Comparing forest structures in the border areas of the demilitarized zone of South Korea

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ABSTRACT
This study was conducted to inventory forest structures focusing on the border areas of the demilitarized zone, which are Goseong, Inje, Yanggu, Hwacheon, Cheolwon, Yeoncheon, and Paju, in South Korea. A total of 707 points were inventoried using a point sampling method. Forest type, tree species, diameter at breast height (DBH), and stand volume per hectare were analyzed and compared. The broad-leaved had the highest frequency with an average of 88%, followed by mixed (7%) and coniferous (5%) forest types in the border areas. A total of 62 tree species were observed and Quercus mongolica had the highest frequency with an average of 28%. By DBH class, small had the highest percentage with 63%, medium was 30%, and large was 7%. Mean DBH was relatively low (16.1 cm) with a range of 13.2 cm to 20.3 cm and the mean stand volume was 107 m³ ha⁻¹ with a range of 80 m³ ha⁻¹ to 123 m³ ha⁻¹. Compared to the stand volume (137 m³ ha⁻¹ in average) of the administrative district of the Korea Forest Service, our results showed that the stand volume of the border area is relatively low.

Introduction
The border area south of the demilitarized zone (DMZ) in South Korea, which is called the civilian controlled zone (CCZ) or Mintongseon and is within c. 5–15 km from the south of the military demarcation line, is an important ecological belt in view of forest ecology and meaningful as a horizontal connection belt from the east to the west of the national territory. Because the CCZ has not been available for civilian access for the past 65 years, it is known to have a unique ecosystem and attracts both internal and external attention. Natural monuments, protected wildlife, unexcavated cultural heritages, and relics related to war and peace are studded throughout the areas (Kim et al. 2008; Kim 2009; Lee et al. 2011; Song et al. 2012).

From the beginning of the 1990s, various reports on the environment and ecology of the zone started to be published at the national level. The Korea Forest Service (2000, 2008), Korea Ministry of Environment (1995, 2001, 2004, 2010) and the Korea Cultural Heritage of Administration (2005, 2007) inventoried the zone, focusing on the ecological status including vegetation, aquatic and forest insects, freshwater fish, and overall landscape. Most previous inventories were done in parts as access to the area was limited due to the possibility of mines and/or military security. Consequently, forest resources have not been monitored systematically (Park 2008). Also, a forest resources’ inventory has never been carried out in the border areas.

Meanwhile, most of the area consists of forest, which occupies 75.5%, while grassland is 20.3%, farmland 2.8%, swampland 1.1%, and others 0.3% (Lee 2014). Although the forest is an important resource, it has been left in a blind spot of systematic forest management due to the difficulty of access and location of military facilities. Even now, tree species and forest type, diameter at breast height (DBH), height, and volume are not known in detail.

Therefore, the objective of this study is to analyze and compare tree species and forest type, DBH, height, and volume in seven administrative border areas (Goseong, Inje, Yanggu, Hwacheon, Cheolwon, Yeoncheon, and Paju) of South Korea to provide basic information for a forest management plan of the areas in the future.

Material and methods
Study area
The study area is a civilian controlled region of the DMZ, which is located north of Gangwon and Gyeonggi provinces and includes the seven administrative districts of Goseong, Inje, Yanggu, Hwacheon, Cheolwon, Yeoncheon, and Paju (Figure 1). Annual precipitation of the seven administrative areas in which the study area lies ranges from 1086 mm to 1493 mm and mean temperature from 9.6 °C to 12.0 °C, as shown in Table 1.

Inventory design and field method
Because the inventory time and area were limited, and military cooperation was necessary, an inventory point was chosen every 500 m along a road operated by the military under the guidance of military officials. To reduce inventory error as much as possible, points were taken alternatively on the left and right hand sides of the road. If access was not possible, because the slope was too steep or there was no forest, distance and an alternate inventory were flexibly applied. The result was that a total of 707 points (Goseong 113, Inje 38, Yanggu 118, Hwacheon 73, Cheolwon 185, Yeoncheon 38, Yanggu 118, Hwacheon 73, Cheolwon 185, Yeoncheon...
93, and Paju 87) were established and inventoried using a point sampling method (Figure 1). Point sampling is a method of selecting trees to be tallied on the basis of their size rather than by their frequency of occurrence. This method has the advantage of not establishing a fixed plot boundary, and a greater cruising speed is possible (Avery and Burkhart 2002).

Sample points were located within a forested tract, and a simple prism that subtends a fixed angle (k = 2 or 4) of view was used to sight each tree with the DBH. Tree boles close enough to the observation point to completely fill the fixed sighting angle were tallied: stems too small or too far away were ignored.

Site factors (slope, aspect, and altitude) and stand factors (tree species and DBH greater than 6 cm) were collected from the points. Mean slope and mean altitude of the points by border region were measured (Table 1).

### Analytical method

In this study, forest types were classified in accordance with the number of trees: broad-leaved, coniferous, and mixed based on the criteria of 5th National Forest Inventory (Korea Forest Research Institute 2011). Coniferous forest is a forest in which coniferous trees occupy more than 75% of the total number of trees. Broad-leaved forest is a forest in which broad-leaved trees occupy more than 75% of the total number of trees. Mixed forest is a forest in which neither coniferous trees nor broad-leaved trees occupy more than 75% of total number of trees.

The point sampling method was used for calculating stand volume per hectare as follows (Lee 1995):

\[
V = G \times \bar{H} \times F
\]

where \(V\) = stand volume per hectare (m³ ha⁻¹); \(G\) = basal area per hectare (m² ha⁻¹); \(\bar{H}\) = estimated mean height of tallied trees in a point; \(F\) = stand form factor (0.5); \(K\) = basal area factor; and \(Z\) = number of tallied trees in a point.

Basal area per hectare is calculated using DBH of tallied trees and the basal area factor (BAF) of a prism \(k = 2\) or \(4\) which was used for tallying trees at a point. BAF of \(k = 2\) was used for a stand having small sized diameter and BAF of \(k = 4\) for a stand having large sized diameter. The tree form factor was set to 0.5 based on the reference of the form factor by species on average (Korea Forest Research Institute 2012). Height was estimated through the developed height models of major species such as *Pinus densiflora*, *Quercus mongolica*, *Q. variabilis*, *Q. serrata*, and *Q. acutissima* (Korea Forest Service 2012). Heights of other hardwood trees, which were observed in the inventory but do not have their height equations, were estimated by using the height equations of the major species which are similar to the height patterns of other species.

### Results and discussion

#### Forest type

Forest type distribution of the border area was found to be different from the administrative district. The broad-leaved forest had the highest occupancy, with 88% on average, followed by the mixed (7%) and the coniferous (5%) (Figure 2). Yeoncheon is 98% covered by broad-leaved trees, which is the highest among the study areas, followed by Paju with 97%, Yanggu with 92%, Cheolwon with 91%, Hwacheon with

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**Table 1.** General status of the administrative districts and site condition of the study area.

| County     | Land area (km²) | Annual precipitation (mm) | Mean temperature (°C) | No. of points | Slope (°) | Altitude (m) |
|------------|----------------|---------------------------|-----------------------|---------------|-----------|-------------|
| Goseong   | 665            | 1218                      | 12.0                  | 113           | 25        | 542         |
| Inje       | 1646           | 1332                      | 10.5                  | 38            | 27        | 647         |
| Yanggu    | 702            | 1086                      | 10.8                  | 118           | 26        | 616         |
| Hwacheon  | 908            | 1324                      | 10.7                  | 73            | 25        | 375         |
| Cheolwon  | 889            | 1318                      | 9.6                   | 185           | 22        | 329         |
| Yeoncheon | 675            | 1493                      | 10.0                  | 93            | 19        | 168         |
| Paju      | 673            | 1347                      | 11.0                  | 87            | 15        | 48          |

Sources: Cheolwon-gun (2015); Goseong-gun (2015); Inje-gun (2015); Paju-si (2015); Hwacheon-gun (2013); Yanggu-gun (2015); Yeoncheon-gun (2015).

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Figure 1. Study area and inventory points in the border areas of the demilitarized zone in South Korea. demilitarized zone (DMZ); civilian control line; inventory points in this study.
82%, Inje with 76%, and Goseong with 73%. This is a very high percentage compared with the forest type distribution of the administrative district in which broad-leaved occupies 45%, mixed 31%, and coniferous 24% on average (Korea Forest Service 2014).

It should be noted that this study represent precisely the forest type of the border area, because the inventory was done every 500 m along the military operation road under military guidance and with limited forest access. It does, however, provide basic forest data as few studies have been conducted on the forests of the border area.

**Tree species composition**

Tree species with DBH greater than 6 cm were inventoried in this study. A total of 62 tree species were observed in the border areas, of which Yanggu had 39 tree species, Goseong 38, Cheolwon 38, Hwacheon 31, Inje 24, Yeoncheon 23, and Paju 22 (Table 2). Most of these species were referenced in the previous reports about the border areas of DMZ (Korea Ministry of Environment 2001, 2004, 2010).

*Quercus mongolica* had the highest frequency with 28%, followed by *P. densiflora* (10%), *Robinia pseudoacacia* (6%), *Fraxinus rhynchophylla* (5%), *Q. variabilis* (5%), *Salix koreensis* (4%), *Q. acutissima* (4%), *Acer tataricum* (3%), *Betula davurica* (3%), and *Q. aliena* (2%), which accounted for 73% of the total frequency (Figure 3).

The three species with the highest rate of occurrence by the district were: Goseong with *Q. mongolica* (46%), *P. densiflora* (17%), *Q. variabilis* (12%), Inje with *Q. mongolica* (34%), *P. densiflora* (16%), *F. rhynchophylla* (14%), Yanggu with *Q. mongolica* (23%), *F. rhynchophylla* (11%), *P.
densiflora (5%), Hwacheon with Q. mongolica (19%), P. densiflora (18%), Acer ginnala (8%), Cheolwon with Q. mongolica (22%), R. pseudosieboldianum (9%), S. koreensis (8%), Yeoncheon with Q. acutissima (19%), R. pseudosieboldianum (13%), Q. mongolica (12%), and Paju with Q. acutissima (22%), R. pseudosieboldianum (17%), Q. mongolica (14%).

**DBH distribution**

Small sized trees were the most observed in the areas, which was inferred to be due to forest fire or coppice regeneration (Korea Ministry of Environment 2004). Consequently, the mean DBH of the areas was 16.1 cm. Yeoncheon had the biggest mean DBH with 20.3 cm, Inje 17.6 cm, Paju 17.0 cm, Hwacheon 15.9 cm, Cheolwon 15.9 cm, Goseong 15.8 cm, and Yanggu 13.2 cm (Figure 4).

When DBH was classified into small (6 cm < DBH ≤ 18 cm), medium (18 cm < DBH ≤ 30 cm), and large (30 cm < DBH) diameter class, small ranged 42%–79% (63% on average), medium 19%–43% (30% on average), and large 2%–15% (7% on average). Small was the highest in Inje with 79% and the lowest in Cheolwon with 42%. By contrast, the

### Table 2. Appearance of tree species with DBH greater than 6 cm in the study area.

| No. | Species                                      | Goseong | Inje | Yanggu | Hwacheon | Cheolwon | Yeoncheon | Paju |
|-----|----------------------------------------------|---------|------|--------|----------|----------|-----------|------|
| 1   | Abies holophylla Maxim.                      |         |      |        |          |          |           |      |
| 2   | Acer tataricum subsp. ginnala (Maxim.) Wesm. |         |      |        |          |          |           |      |
| 3   | Acer komarovii Pojark.                       |         |      |        |          |          |           |      |
| 4   | Acer pictum subsp. mono (Maxim.) Ohashi      |         |      |        |          |          |           |      |
| 5   | Acer palmatum Kom.                           |         |      |        |          |          |           |      |
| 6   | Alnus sibirica Fisch. ex Turcz.              |         |      |        |          |          |           |      |
| 7   | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 8   | Betula ermanii Cham.                         |         |      |        |          |          |           |      |
| 9   | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 10  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 11  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 12  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 13  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 14  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 15  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 16  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 17  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 18  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 19  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 20  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 21  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 22  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 23  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 24  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 25  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 26  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 27  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 28  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 29  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 30  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 31  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 32  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 33  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 34  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 35  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 36  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 37  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 38  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 39  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 40  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 41  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 42  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 43  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 44  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 45  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 46  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 47  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 48  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 49  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 50  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 51  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 52  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 53  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 54  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 55  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 56  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 57  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 58  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 59  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 60  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 61  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
| 62  | Betula platyphylla var. japonica (Miq.) Harc. |         |      |        |          |          |           |      |
|     | Total                                        | 38      | 24   | 39     | 31       | 38       | 23        | 22   |

Y. SEO ET AL.
Figure 3. Major tree species distribution adjacent to the study area. At, Acer tataricum subsp. ginnala (Maxim.) Wesm.; As, Alnus sibirica Fisch. ex Turcz.; Bd, Betula davurica Pall.; Bs, Betula schmidtii Regel; CsS, Castanea crenata Siebold & Zucc.; CcH, Comus controversa Hemsl.; Fr, Fraxinus rhynchophylla Hance; Jm, Juglans mandshurica Maxim.; Lk, Larix kaempferi (Lamb.) Sarg.; Ma, Maackia amurensis Rupr.; Mb, Morus bombycis Koidz.; Pd, Pinus densiflora Siebold & Zucc.; Ps, Prunus padus L.; Ps, Prunus sargentii Rehdeter; QaC, Quercus acutissima Carruth.; QaB, Quercus aliena Blume; Qd, Quercus dentata Thumb.; Qm, Quercus mongolica Fisch. ex Ledeb.; Qv, Quercus variabilis Blume; Qs, Quercus serrata Murray; Rp, Robinia pseudoacacia L.; Sk, Salix koreensis Andersson; Ta, Tilia amurensis Rupr.; Ud, Ulmus davidiana var. japonica (Rehdeter) Nakai.

Figure 4. Distribution of DBH class and mean DBH in the study area. small (DBH < 18 cm); medium (18 cm ≤ DBH < 30 cm); large (DBH ≥ 30 cm); —— mean DBH.
medium and the large were highest in Cheolwon with 43% and 15% and the lowest in Inje with 19% and 2%.

Stand volume distribution

As the mean DBH level is low, the stand volume level was also found to be relatively low. The mean stand volume per hectare of the border area is 107 m$^3$ ha$^{-1}$, the highest in Hwacheon with 121 m$^3$ ha$^{-1}$ and the lowest in Paju with 80 m$^3$ ha$^{-1}$ (Figure 5). Compared with the mean stand volume (134 m$^3$ ha$^{-1}$) of the administrative districts and the national mean volume (126.3 m$^3$ ha$^{-1}$) provided by Korea Forest Service (2014), the results show that the stand volume of the border areas is relatively low.

It should be mentioned that this study represent precisely the stand volume of the border area as it was shown in case of forest type. It does, however, provide basic forest data as few studies have been conducted on the forests of the border area.

Meanwhile, coniferous trees had the highest stand volume with 116 m$^3$ ha$^{-1}$, followed by mixed with 113 m$^3$ ha$^{-1}$, and broad-leaved with 106 m$^3$ ha$^{-1}$. Coniferous had the highest stand volume in Yanggu with 138 m$^3$ ha$^{-1}$, mixed and broad-leaved were the highest in Cheolwon, with 131 m$^3$ ha$^{-1}$ and 123 m$^3$ ha$^{-1}$, respectively.

Conclusion

Forest resources and stand structures were analyzed and compared in the border areas of the DMZ of Goseong, Inje, Yanggu, Hwacheon, Cheolwon, Yeoncheon, and Paju in Gangwon and Gyeonggi provinces. Key results are as follows.

First, the broad-leaved forest had the highest occupancy, ranging from 73% to 98%, followed by coniferous and mixed forests. This is compared with the forest type distribution of the administrative districts of which broad-leaved occupies 45%, coniferous 24%, and mixed 31%.

Second, a total of 62 tree species were found in the border areas of Gangwon and Gyeonggi provinces in which Yanggu had 39 tree species, Goseong 38, Cheolwon 38, Hwacheon 31, Inje 24, Yeoncheon 23, and Paju 22. Quercus mongolica had the highest frequency with 28% on average in the border areas. Goseong had 46%, Inje 34%, Yanggu 34%, and Cheolwon 22%.

Third, the mean DBH of the seven districts was relatively low at 16.1 cm. By district, Yeoncheon had the biggest mean DBH with 20.3 cm, Inje 17.6 cm, Paju 17.0 cm, Cheolwon 15.9 cm, Hwacheon 15.9 cm, Goseong 15.8 cm, and Yanggu 13.2 cm. By DBH class, small (6 cm $\leq$ DBH $< 18$ cm) ranged 42%–79% (63% on average), medium (18 cm $\leq$ DBH $< 30$ cm) 19%–43% (30% on average), and large (30 cm $<$ DBH) 2%–15% (7% on average).

Finally, mean stand volume is 107 m$^3$ ha$^{-1}$, the highest in Hwacheon with 123 m$^3$ ha$^{-1}$ and the lowest in Paju with 80 m$^3$ ha$^{-1}$. Compared with the stand volume of the administrative district (137 m$^3$ ha$^{-1}$ on average) by Korea Forest Service, the results show that the stand volume of the border area is relatively low.

Disclosure statement

No potential conflict of interest was reported by the authors.

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