	0.604 (92)	0.893 (89)	1.002 (93)	1.248 (96)	1.765 (96)	1.758 (95)	2.218 (97)	-	-
No. of sample trees		15	69	86	63	39	15	9	8	8	2	-	314

With the merchantable volume (m^3), the bucking rate (%) is shown in parenthesis. Unit: m^3 (%).

Results and Discussion

Merchantable volume and bucking rate of all log types

A table of bucking rates has been provided in Table 1 by sorting the sample trees with 4 cm DBH and 2 m height to determine the merchantable volume and bucking rate of all types of logs produced during the sales of standing trees. The merchantable volume and bucking rate of all logs were analyzed using 3.6 m, 2.7 m, and 1.8 m-long logs. The overall bucking rate of all logs was above 89% in all DBH classes and approximately 95% in the DBH class greater than 42 cm.

On comparing the volumes and yield percentages of board and rectangular timbers of Japanese larch, as suggested by Kwon et al. (2007), the merchantable volume and bucking rate in the present study were higher, and the difference was considered to originate from the dissimilarity of the model characteristics and utilization purposes of the preceding study; that is, the small-end log diameters were restricted to diameters ≥16 cm as followed by Kwon et al. (2007). Moreover, a yield percentage that included the scale of slab, kerf, and sawdust (i.e., the estimated amount of usable timber in a log) was obtained by calculating the board and squared timber volume using the small-end diameter. In our study, the small-end diameter of real tree samples from the forestry field was possibly less than 16 cm. To compute log volumes before processing square timbers, we calculated the log volumes and bucking rate in our study using Smalian's formula, and scales of slab, kerf, and sawdust were not included (Lee 2018).

Son et al. (2016) suggested bucking rates through modeling results based on stem taper functions and compared with our study results wherein the DBH ranged between 26 cm and 50 cm, the bucking rate in our study was 1.3%-7.0% higher. Therefore, the actual bucking rate in the forestry field was slightly higher. However, estimating the bucking rate beyond the range (e.g., larger than 46 cm DBH) provided in Table 2 should be done cautiously due to the limitation and a lack of sample trees in our study.

Merchantable volume and bucking rate of long-length logs

The use of roundwood varies by log length, and long-length logs are traded at a higher price than short-length logs in the market; thus, merchantable volume, bucking rate, and the number of long-length logs that are utilized as high-quality sawn timber were proposed at an interval of 4 cm DBH and 2 m height (Table 2). In small trees with <18 cm DBH and 16 m height, the number of long-length logs was

Table 2. Merchantable volume, bucking rate, and number of logs for long-length logs (3.6 and 2.7 m) of *Larix kaempferi*

Measurement factor		DBH class (cm)									Total	No. of sample trees
		18	22	26	30	34	38	42	46	50		
Height class (m)	16	0.106 (61/2)	0.082 (40/1)	0.099 (29/1)							0.100 (55/2)	6
	18	0.125 (63/2)	0.11 (47/1)	0.279 (71/2)		0.607 (91/2)					0.157 (57/2)	16
	20	0.146 (63/2)	0.206 (68/2)	0.302 (67/3)	0.272 (56/2)	0.78 (91/4)			1.468 (89/4)		0.278 (67/3)	30
	22	0.166 (57/2)	0.226 (66/3)	0.307 (67/3)	0.493 (76/3)	0.749 (91/3)	0.520 (92/4)				0.280 (67/3)	41
	24	0.157 (54/2)	0.293 (72/3)	0.461 (71/3)	0.491 (76/4)	0.789 (86/3)	1.171 (87/4)	1.521 (94/5)	1.263 (86/4)		0.558 (75/3)	48
	26	0.265 (89/4)	0.356 (80/4)	0.716 (73/4)	0.622 (76/4)	0.785 (85/5)	1.287 (91/5)	1.54 (90/5)	1.808 (95/5)		0.776 (80/4)	38
	28		0.448 (85/4)	0.565 (83/4)	1.090 (70/4)		1.370 (94/6)	2.03 (95/6)	2.041 (94/6)	2.183 (96/6)	1.225 (80/5)	24
	30		0.510 (80/4)	0.686 (92/6)	0.735 (67/4)		1.421 (98/7)	1.544 (79/5)	2.445 (98/5)		1.019 (78/5)	13
	32					1.785 (71/5)		2.01 (95/7)			1.860 (79/6)	3
	Total	0.151 (62/2)	0.231 (66/3)	0.466 (71/3)	0.751 (72/4)	0.905 (84/4)	1.196 (91/5)	1.659 (89/5)	1.699 (91/5)	2.183 (96/6)	-	-
No. of sample trees		30	51	59	37	15	9	8	8	2	-	219

With the merchantable volume (m^3), the bucking rate (%) is shown on the left side and the number of logs (logs) on the right side in parenthesis. Unit: m^3 (%/logs).
The number of logs was calculated based on sample trees that produced only 3.6 m-long logs and not 2.7 m-long logs.

rarely found in two trees, and it was judged that long-length logs were not produced because the extremely small-end diameter of a log was not suitable for practical forestry applications (Kwon et al. 2007). Long-length logs for board and square timber were mostly produced from trees with 18 cm DBH and 16 m height. This result was consistent with the modeling results of Kwon et al. (2007), which suggested that 3.6 m-long logs were produced with 18 cm DBH. The merchantable volume and bucking rate increased with DBH and height classes; particularly, the bucking rate increased from 62% to 96% for the DBH class and 55% to 80% for the height class. The bucking rate of long-length logs in large trees ≥34 cm DBH exceeded 84%. The amount of volume, which was bucked and utilized as long-length logs, comprised a large proportion due to the straightness of the stem of Japanese larch.

The merchantable volume and bucking rate of long-length logs increased with increasing DBH and height, but the pattern of increase was not uniform. This was caused by deviations possibly originating from various flaws in roundwood grade (knot, cleavage, curvature, and decay), damage to wood when felled and chopped, and cross-cut allowance of logs. On average, 2-4 and 5-6 long-length logs were produced in the DBH classes of < 30 cm and ≥30 cm. When comparing the number of long-length logs of Japanese larch bucked from actual forestry fields, the results of our study were more similar to those obtained by the model of Kwon et al. (2007) than by the model of Kwon et al. (2013).

These results were reported only based on models using actual sample trees from forestry fields. Accordingly, although the models by Son et al. (2016) suggest an entire bucking rate, including all types of log lengths by inputting tree DBH and the last chopped log's small-end diameter (e.g., 6 or 10 cm), information on long-length logs can be complementarily found from the results and tables of our study. Similarly, in Japan, Nishizono et al. (2005) studied the merchantable volume and the ratio of unutilized volume for Japanese larch. They collected 42 sample trees in a range of 38-52 years that were cut into logs either for short-wood logging or for merchantable bole and a top part. The ratio of volume in utilized parts of the stem to total stem in their study was up to 92% in mature stands with high site productivity (Nishizono et al. 2005); this was consistent with the bucking rate of long-length logs of a tree larger than 38 cm of DBH class in our study (Table 2).

Merchantable volume table and bucking rate table by use

A merchantable volume table and bucking rate table by DBH class according to the number of long-length logs

Table 3. Merchantable volume and bucking rate by the number of 3.6 m-long logs of *Larix kaempferi*

DBH class (cm)	No. of 3.6 m-long logs							Total	No. of sample trees
	1	2	3	4	5	6	7		
14		0.083 (68)						0.083 (68)	2
18	0.062 (28)	0.126 (47)	0.196 (68)	0.276 (72)	0.254 (79)			0.151 (53)	30
22	0.081 (31)	0.168 (47)	0.253 (65)	0.372 (74)	0.499 (80)			0.231 (56)	53
26	0.107 (25)	0.360 (46)	0.558 (57)	0.473 (72)	0.562 (83)	0.656 (86)	0.706 (88)	0.464 (61)	57
30		0.357 (43)	0.542 (55)	0.871 (60)	1.010 (76)	0.744 (84)		0.735 (60)	33
34			0.502 (57)	0.885 (71)	0.824 (83)	1.653 (79)		0.95 (72)	10
38				0.830 (77)	1.297 (84)	1.418 (86)	1.421 (91)	1.149 (82)	7
42			0.794 (51)		1.536 (85)	2.030 (89)	2.151 (91)	1.659 (83)	8
46			0.895 (59)	1.468 (83)	1.743 (87)	2.041 (87)		1.655 (82)	6
50						2.183 (89)		2.183 (89)	2
Total	0.080 (29)	0.242 (47)	0.395 (61)	0.615 (70)	0.927 (81)	1.638 (86)	1.607 (90)	-	-
No. of sample trees	24	37	57	47	28	11	4	-	208

With the merchantable volume (m^3), the bucking rate (%) is shown in parenthesis. Unit: m^3 (%).

were suggested, considering that the number of logs can differ according to the roundwood grade, even with the same DBH, when a felled tree was bucked (Table 3). Merchantable volumes were computed by the number of 3.6-long logs at an interval of 4 cm DBH, by considering that long-length logs are produced from the stump toward the upper height. This result is applicable for simulations to establish reasonable roundwood production plans by computing merchantable volume and bucking rate of 3.6 m-long logs according to the number of long-length logs by DBH class. An economical assessment of roundwood production can be achieved more reasonably if merchantable volume tables that include additional characteristics, such as Girard Form Class, can be considered in future studies (Mesavage and Girard 1956; Wiant 1986; Scrivani 1989).

Although the roundwood used as board or square timber has the same log length of 3.6 m, small-end diameters differ as the log is collected from upper height due to the tapering of a stem. Because this results in a large difference in profitability, the number of long-length logs and the merchantable volume by small-end diameter are also important. Considering the characteristics and the number of sample trees, the number of long-length logs and merchantable volume according to a 10-cm range of small-end diameter

Table 4. Merchantable volume and the number of long length logs by small-end diameter class for *Larix kaempferi*

DBH (cm)	Small-end diameter class of long-length logs					No. of sample trees
	dib $<$ 10 cm	10 cm $\leq$ dib $<$ 20 cm	20 cm $\leq$ dib $<$ 30 cm	30 cm $\leq$ dib $<$ 40 cm	dib $\geq$ 40 cm	
14	0.029 (1)	0.068 (2)				2
18	0.031 (1)	0.147 (2)				30
22		0.201 (2)	0.178 (1)			53
26	0.040 (1)	0.225 (2)	0.232 (1)			50
30		0.163 (2)	0.397 (2)			23
34		0.148 (1)	0.584 (3)	0.321 (1)		13
38	0.050 (1)	0.147 (2)	0.510 (2)	0.695 (2)		9
42		0.145 (1)	0.454 (2)	1.064 (3)	0.552 (1)	8
46		0.140 (1)	0.352 (2)	1.128 (3)	0.607 (1)	8
50		0.124 (1)	0.218 (1)	1.148 (3)	0.692 (1)	2

With the merchantable volume (m^3), the number of logs is shown in parenthesis. Unit: m^3 (logs). dib represents the small-end diameter inside the bark.
The number of logs was calculated based on sample trees that produced only 3.6 m-long logs and not 2.7 m-long logs.

Table 5. Tree volume, merchantable volume, bucking rate, and number of logs by DBH class for long- and short-length logs of *Larix kaempferi*

DBH class (cm)	Tree volume (m^3)		Merchantable volume (m^3)		Bucking rate (%)		No. of logs		No. of sample trees
	Outside bark	Inside bark	3.6 m-long and 2.7 m-long logs	1.8 m-long logs	3.6 m-long and 2.7 m-long logs	1.8 m-long logs	3.6 m-long logs	1.8 m-long logs	
14	0.164	0.149	0.071	0.044	60	30	2	1	3
18	0.265	0.224	0.147	0.072	61	31	2	3	29
22	0.430	0.365	0.231	0.082	66	27	3	3	53
26	0.764	0.689	0.451	0.167	66	26	3	4	49
30	1.232	1.055	0.743	0.18	70	18	4	3	35
34	1.196	1.098	0.927	0.146	80	13	4	3	10
38	1.397	1.303	1.084	0.078	90	6	4	2	6
42	1.939	1.829	1.659	0.106	89	7	5	2	8
46	1.984	1.841	1.394	0.117	87	8	4	2	4
50	2.389	2.284	2.183	0.036	96	2	6	1	2

Bucking rates and the number of logs were calculated based only on sample trees that produced both long and short-length logs together.

of a long-length log was analyzed (Table 4). If applied when a tree with a certain DBH class is felled, the merchantable volume and number of long-length logs by the small-end diameter of chopped logs can be determined, and the relevant roundwood production plan scenario can be established.

Lastly, the stem volume of a standing tree, the merchantable volume, bucking rate, and the number of logs classified as long- and short-length logs are summarized and listed in Table 5. If the ratio of trees that is not bucked as logs is used in conjunction with the information provided in Table 5, the by-products of a stem can be calculated, and thus, the potential stem biomass that is left in a forest stand after harvesting can be estimated. The reliability of the statistical information is limited by the low number of samples. A wider range of DBH and height based on a greater number of tree samples from the field should be considered in future studies because the number of tree samples is fundamental to reducing bias and improving accuracy in such research in the field of forestry. Moreover, it would be informative and valuable to consider any site and/or tree factors (i.e., soil fertility, soil texture, topography, stand age, and other tree biometrics) which could indicate log grade regarding curvature and/or decay based on a large number of sample trees.

Conclusion

This study proposed the merchantable volume and bucking rate of Japanese larch from a forestry field in Gangwon Province. The overall bucking rate of all-length logs exceeded 89%, and by comparing the bucking rate computed from the models of previous studies and the tree samples of our study, the difference to a certain degree was examined and discussed. Moreover, based on the number of logs and bucking rate of logs bucked as long-length logs, large trees with DBH >34 cm produced 5-6 logs that were 3.6 m-long; additionally, the bucking rate was evidently high (>84%). Therefore, the Japanese larch was evaluated as a suitable species for producing highly profitable long-length logs. Accordingly, merchantable volume tables were designed based on the number of long-length logs and the range of small-end diameters, and information on the economic trade of standing trees and the establishment of management plans were provided. Finally, a summary table of the merchantable volume and bucking rate of long- and short-length logs by DBH class was offered that can be easily applied for practical forestry. Overall, the results of the current study are useful in understanding the merchantable volume and logs of Japanese larch that are bucked and produced in actual forestry fields. In the future, the issues in the forestry field will be solved by collecting more sample trees and considering additional variable characteristics.

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