Estimating Availability of Logging Residues Using Forest Management Records at Aggregated Stands of Nasushiobara City in Tochigi Prefecture, Japan

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Abstract: Using forest management records from 2005 to 2010, this study compared supply potentials and available logging residue amounts from profitable aggregated stands in Nasushiobara city in Tochigi prefecture with those from profitable subcompartments. Supply potentials from precommercial, commercial thinning, and final felling operations were 39,584 tons, 10,376 tons, and 3,385 tons, respectively. Available amounts at 3,000, 6,000, and 10,000 yen/ton were estimated to be 2,920 tons, 3,495 tons, and 13,334 tons from profitable subcompartments and 2,628 tons, 5,143 tons, and 29,940 tons from profitable aggregated stands, respectively. The available logging residue amounts were increased according to logging residue prices and for aggregated stands. Considering the subsidy, available amounts at 3,000, 6,000, and 10,000 yen/ton were increased to 20,526 tons, 34,981 tons, and 45,175 tons, respectively. The annual available logging residue amounts with a 3,000-yen/ton logging residue price were 3,421 tons/year over the expected demand of logging residues of 2,000 tons/year. Furthermore, the annual available logging residue amounts with a 6,000-yen/ton and a 10,000-yen/ton logging residue price were 5,830 tons/year and 7,529 tons/year over the expected demand for woody biomass of 5,000 tons/year. The supply potential and availability of logging residues, particularly from precommercial thinning operations, were significantly increased from 2009 because of the new tax that started in April 2008.

Keywords: available amount, forest management record, logging residue, subsidy, supply potential

1. Introduction

Japan depends on the import of oil, coal, and natural gas for the majority of its energy supply. The country's energy self-sufficiency rate in 2010 was just 5% (Forestry Agency, The Ministry of Agriculture, Forestry and Fisheries of Japan, 2013). To secure a stable supply of energy, alternatives to fossil fuel, such as "renewable energy" including solar, wind, rivers, geothermal heat, and biomass, need to be developed. Among various biomass resources in Japan, woody biomass in particular attracts attention, not just because of its abundance but also because its energy use is expected to contribute to revitalizing forests and forestry product industries, which have been depressed for the last 30 years. Maintaining the relevant ecological, economic, and social functions of man-made forests, which are behind in tending, is also important.

In July 2011, the "Feed-in Tariff (FIT) Scheme for Renewable Energy Use" was introduced in accordance with new legislation entitled the "Act on Purchase of Renewable Energy Sourced Electricity by Electric Utilities." Under the FIT program, electricity generated from woody biomass is to be procured for 20 years at a fixed price (without tax) for unused materials such as logging residue: 32 yen/kWh, general materials such as sawmill residue: 24 yen/kWh, and recycled materials such as construction waste wood: 13 yen/kWh (Agency for Natural Resources and Energy, 2012). Power generated from unused materials is offered incentives, which is expected to promote the use of logging residue in the near future.

The Tochigi prefecture contains facilities such as biomass power plants, chip production factories, and pellet plants that require woody biomass resources. To examine the availability of woody biomass resources, the annual supply potential and availability of timber and logging residue from profitable subcompartments for all cities and towns in Tochigi prefecture were estimated using 2008 forest management records (Yamaguchi *et al.*, 2014a, 2014b). In this study, estimations were conducted on the basis of subcompartments that were normal operation units in Japan. However, some forest owners' cooperatives aggregated subcompartments, established road networks, and promoted mechanization of aggregated stands to improve operational efficiency and reduce operation costs.

Therefore, Uemura *et al.* (2013) investigated stands aggregated with subcompartments in the Takahara area of Tochigi prefecture using subsidy applications and 2008 forest management records.

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Then, the annual availability of timber and logging residue for aggregated stands was estimated as the annual supply potential from profitable stands, which was then compared with those for subcompartments. The results showed that operation costs were reduced and the annual availability of timber was increased from subcompartments to aggregated stands, whereas the annual availability of logging residues remained the same. Then, the system to aggregate neighboring subcompartments was developed. The results showed that the number and areas of stands aggregated by the system were similar to those of actual aggregated stands. Therefore, the operation costs and annual availability of timber and logging residue estimated by the system were also similar to those of actual aggregated stands.

This study first examined the system to aggregate neighboring subcompartments and compared the supply potential and availability of logging residue from profitable stands with those for subcompartments in Nasushiobara city in Tochigi Prefecture, where an agrarian organization was willing to conduct thinning operations and extract thinned wood for biomass power generation in cooperation with the Forest Owners' Co-operative (Aruga *et al.*, 2013b). This supply potential and availability were estimated using forest management records for several fiscal years between 2005 and 2010 to examine the trends, particularly, with a new tax –Tochigi no genkina moridukuri kenmin zei– to make forests healthy, along with subsidies for thinning operations, that started in April 2008 (Tochigi Prefectural Government, 2010a).

2. Study Site and Data

The study site was Nasushiobara city in Tochigi Prefecture, Japan (Figure 1), with a gross area of 59,282 ha, and forest area of 37,433 ha (63% of the gross area). The national forest and privately held and local government forest areas were 23,726 ha and 13,707 ha, respectively. In this study, major plantation species, such as Japanese cedar (*Cryptomeria japonica*) and Japanese cypress (*Chamaecyparis obtuse*) owned by private individuals and local governments, were analyzed. Private individuals and local governments owned 7,360 subcompartments of Japanese cedar comprising 2,855 ha, and 2,521 subcompartments of Japanese cypress comprising 1,103 ha. These forests are primarily 45 to 55 years old. The northern parts of Nasushiobara are mountainous; however, these areas are comprised mostly of national forests. Private and local government forests are located on relatively gentle slopes; therefore, the average slope angle is relatively low (17.6%) and the forest road network density is relatively high (27 m/ha).

Forest-registration data (stand ages, tree species, and site indices) and GIS data (information on roads and subcompartment layers) from the Tochigi Prefectural Government were used in the study, as were 10-m-grid digital elevation models (DEMs) from the Geographical Survey Institute. Private individuals and local governments own 6,342 subcompartments of Japanese cedar comprising 2,464 ha and 1,862 subcompartments of Japanese cypress comprising 839 ha, based on combined forest registration and GIS data. These numbers and subcompartment areas were 17% less than those of the actual subcompartments because of the relational problem between forest registration data and GIS data.

We used forest management records from 2005 to 2010 that were established from subsidy records. Therefore, final felling operations without a subsidy were not in the records. In this study, planting operations were assumed to occur the year after the final felling operations. Precommercial and commercial thinning operations, and final felling operations, were conducted on 1,004 subcompartments, 496 subcompartments, and 67 subcompartments of forest management records, respectively. However, only 894 subcompartments, 452 subcompartments, and 37 subcompartments were combined with forest registration data and GIS data (Table 1, Figure 2).

Because forests are almost 45 to 55 years old, many thinning operations were conducted and very few final felling operations were conducted (Figure 3) because of the low profitability of such operations with regeneration expenses on the current Japanese forestry situation (Aruga *et al.*, 2013b). Given delays in thinning operations – a serious problem for man-made forests in Japan – in April 2008, the Tochigi Prefectural Government introduced the new tax. As a result, precommercial thinning operations increased significantly from 2009 (Figure 2).

Figure 1. Distribution map of operation sites, log markets, and a plant (1: Yaita log market, 2: Ootawara log market, 3: A planned woody biomass power generation plant)
(the points were magnified ten times to make them easier to see)

Figure 2. Operation site areas from 2005 to 2010.

Table 1. The number and areas of subcompartments and supply potentials of timber and logging residues from 2005 to 2010.

	No. subcompartments		Area of subcompartments		Supply potentials of timber		Supply potentials of logging residues	
Precommercial thinning	894	64.64%	820 ha	68.38%	5,161 m ³	17.44%	39,584 ton	74.20%
Commercial thinning	452	32.68%	298 ha	24.82%	12,375 m ³	41.83%	10,376 ton	19.45%
Final felling	37	2.68%	82 ha	6.80%	12,051 m ³	40.73%	3,385 ton	6.35%
Total	1,383	100.00%	1,200 ha	100.00%	29,587 m ³	100.00%	53,345 ton	100.00%

Figure 3. Frequency distribution of operation site areas from 2005 to 2010.

3. Methods

In this study, available logging residue amounts were projected in the following order: 1) the system aggregated neighboring subcompartments; 2) supply potentials were estimated on the basis of cutting and extraction rates; 3) forwarding and transportation distances were estimated; 4) total expenses for thinning and final felling operations for each operation system were estimated; 5) incomes were estimated without or with a subsidy; 6) profitability was estimated; and 7) available amounts were projected as supply potentials from profitable stands. Full technical details will be found in earlier papers (Yamaguchi *et al.*, 2014a; Uemura *et al.*, 2013).

The system aggregated adjacent subcompartments. As a result, 1,383 subcompartments were aggregated to 560 aggregated stands. The average area was increased from 0.87 ha for subcompartments to 2.14 ha for aggregated stands (Figure 4).

Estimation of the supply potential of timber and logging residue was based on the cutting rate (Cr), extraction rate (Er), timber rate (Tr), and logging residue rate (Lr). The cutting rate (Cr) is 100% of the final felling operations and the thinning ratio of each subcompartment in the forest management records. The extracting rate (Er), which is the ratio of the extracted volume to the felled tree volume (stocks of stems), was assumed to be 123% and 124% for Japanese cedar and

Japanese cypress (Greenhouse Gas Inventory Office of Japan, 2006), respectively, considering branch extractions. The timber rate (Tr) is the ratio of the timber to be transported to log markets to the total felled and extracted tree volume, whereas the logging residue rate (Lr) is the ratio of the logging residue to be transported to the factories to the total felled and extracted tree volume. Tr and Lr are 10% and 90% of the stocks in precommercial thinning operations, respectively, both are 50% of the stocks in the commercial thinning operation, and 75% and 25% of the stocks in the final felling operations, respectively.

Figure 4. Areas before and after aggregating.

The supply potential of timber and logging residue was estimated by the following expressions.

$$[1] \quad H = S \times Cr \times Er = V \times A$$

$$[2] \quad H_T = H \times Tr$$

$$[3] \quad H_L = H \times Lr \times Gr$$

H is the extracted volume (m^3), S is the stock of the stems of a sub-compartment in the forest registration data (m^3), V is the extracted volume per hectare (m^3/ha), A is area of sub-compartment (ha), H_T is the extracted timber volume (m^3), H_L is the extracted logging residues weight (ton), and Gr is the volume density, which is assumed to be $0.68 \text{ tons}/\text{m}^3$ based on the Mikamo Forest Owners' Association survey results (2008).

Forwarding distances were estimated as the average distances from landings to all grids within the subcompartments. Landings were set within grids to minimize their distance from the roads, the centers of gravity in the sub-compartment, and a planned woody biomass power generation plant (Figure 1). Transportation distances from the landings to Yaita and Ootawara log markets and the plant were calculated by the shortest path algorithm, i.e., the Dijkstra method (Dijkstra, 1959). The plant needs 5,000 tons/year of woody biomass, of which 2,000 tons/year is expected from logging residues.

The direct and indirect operation expenses associated with each machine, and strip road and landing establishment expenses were estimated by the following equation.

$$[4] \quad A = D + R + L + I$$

where A denotes all costs, D is the direct operation expenses, R is the strip-road-establishment expenses, L is the landing-establishment expenses, and I is the indirect operation expenses.

The direct expenses include labor and machinery expenses (maintenance, management, depreciation, and fuel and oil expenses). Machine transportation expenses, garage-maintenance expenses, overhead costs, handling fees associated with the log market, and consumption tax were considered as indirect operation expenses (Zenkoku Ringyo Kairyo Fukyu Kyokai, 2001).

The forest operation system was determined on the basis of interviews with forest owners' cooperative officials. The forest operation system included chainsaw felling and processing, grapple loader bunching, and forwarder forwarding. Only operations after chainsaw processing are considered in logging residue harvesting. In addition to the forest operation system, the forest operation system of the subcompartments on roads is assumed to consist only of piling by a grapple loader and transportation by a truck.

Revenue was estimated using supply potential and log prices for Japanese cedar and others (10,000 yen/m³), Japanese cypress (20,000 yen/m³), and logging residue (3,000 yen/ton). In addition, a logging residue price of 6,000 yen/ton was assumed with additional subsidies (Japanese Forestry Investigation Committee, 2011a), and a price of 10,000 yen/ton was assumed if FITs were introduced in Japan (Japanese Forestry Investigation Committee, 2011b).

For thinning operations, subsidies were received in Japan. Subsidies (Table 2) were estimated using standard unit costs, areas, assessment coefficients, and the subsidy rate of the Tochigi Prefectural Government (2010b). Standard unit costs were determined on the basis of ages and thinning rates. The assessment coefficient and the subsidy rate were assumed to be 1.7 and 4/10, respectively.

In Japan, subcompartments with subsidized thinning operations also received subsidies for the establishment of strip roads. Standard unit costs for the establishment of strip roads were determined using the average slope angle (degree) and the road width. Then, subsidies (Table 3) were estimated using standard unit costs, length, assessment coefficients, and the subsidy rate of Tochigi Prefectural Government (2010b). The assessment coefficient and the subsidy rate were assumed to be 1.7 and 4/10, respectively.

After estimating the economic balances from revenue and costs, production forests were extracted as profitable stands. Then, the availability of timber and logging residues was estimated using the supply potential from the profitable stands.

Table 2. Subsidies for thinning operation (yen/ha).

Thinning rate	Stand age (year)				
	–15	16–25	26–35	36–45	46–60
20%–	204,735	235,504	236,990	225,457	228,348
30%–	307,788	352,910	355,145	338,188	342,520

Table 3. Subsidies for strip road establishment (yen/m).

Average slope angle	Width	
	2.5m	3.5m
Gradual (–15 degrees)	102	153
Medium (15–30 degrees)	203	358
Steep (30– degrees)	501	1,262

4. Results and Discussions

4.1 Supply Potentials

The supply potentials of timber and logging residue were 29,587 m³ and 53,345 tons (8,890 tons/year), of which 17% (5,161 m³) and 74% (39,584 tons or 6,597 tons/year) were from precommercial thinning operations, 42% (12,375 m³) and 19% (10,376 tons or 1,729 tons/year) were from

commercial thinning operations, and 41% (12,051 m³) and 6% (3,385 tons or 564 tons/year) were from final felling operations, respectively (Table 1, Figure 5).

Figure 5. Supply potentials of logging residues from 2005 to 2010.

4.2 Available Amounts from Profitable Subcompartments without Subsidy

The number and areas of profitable subcompartments with a 3,000-yen/ton logging residue price were 19 subcompartments (1.37%) and 63 ha (5.28%), of which 0 subcompartments (0.00%) and 0 ha (0.00%) were from precommercial thinning operations, 7 subcompartments (1.55%) and 8 ha (2.79%) were from commercial thinning operations, and 12 subcompartments (32.43%) and 55 ha (67.45%) were from final felling operations, respectively (Table 4). No precommercial thinning operations were profitable. Almost all profitable subcompartments were from final felling operations. Therefore, the available timber and logging residue amounts from profitable subcompartments with a 3,000-yen/ton logging residue price were 9,991 m³ and 2,920 tons (487 tons/year), of which 0% (0 m³) and 0% (0 tons or 0 tons/year) were from precommercial thinning operations, 2% (237 m³) and 7% (200 tons or 33 tons/year) were from commercial thinning operations, and 98% (9,754 m³) and 93% (2,721 tons or 454 tons/year) were from final felling operations, respectively (Tables 5 and 6, Figure 6). The supply potential of logging residues from precommercial thinning operations occupied 74%. However, no available logging residue amount from precommercial thinning operations were estimated and almost all available logging residue amounts were from final felling operations because of profitability (Table 7). The number and areas of profitable subcompartments and available logging residue amounts were increased according to logging residue prices (Tables 4 and 6). In particular, the logging residue amount from precommercial thinning operations was significantly increased with a 10,000-yen/ton logging residue price from 2008 because the new tax started in April 2008 (Figure 6).

Table 4. The number and areas of profitable subcompartments without subsidy from 2005 to 2010.

Unit prices	3,000 yen/ton				6,000 yen/ton				10,000 yen/ton			
	No.	Ratio (%)	Area (ha)	Ratio (%)	No.	Ratio (%)	Area (ha)	Ratio (%)	No.	Ratio (%)	Area (ha)	Ratio (%)
Precommercial thinning	0	0.00	0	0.00	0	0.00	0	0.00	42	4.70	135	16.47
Commercial thinning	7	1.55	8	2.79	18	3.98	16	5.33	45	9.96	47	15.61
Final felling	12	32.43	55	67.45	20	54.05	67	82.33	25	67.57	71	86.37
Total	19	1.37	63	5.28	38	2.75	83	6.93	112	8.10	252	21.01

Table 5. Available amounts of timber and ratio to supply potentials on profitable sub-compartments without subsidy from 2005 to 2010.

Unit prices	3,000 yen/ton		6,000 yen/ton		10,000 yen/ton	
	Amounts (m ³)	Ratio (%)	Amounts (m ³)	Ratio (%)	Amounts (m ³)	Ratio (%)
Precommercial thinning	0	0.00	0	0.00	1,137	22.03
Commercial thinning	237	1.91	425	3.43	1,832	14.80
Final felling	9,754	80.94	11,197	92.91	11,549	95.83
Total	9,991	33.77	11,622	39.28	14,517	49.07

4.3 Available Amounts from Profitable Aggregated Stands without Subsidy

The number and areas of profitable aggregated stands with a 3,000-yen/ton logging residue price were 17 aggregated stands including 42 subcompartments (3.04%) and 76 ha (6.30%), of which 0 subcompartments (0.00%) and 0 ha (0.00%) were from precommercial thinning operations, 35 subcompartments (7.74%) and 24 ha (8.11%) were from commercial thinning operations, and 7 subcompartments (18.92%) and 51 ha (63.02%) were from final felling operations, respectively (Table 8). The available timber and logging residue amounts from profitable aggregated stands with a 3,000-yen/ton logging residue price were 7,992 m³ and 2,628 tons (438 tons/year), of which 0% (0 m³) and 0% (0 tons or 0 tons/year) were from precommercial thinning operations, 8% (634 m³) and 20% (537 tons or 90 tons/year) were from commercial thinning operations, and 92% (7,359 m³) and 80% (2,091 tons or 349 tons/year) were from final felling operations, respectively (Tables 9 and 10, Figure 7). The number and areas of profitable subcompartments and available logging residue amounts from commercial thinning operations were increased for aggregated stands. However, the number and areas of profitable subcompartments and available logging residue amounts from final felling

Table 6. Available amounts of logging residues and ratio to supply potentials on profitable sub-compartments without subsidy from 2005 to 2010.

Unit prices	3,000 yen/ton		6,000 yen/ton		10,000 yen/ton	
	Amounts (ton)	Ratio (%)	Amounts (ton)	Ratio (%)	Amounts (ton)	Ratio (%)
Precommercial thinning	0	0.00	0	0.00	8,558	21.62
Commercial thinning	200	1.93	358	3.45	1,536	14.80
Final felling	2,721	80.38	3,137	92.67	3,240	95.72
Total	2,920	5.47	3,495	6.55	13,334	25.00

Table 7. Average economic balances (yen/m³).

Unit prices	Subcompartment without subsidy			Aggregated stand without subsidy			Aggregated stand with subsidy	
	Revenues	Cost	Balance	Revenues	Cost	Balance	Subsidy	Balance
Precommercial thinning	2,850	13,955	-11,104	2,905	9,966	-7,062	4,410	-2,652
Commercial thinning	6,194	11,403	-5,210	6,093	8,385	-2,292	3,549	1,257
Final felling	7,451	7,757	-306	7,931	7,819	111	0	111
Total	4,506	12,224	-7,718	4,506	9,227	-4,721	3,500	-1,221

Figure 6. Available amounts of logging residues on profitable sub-compartments without subsidy from 2005 to 2010 .

operations were decreased because the profitability of these operations was reduced by aggregating the deficit thinning operations. Similar to subcompartments, the available logging residue amounts from profitable aggregated stands were increased according to logging residue prices. Increases in the available logging residue amounts from profitable aggregated stands were higher than those from profitable subcompartments. In particular, the available logging residue amounts from profitable aggregated stands with a 10,000-yen/ton logging residue price were more than double those for profitable subcompartments.

Table 8. The number and areas of profitable aggregated stands without subsidy from 2005 to 2010.

Unit prices	3,000 yen/ton				6,000 yen/ton				10,000 yen/ton			
	No.	Ratio (%)	Area (ha)	Ratio (%)	No.	Ratio (%)	Area (ha)	Ratio (%)	No.	Ratio (%)	Area (ha)	Ratio (%)
Stand	17	3.04	76	6.30	34	6.07	144	12.02	134	23.93	697	58.03
Precommercial thinning	0	0.00	0	0.00	0	0.00	0	0.00	239	26.73	399	48.57
Commercial thinning	35	7.74	24	8.11	108	23.89	74	24.98	334	73.89	219	73.54
Final felling	7	18.92	51	63.02	14	37.84	70	85.56	26	70.27	79	96.49
Total subcompartment	42	3.04	76	6.30	122	8.82	144	12.02	599	43.31	697	58.03

Table 9. Available amounts of timber and ratio to supply potentials on profitable aggregated stands without subsidy from 2005 to 2010.

Unit prices	3,000 yen/ton		6,000 yen/ton		10,000 yen/ton	
	Amounts (m ³)	Ratio (%)	Amounts (m ³)	Ratio (%)	Amounts (m ³)	Ratio (%)
Precommercial thinning	0	0.00	0	0.00	2,379	46.11
Commercial thinning	634	5.12	2,777	22.44	8,802	71.13
Final felling	7,359	61.06	9,924	82.35	11,444	94.96
Total	7,992	27.01	12,700	42.93	22,625	76.47

4.4 Available Amounts from Profitable Aggregated Stands with Subsidy

The number and areas of profitable aggregated stands with a 3,000-yen/ton logging residue price and a subsidy were 185 aggregated stands including 601 subcompartments (43.46%) and

Table 10. Available amounts of logging residues and ratio to supply potentials on profitable aggregated stands without subsidy from 2005 to 2010.

Unit prices	3,000 yen/ton		6,000 yen/ton		10,000 yen/ton	
	Amounts (ton)	Ratio (%)	Amounts (ton)	Ratio (%)	Amounts (ton)	Ratio (%)
Precommercial thinning	0	0.00	0	0.00	19,301	48.08
Commercial thinning	537	5.17	2,323	22.38	7,664	73.86
Final felling	2,091	61.77	2,820	83.31	3,245	95.85
Total	2,628	4.93	5,143	9.64	29,940	56.13

Figure 7. Available amounts of logging residues on profitable aggregated stands without subsidy from 2005 to 2010.

593 ha (49.43%), of which 222 subcompartments (24.83%) and 304 ha (37.03%) were from pre-commercial thinning operations, 365 subcompartments (80.75%) and 234 ha (78.71%) were from commercial thinning operations, and 14 subcompartments (37.84%) and 55 ha (67.27%) were from final felling operations, respectively (Table 11). The available timber and logging residue amounts from profitable aggregated stands with a 3,000-yen/ton logging residue price and a subsidy were 18,454 m³ and 20,526 tons (3,421 tons/year), of which 8% (1,399 m³) and 50% (10,349 tons or 1,725 tons/year) were from precommercial thinning operations, 49% (9,100 m³) and 39% (7,922 tons or 1,320 tons/year) were from commercial thinning operations, and 43% (7,955 m³) and 11% (2,255 tons or 376 tons/year) were from final felling operations, respectively (Tables 12 and 13, Figure 8). The number and areas of profitable aggregated stands and available logging residue amounts were increased with a subsidy. The available logging residue amounts with unit prices of logging residues of 3,000, 6,000, and 10,000 yen/ton were increased to 20,526 tons (3,421 tons/year), 34,981 tons (5,830 tons/year), and 45,175 tons (7,529 tons/year), respectively. The ratios of the available amounts to supply potentials with logging residue unit prices of 3,000, 6,000, and 10,000 yen/ton were also increased to 38.48%, 65.57%, and 84.68%, respectively. The increases in logging residue unit prices of 3,000, 6,000, and 10,000 yen/ton were 7.8, 6.8, and 1.5 times the available amounts without a subsidy.

Table 11. The number and areas of profitable aggregated stands with subsidy from 2005 to 2010.

Unit prices	3,000 yen/ton				6,000 yen/ton				10,000 yen/ton			
	No.	Ratio (%)	Area (ha)	Ratio (%)	No.	Ratio (%)	Area (ha)	Ratio (%)	No.	Ratio (%)	Area (ha)	Ratio (%)
Stand	185	33.04	593	49.43	276	49.29	837	69.75	366	65.36	1,001	83.42
Precommercial thinning	222	24.83	304	37.03	443	49.55	507	61.73	597	66.78	650	79.23
Commercial thinning	365	80.75	234	78.71	392	86.73	254	85.24	414	91.59	272	91.39
Final felling	14	37.84	55	67.27	23	62.16	77	93.88	26	70.27	79	96.49
Total subcompartment	601	43.46	593	49.43	858	62.04	837	69.75	1,037	74.98	1,001	83.42

Table 12. Available amounts of timber and ratio to supply potentials on profitable aggregated stands with subsidy from 2005 to 2010.

Unit prices	3,000 yen/ton		6,000 yen/ton		10,000 yen/ton	
	Amounts (m ³)	Ratio (%)	Amounts (m ³)	Ratio (%)	Amounts (m ³)	Ratio (%)
Precommercial thinning	1,399	27.10	3,131	60.66	4,235	82.07
Commercial thinning	9,100	73.54	10,093	81.56	11,077	89.51
Final felling	7,955	66.01	11,217	93.07	11,444	94.96
Total	18,454	62.37	24,440	82.60	26,756	90.43

Table 13. Available amounts of logging residues and ratio to supply potentials on profitable aggregated stands with subsidy from 2005 to 2010.

Unit prices	3,000 yen/ton		6,000 yen/ton		10,000 yen/ton	
	Amounts (ton)	Ratio (%)	Amounts (ton)	Ratio (%)	Amounts (ton)	Ratio (%)
Precommercial thinning	10,349	26.14	23,039	58.20	32,581	82.31
Commercial thinning	7,922	76.35	8,763	84.46	9,349	90.11
Final felling	2,255	66.62	3,179	93.89	3,245	95.85
Total	20,526	38.48	34,981	65.57	45,175	84.68

Figure 8. Available amounts of logging residues on profitable aggregated stands with subsidy from 2005 to 2010.

5. Conclusions

In this study, forest management records from 2005 to 2010 were used to estimate and compare supply potentials and available logging residue amounts from profitable aggregated stands from Nasushiobara city in Tochigi prefecture with those from profitable subcompartments. As a result, the available logging residue amounts from commercial thinning operations were increased for aggregated stands. However, the available logging residue amounts from final felling operations were decreased because the profitability of the final felling operations was reduced by aggregating the deficit thinning operations. In this study, aggregating subcompartments decreased indirect costs such as machine transportation expenses and garage-maintenance expenses because such indirect costs were fixed, the larger the volume, the lower the cost. However, aggregating subcompartments would improve operational efficiency and reduce operation costs by establishing road networks and promoting mechanization although this study did not consider. It is difficult to find out increases on operational efficiency and reduction of operation costs by aggregating subcompartments (Aruga *et al.*, 2013a), but the system should be improved to consider this.

Considering the subsidy, the available logging residue amounts were significantly increased, and those with a 3,000-yen/ton logging residue price were 3,421 tons/year over the expected demand of logging residues of 2,000 tons/year. Furthermore, the available logging residue amounts with a 6,000-yen/ton and a 10,000-yen/ton logging residue price were 5,830 tons/year and 7,529 tons/year over the expected demand for woody biomass of 5,000 tons/year. This study estimated the supply potential and availability using forest management records from 2005 to 2010, and examined the trends. As a result, the supply potential and availability of logging residues, particularly from precommercial thinning operations, were significantly increased from 2009 because of the new tax that started in April 2008. The next study will project the supply potentials and available logging residue amounts using forest management plans.

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References

- Agency for Natural Resources and Energy (2012) Settlement of the details of the Feed-in Tariff scheme for renewable energy, including purchase price and surcharge rates, <http://www.meti.go.jp/english/press/2012/0618_01.html> (Accessed 18 June 2012).
- Aruga, K., Hiyamizu, G., Nakahata, C., and Saito, M. (2013a) Effects of aggregating forests, establishing forest road networks, and mechanization on operational efficiency and costs in a mountainous region in Japan, *J. Forestry Res.* 24: 747–754.
- Aruga, K., Murakami, A., Nakahata, C., Yamaguchi, R., Saito, M., and Kanetsuki, K. (2013b) A model to estimate available timber and forest biomass and reforestation expenses in a mountainous region in Japan, *J. Forestry Res.* 24: 345–356.
- Dijkstra, E.W. (1959) A note on two problems in connection with graphs, *Numerische Mathematik* 1: 269–271.
- Forestry Agency, The Ministry of Agriculture, Forestry and Fisheries of Japan (2013) *Annual Report on Forest and Forestry in Japan. Fiscal Year 2012 (summary)*, Tokyo.
- Greenhouse Gas Inventory Office of Japan (2006) *Greenhouse Gas Inventory Report in Japan*, Tokyo (in Japanese).
- Japanese Forestry Investigation Committee (2011a) Tosa No Mori System in which Thinned Trees are Traded with Community Currency for 6,000 yen/ton Begins in Chizu Town, Tottori Prefecture and the System has been Prevailing, **Rinsei (Forest policy*) News* 409: 14 (in Japanese).
- Japanese Forestry Investigation Committee (2011b) Wood Chip for Power Generation Paid Attention to Feed-in Tariff (FIT), which would Improve the Unit Price of Logging Residue to 20 yen/kWh.

This Would Promote Effective Utilization of Logging Residues, **Rinsei (Forest policy*) News* 405: 7 (in Japanese).

Mikamo Forest Owners' Association and Sumitomo Osaka Cement Company (2008) *Research Report on Extracting Forest Biomass Resources*,* Mikamo Forest Owners' Association and Sumitomo Osaka Cement Company, Tochigi (in Japanese).

Tochigi Prefectural Government (2010a), Tochigi No Genkina Moridukuri Prefectural Tax (to Make Healthy Forests with Subsidies for Thinning Operations*) *Business Evaluation Report of Fiscal Year 2009*, Tochigi Prefectural Government, Utsunomiya (in Japanese).

Tochigi Prefectural Government (2010b) *Forestation Program Standard Unit Cost Table of Fiscal Year 2010*, Tochigi Prefectural Government, Tochigi, 2010 (in Japanese).

Uemura, R., Aruga, K. and Tasaka, T. (2013) Estimating the annual supply potential and availability of timber and logging residue at aggregated stands of Takahara area, Tochigi prefecture, Japan. *Proc. IUFRO3.08&6.08 Joint Conference in Fukuoka*, pp. 435–462.

Yamaguchi, R., Aruga, K. and Nagasaki, M. (2014a) Estimating the annual supply potential and availability of timber and logging residue using the forest management records of the Tochigi prefecture, Japan, *J. Forest Res.* 19: 22–33.

Yamaguchi, R., Aruga, K., Murakami, A., Nakahata, C., Saito, M. and Nagasaki, M. (2014b) Effects of stand conditions on annual availability of logging residue estimated using forest management records in Tochigi prefecture, Japan, *FORMATH* 13: 20–40.

Zenkoku Ringyo Kairyo Fukyu Kyokai (2001) *Management of Forestry Mechanization*, Zenkoku Ringyo Kairyo Fukyu Kyokai, Tokyo (in Japanese).

*Approximate translations by the authors.