ABSTRACT

This study was carried out to investigate the potential of timber production in private forest that is typically small in size, and to schedule timber yield for sustainable forest management. The study target areas were 1424 ha of Jinan-gun pioneer forest management sites in Jeollabuk-do, Korea. To schedule the timber yield, analysis and statistical processing were conducted based on materials obtained from the Forest Resources Inventory Center of the National Forestry Cooperatives Federation. The timber yield schedule, which induced legal forest state using the concept of maturity based on resource analysis, showed that total maturity level of *Pinus densiflora* species was 2108.5. The total maturity level of *Pinus densiflora* at that time was 1335.4, which was higher than 1316, the total maturity level under legal state. By suggesting solutions of systematic management through private forest management scaling, for private forest promotion equivalent to 68.1% of Korean forest, the economic feasibility on timber yield simulation was developed. In the economic analysis, the net present value (NPV) of *Quercus* species was 1410 billion KRW. The benefit–cost ratio (BCR) was 2.0 and *Pinus densiflora* was 3150 billion KRW in NPV and had a BCR of 4.0, showing economic feasibility.

Introduction

Forests occupy approximately 63.7% of the land area in South Korea. They provide economic benefits through timber and forest products as well as public interest functions including water resource conservation, land conservation, and water purification. Due to the importance of forests, interest in managing private forests has increased. In particular, 61.5% of private forests are age class IV and higher. Private forests could be managed more sustainably and actively because the harvesting age restriction has been mitigated by amendment of the Creation and Management of Forest Resources Act 2014 (Korea Forest Service 2015).

Forest resources in private forests have not been adequately managed, although the importance of private forests is increasing. Forest owners and the government have invested numerous resources and effort to make rational management to the private forests. However, full-scale forest management has not been achieved, partly because private owners generally have only a small parcel of forest and lack a strong desire to manage it (Baek 1983; Park 1994; Chung and Chung 1999). Moreover, 55% of private forest owners (2,284,826 people) are absentee forest owners, resulting in poorly managed forests (Korea Forest Service 2015). Although some owners do want to manage their small forests more sustainably, they lack the manpower and technological resources to do so even if they have financial means available (Jang 2000).

Since 2013 the Korea Forest Service has conducted the Pioneer Forest Management Complex Project to solve these problems and determine a method of rationalizing private forest management. The project selects appropriately sized and collectivized private forest complexes that are healthy and actively managed by owners; currently, more than 1000 ha of forest cultivation complexes exist. Pioneer Forest Management Complexes will be built and expanded to 50 areas by 2017 but it has been built 10 areas at present. The main objective of designating these Pioneer Forest Management Complexes is to increase the efficiency of timber supply and self-sufficiency by running the forests as bases for future timber supply.

Consequently, this study analyzed private forests, which are very small and dispersed, to check the potential for timber supply from small parcels of private forest and to schedule a timber yield model by accurately analyzing forest resources. In addition, the study aimed to provide baseline data to rationalize private forest management using an economic analysis of simulation results.

Materials and methods

Survey site selection

This study targeted 1424 ha of forest in Samnak-ri, Ancheon-myeon adjacent to Songpung-ri, Yongdam-myeon and Jinan-gun, which was included in the Pioneer Forest Management Complex and had the highest proxy management contract ratio among Muju-gun, Jinan-gun, and Jangsu-gun in Jeollabuk-do, Korea. More than 75% of these areas are covered by forests.
study employed net present value (NPV) and benefit–cost ratio (BCR).

The NPV method was defined as follows:

\[
NPV = \sum_{t=0}^{n} \frac{R_t - C_t}{(1+i)^t}
\]  

(2)

\(n\): End of Investment; \(R_t\): Benefits at the time; \(C_t\): Cost at the time; \(i\): Discount rate

BCR analysis was defined as follows:

\[
BCR = \frac{\sum_{t=0}^{n} \frac{R_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}}
\]

(3)

**Benefit estimation**

Benefit was estimated by calculating the harvesting area, harvested stock per ha, and timber unit price per m³ as follows:

\[
B = A_c \cdot G_t \cdot P
\]

(4)

\(A_c\): Harvesting area; \(G_t\): Stock per ha; \(P\): Unit price per m³

The standard harvest area was calculated by estimating and applying the total maturity concept. Unit price per m³ was estimated using the unit price listed in the 2015 Fall Domestic Timber Market Value Trend (Seo et al. 2015). Standing stock per ha was calculated using the stock per tree and stem density (trees/ha) as follows:

\[
G_t = V \cdot S
\]

(5)

\(G_t\): Stock per ha; \(V\): Stock per tree (m³/tree); \(S\): Stem density per ha

Mean diameter at breast height (DBH) and mean tree height were estimated from stock, density, and yield tables (Lee et al. 2009) and stock for each tree was estimated from the volume table. The stem density (trees/ha) after harvest was set based on the stem density standard after thinning as listed in the Manual for Sustainable Forest Resources Management (Korea Forest Service 2015).

**Cost estimation**

The cost of cutting, afforestation, weeding, vine cutting, and young tree tending was estimated using the unit cost listed in the Forest Management Standard Unit (Kang et al. 2014).

**Results and discussion**

**Schedule for timber yield model**

A timber yield plan was established considering the harvesting rotation of *Quercus* species (579.6 ha) and *Pinus densiflora* (329.3 ha), which occupied most of the study area (1424 ha) where is shown in Figure 1.

Maturity is a quantitative index indicating the maturity of forest resources and is calculated using the age class structure and the area of each age class. This type of work inevitably has a wider harvest age range than harvesting a forest based on age.

### Scheduling of timber yield

**Forest resources database construction**

In this study on forest resources, data collected by the Forest Resources Survey Center of National Forestry Cooperatives Federation were analyzed and statistical analyses were conducted to schedule a timber yield model.

Three hundred and sixty-nine sample sites, constructed by a systematic sampling method (1424 ha; more than 1% of the total area), were analyzed including 195 m interval grids and 329 lots, 12 compartments, and 77 sub-compartments.

The mean growing stock was 120.98 m³/ha. The growing stock of artificial forest was 137.72 m³/ha and that of natural forest was 120.25 m³/ha. The study area was composed of coniferous forest (27.5%), broadleaved forest (25.1), and mixed forest (44.3%), indicating that mixed forest is the major forest type.

**Economic analysis**

An economic analysis was conducted based on the benefit acquired during the process of harvesting and the cost induced by afforestation, management, and harvest. The

### Table 1. Status of area and growing stock by origin of forest and forest types.

| Forest land area | Growing stock | Growing stock per ha |
|------------------|---------------|----------------------|
| Area (ha)        | Ratio (%)     | Stock (m³)           | Ratio (%) | Stock per ha (m³/ha) |
| Artificial       | 324.7         | 25.5                 | 49,950.8  | 29.0                 | 137.72 |
| Natural          | 1,017.3       | 71.4                 | 122,326.7 | 71.0                 | 120.25 |
| Unstocked        | 44.0          | 3.3                  | 51,635.1  | 30.0                 | 132.06 |
| Coniferous       | 391.0         | 27.5                 | 77,444.3  | 45.0                 | 122.73 |
| Broadleaved      | 358.0         | 25.1                 | 43,198.1  | 25.0                 | 120.67 |
| Mixed            | 631.0         | 44.3                 | 77,444.3  | 45.0                 | 122.73 |
| Unstocked        | 44.0          | 3.1                  | –         | –                   | –       |
| Total            | 1,424.0       | 100.0                | 172,277.5 | 100.0                | 120.98 |

### Table 2. Area by age class.

| Age class | I | II | III | IV | V | Unstocked | Total |
|-----------|---|----|-----|----|---|-----------|-------|
| Area (ha) | 33| 56 | 177 | 994| 120| 44        | 1,424 |
| Ratio (%) | 2.3| 3.9| 12.4| 69.8| 8.5| 3.1       | 100   |
In this study, the standard harvest rotation listed in Article 7 (Application of the Forest Management Plan) of the Creation and Management of Forest Resources Act, which was amended in 2012, was used. Short harvesting rotation was from the harvesting rotation of public and private forests, the standard harvesting rotation was set by national forests, and the long harvesting rotation was relatively longer than the standard harvesting rotation.

**Quercus species**

*Quercus* species occupied 579.6 ha of the study area, a majority. The distribution is shown in Figure 2.

The harvest age of public and private *Quercus* species forests is 25 years. Therefore, immediate harvest after the project is implemented would be possible. However, the harvest age of national *Quercus* species forests is 60 years; thus, the regular harvest age was set at 60 years. The harvest age of *Quercus* species were set at 25, 60, and 95 years for short, standard, and long harvesting rotations, respectively.

The age class in the study area was between I and V. The III and IV age classes occupied 85% of all *Quercus* species forests. The total maturity of *Quercus* species forests estimated from Equation (1) was 2108.5. The total maturity estimated was 2318.4 when reaching the normal forest condition, indicating that the size of each age class is equal. The study forest was managed to reach the normal forest condition containing 82.8 ha of each age class and planting 82.8 ha in each period (Table 3), harvesting 116.3 ha of age classes IV and V in the first period, 99.8 ha of age class V in the second period, 83.1 ha of age class VI in the third period, 73.1 ha of age classes VI and VII in the fourth period, 73.7 ha of age class VII in the fifth period, 67.0 ha of age class VIII in the sixth period, and 66.7 ha of age classes VII–IX in the seventh period.

*Quercus* species had a longer practice period determined by the short and long harvesting rotations compared to other species. Therefore, planting and harvesting plans could be established and the amount of practice per period maintained stable. The planting and harvest plans for each period are shown in Table 4.

**Pinus densiflora**

In 2015 *Pinus densiflora* sold at 228,000 KRW per m³ with timber sales being the main income. *Pinus densiflora* forest occupied 329.3 ha of the study area and represented the largest area covered by a single species (Figure 3).

The harvesting rotation of public and private *Pinus densiflora* forests is 40 years and of national forest 60 years. Therefore, short, standard, and long harvesting rotations were set as 40, 60, and 80 years, respectively.

The age class distribution of *Pinus densiflora* in the study area was III–VI and 84% of the forest was age class IV, showing an imbalanced distribution.

The total current maturity estimated using Equation (1) was 1335.4, higher than the normal forest condition (1316.0),

### Table 3. Area of *Quercus* species by age class (ha).

| Quarter | I   | II  | III | IV  | V   | VI  | VII | VIII | IX  | Total | Total maturity |
|---------|-----|-----|-----|-----|-----|-----|-----|------|-----|-------|---------------|
| 1       | 14.0| 22.7| 173.7| 318.5| 50.8|     |     |      |     | 579.7 | 2108.5        |
| 2       | 82.8| 14.0| 22.7 | 173.7| 253.0|     |     |      |     | 546.2 | 2138.5        |
| 3       | 82.8| 82.8| 14.0 | 22.7 | 173.7|     |     |      |     | 529.4 | 2170.1        |
| 4       | 82.8| 82.8| 82.8 | 14.0 | 22.7 | 133.4|     | 173.7| 70.1 | 528.9 | 2199.2        |
| 5       | 82.8| 82.8| 82.8 | 82.8 | 14.0 | 22.7 | 170.7|     | 170.7| 538.6 | 2229.1        |
| 6       | 82.8| 82.8| 82.8 | 82.8 | 82.8 | 14.0 | 22.7 | 97.0 |     | 547.7 | 2260.9        |
| 7       | 82.8| 82.8| 82.8 | 82.8 | 82.8 | 82.8 | 14.0 | 22.7 | 30.0 | 563.5 | 2288.4        |
| 8       | 82.8| 82.8| 82.8 | 82.8 | 82.8 | 82.8 | 82.8 | 82.8 |     | 579.6 | 2318.4        |

### Table 4. Plan for cutting of *Quercus* species (ha).

| Age class | Quarter | IV | V  | VI  | VII | VIII | IX  | Total |
|-----------|---------|----|----|-----|-----|------|-----|-------|
| 1         | 65.5    | 50.8|   |     |     |      |     | 116.3 |
| 2         | 99.8    |     |   |     |     |      |     | 99.8  |
| 3         | 83.1    |     |   |     |     |      |     | 83.1  |
| 4         | 3.0     | 70.1|   |     |     |      |     | 73.1  |
| 5         | 73.7    |     |   |     |     |      |     | 73.7  |
| 6         |         | 67.0|   |     |     |      |     | 67.0  |
| 7         | 14.0    | 22.7| 30.0|     |     |      |     | 66.7  |

Figure 1. Location of study area.

Figure 2. Distribution of *Quercus* species in the study area.
mainly because it was occupied by older age classes. Achieving a balanced practice for each period was not possible; therefore, it was urgent to lead it to the normal condition with minimizing the changes in the total maturity. Subsequently, 47.0 ha of the forest was planted in each period to create a normal forest in the eighth period by having 47.0 ha of each age class, harvesting 64.1 ha and 8.0 ha of age classes IV and VI in the first period, 59.4 ha of age class V in the second period, 45.7 ha of age classes VI–VII in the third period, 43.2 ha of age class VII in the fourth period, 38.6 ha of age class VIII in the fifth period, 48.9 ha of age class IX in the sixth period, and 21.5 ha of age class IX in the seventh period (Tables 5–6).

Most Pinus densiflora was classified as age class IV and the duration of practice was restricted by harvest age. Therefore, the maturity of the forest was expected to abruptly decrease in the seventh period.

Figure 3. Distribution of Pinus densiflora in the study area.

Figure 4. Changes in benefit and costs of Quercus species.

Figure 5. Changes in benefit and costs of Pinus densiflora.
Economic analysis through scheduling of timber yield

**Quercus species**

*Quercus* species forest management costs 5817 million KRW over a 70 year period due to afforestation, mowing, vine removal, sapling tending, and harvesting. Results showed harvesting would produce 75,553.8 m$^3$ of timber and generate 9036.2 million KRW (Table 7, Figure 4). Economic analysis results revealed NPV was 1410 million KRW and BCR was 2.0 ($>1$). Consequently, economic benefit was proven.

The results showed that *Quercus* species forests could be economic if forest practices were conducted with rightsizing the *Quercus* species forests in the study area. The analysis results only reflected that the timber value and the economic value of *Quercus* species would be higher if other values (e.g. trees for growing shiitake mushrooms and wood chips) were included. However, this study showed that the *Quercus* species forest had lower economic value than *Pinus densiflora* forest due to the lower stem density and timber price of *Pinus densiflora*.

**Pinus densiflora**

Afforestation, mowing, vine removal, sapling tending, and harvesting of *Pinus densiflora* forests would cost 3766.5 million KRW over a 70 year period. Results showed the harvest would produce 68,948.4 m$^3$ of timber and generate 15,720.3 million KRW (Table 8, Figure 5).

Economic analysis results showed NPV was 3150 million KRW and BCR was 4.0. Consequently, economic feasibility was established.

Most *Pinus densiflora* was in the IV age class; thus, it was harvested through thinning in the first period, which generally costs more than clearcutting. However, the species still showed high economic value. The results showed *Pinus densiflora* timber had a good economic value and unit timber price (KRW/m$^3$) was higher than that of *Quercus* species.

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**Table 5. Area of *Pinus densiflora* by age class (ha).**

| Quarter | I | II | III | IV | V | VI | VII | VIII | IX | Total | Total maturity |
|---------|---|----|-----|----|---|----|-----|------|----|-------|----------------|
| 1       | 21.5 | 276.1 | 23.7 | 8.0 | 329.3 | 1335.4 |
| 2       | 47.0 | 21.5 | 212.0 | 23.7 | 304.2 | 1335.2 |
| 3       | 47.0 | 21.5 | 152.6 | 23.7 | 291.8 | 1330.0 |
| 4       | 47.0 | 21.5 | 215.0 | 130.6 | 293.1 | 1325.2 |
| 5       | 47.0 | 21.5 | 87.4 | 21.5 | 296.9 | 1319.7 |
| 6       | 47.0 | 21.5 | 48.9 | 21.5 | 305.4 | 1317.1 |
| 7       | 47.0 | 21.5 | 21.5 | 21.5 | 303.5 | 1180.5 |
| 8       | 47.0 | 21.5 | 21.5 | 21.5 | 329.0 | 1316.0 |

**Table 6. Plan for cutting of *Pinus densiflora* (ha).**

| Age class | IV | V | VI | VII | VIII | IX | Total |
|-----------|----|---|----|-----|------|----|-------|
| 1         | 64.1 | 8.0 | 72.1 |      |      |     |       |
| 2         | 59.4 | 59.4 |      |      |      |     |       |
| 3         | 22.0 | 23.7 | 45.7 |      |      |     |       |
| 4         | 43.2 | 43.2 |      |      |      |     |       |
| 5         | 38.5 | 38.5 |      |      |      |     |       |
| 6         | 48.9 | 48.9 |      |      |      |     |       |
| 7         | 21.5 | 21.5 |      |      |      |     |       |

**Table 7. Total project amount and cutting amount of *Quercus* species.**

| Cutting amount | Afforestation | Weeding | Vine cutting | Young tree tending | Final clearing | Thinning | Total maturity |
|----------------|---------------|---------|--------------|--------------------|----------------|----------|----------------|
| Final clearing | 510.8| 1,532.4 | 306.5 | 510.8 | 579.7 | – | 75,553.8 m$^3$ | – |
| Cost (million KRW) | 2,481.0| 1,713.2 | 312.6 | 798.4 | 511.9 | – | – | – |
| Benefit (million KRW) | – | – | – | – | – | 9,036.2 | – | – |

**Table 8. Total project amount and cutting amount of *Pinus densiflora*.**

| Cutting amount | Afforestation | Weeding | Vine cutting | Young tree tending | Final clearing | Thinning | Total maturity |
|----------------|---------------|---------|--------------|--------------------|----------------|----------|----------------|
| Final clearing | 329.0| 987.0 | 197.4 | 329.0 | 257.2 | 72.1 | 61,245.8 m$^3$ | 7,702.5 m$^3$|
| Cost (million KRW) | 1,598.0| 1,103.5 | 201.3 | 514.2 | 227.1 | 122.4 | 13,964.1 | 1,756.2 |
| Benefit (million KRW) | – | – | – | – | – | – | – | – |

**Conclusion**

Private forests in Korea have not been adequately managed because private forest owners usually manage small plots of 0.5 to 2 ha. In order to solve this problem, the Korea Forest Service has conducted the Pioneer Forest Management Complex Project since 2013. However, there has been no adequate schedule for timber yield and economic analysis for private forests in Jinan-Gun. The result of this study shows that small scale forests have the potential to produce timber with appropriate scheduling of timber production, reaping economic benefits. Therefore, this study can be used as a model for national management of Pioneer Forest Management Complexes in Korea.

**Disclosure statement**

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