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# Changes of Site Index and Production of Black Pine (*Pinus thunbergii* Parl.) Stand from Coast to Inland

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## 곰솔林의 地位指數와 生産의 海岸으로부터 內陸으로의 變化

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**ABSTRACT**

Black pine, *Pinus thunbergii*, stands in southwestern Korea were investigated.

The black pine forest with 90 percent or more in the relative basal area (black pine basal area/whole pine basal area, RBA) was found in the coastal area. However, from the coastal area to the inland, RBA of the pine was decreased because the competition with red pine (*P. densiflora*) and/or pitch pine (*P. rigida*). In 25 year-old plants at the coastal areas, the wood volume of black pine is twofold or more than that of red pine, fourfold or more than that of pitch pine. The optimum rotation period for the maximum yield of black pine is estimated to take 35 years, based on the site index calculated. The optimal temperature for the pine plantation in Korean peninsula should be the area in over 105°C·month in warmth index. And the soil conditions with 50% of RBA or over were 0.025~0.151% of soil salinity, 3~6% of organic matter content, pH value 4.50~5.04, 8.5~11.0 me/100g of C.E.C..

## INTRODUCTION

According to Kim and Kil (1983, 1984), the northern limit of the distributional range of black pine (*Pinus thunbergii*) in the Korean peninsula coincides with the isopleth of WI 100°C·month (Yim and Kira, 1975). This fact indicates that thermal climate will be a main factor limiting black pine distribution. However, soil conditions and interspecific competition of other pines should be considered as factors limiting the pine tree distribution.

Therefore, this study was focussed on species composition and their interspecific competition among genus *Pinus*.

We thank to Mr. Hyon-Bok Lee for his help with the field work.

## MATERIALS AND METHODS

**Vegetation survey** Seventy pine stands in the similar latitude were selected from Kunsan where is western coast to Pongdong where is a distribution limit of inland for black pine, ca. 40km long.

One quadrat (10m×10m) was set randomly at every stand, and the census for trees over 2cm in DBH were carried out.

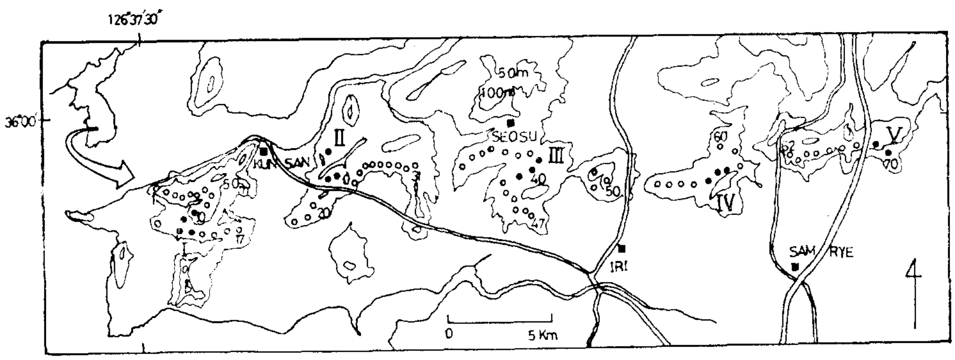


**Fig. 1.** Map showing the studied sites. Arabian and Roman numerals: stand for quadrat and group number. Black circles boring sites (I, II, III, IV, V).

**Environmental gradient analysis** Soils sampled from B horizon were dried, crushed and then sifted with both a 20-mesh sieve for chemical analysis and a 60-mesh for measurement of organic matter content.

To determine soil salinity, 10g soil poured 50m*l* dist. water was filtered with gauze and measured by electric conductivity cell. The soil salinity was calculated by follow:

$$\text{Salinity}(\%) = 0.064 \times \frac{\text{Volume of dist. water}}{\text{Weight of soil sample}} \times \text{conductivity}$$

Soil pH was determined in solution (soil: dist. water=1 : 5, W/V) by glass electode. Organic matter was determined by the tyurin method; available phosphorus ($P_2O_5$) by the lancaster method; available silicon ($SiO_2$) by 1 N—$CH_3COONa$ (pH 4.0) extract method; concentration of exchangeable calcium (CaO), magnesium (MgO), potassium ($K_2O$) by atomic absorption spectrophotometry; exchangable hydrogen(H) by drown method and cation exchangeable capacity(C.E.C.) by kjeldahl method. Relative basal area (RBA), basal area (BA) of black pine to whole plant basal area (TBA) was calculated as follow (Yim and Ko, 1984);

$$RBA\ (\%)=\frac{BA}{TBA}\times 100$$

**Estimate tree age and phytomass** Tree age was determinated from annualring on wooden cores pullout by a increment borer on 50cm height of trunk.

A tree volume(V) was calculated by the basal area (BA) and tree height (TH), V=a(BA×TH) (Yim *et al.*, 1984).

Sampling site was evaluated with site index obtained from the age-height curve of trees.

## RESULTS

**Structure of black pine stand** Black pine stands were classified into 5 groups by RBA class *i.e.* group I, or coastal area, having more than 80% in RBA of black pine, group II, or near coastal area, 60~79%, group III, or mid area, 40~59%, group IV, or near inland area, 20~39% and group V, or inland area, below than 20% (Fig. 2).

In frequency of DBH class the highest value was 4~8cm class in group I (Fig.

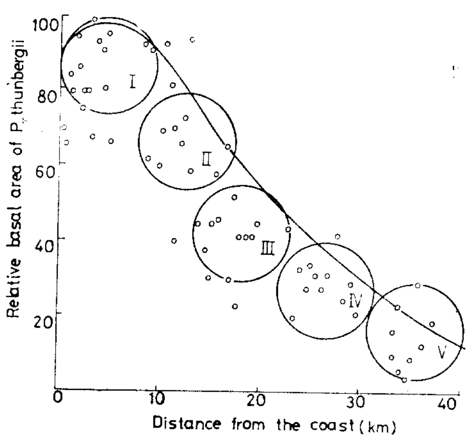


Fig. 2. Grouping relative basal area of black pine along the distances from coast to inland.

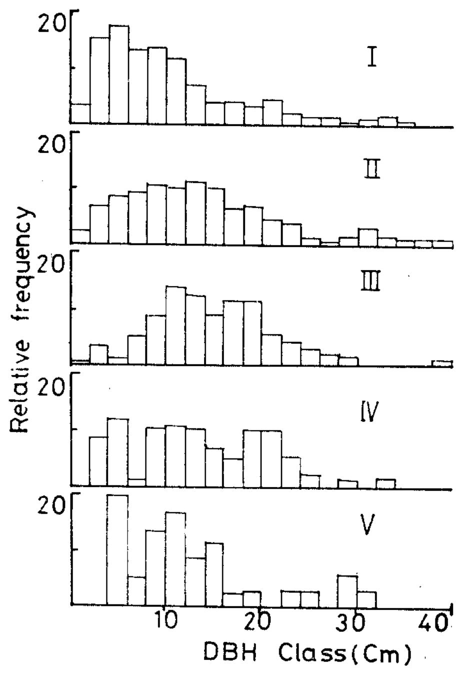


Fig. 3. Relative frequency of DBH class at the different sites of black pine.

3). This group showed negative exponential or J-shaped distribution. This means that the black pine forest at the coastal area becomes relatively stable as reported by Despain (1983).

In group III black pine and other pines may compete severely to adapt for the soil salinity and thermal climate. Fig. 4 illustrates that RBA of black pine decreased but that of red one increased conspicuously along the distance from coast to inland. The black pine with high salt tolerance should overcome the red pine with low salt tolerance. In inland area, however, the black pine was gradually replaced by the red pine and other pine because of low air temperature and soil salinity (Fig. 4).

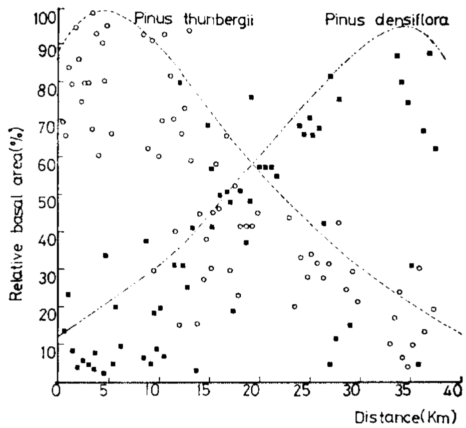


**Fig. 4.** Changes of relative basal area of black pine (*P. thunbergii*: ○—○) and red pine (*P. densiflora*: ■—■) along the distance from coast to inland showing the mirror image.

**Pine growth and soil condition** Far away from the coast to the inland, soil salinity decrease exponentially (Fig. 5) and that was direct proportional to the RBA value of black pine (Fig. 6) as was pointed by Kim and Kil (1983). The RBA of black pine was also positive correlation ($r$=0.56) with the contents of soil organic matter (Fig. 7).

The black pine grew well, for 50% of RBA or over, in the soil conditions of 0.025~0.151% in soil salinity, 3~6% in soil organic matter content, pH value

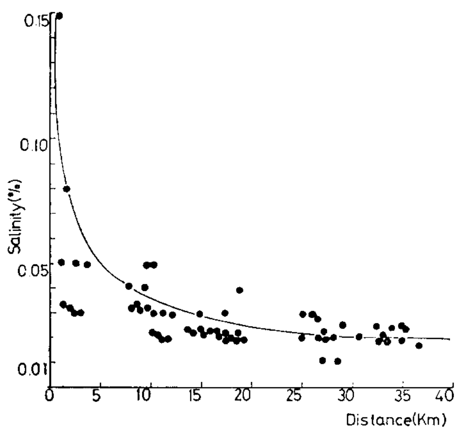


**Fig. 5.** Changes of salinity along the distances from coast to inland.

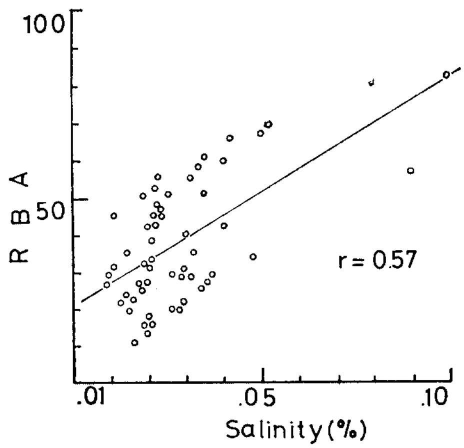


**Fig. 6.** Relationships between soil salinity and RBA of black pine.

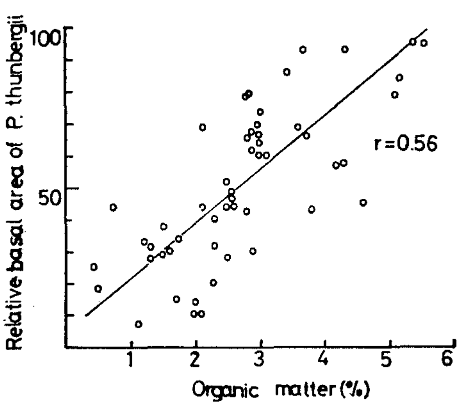


**Fig. 7.** Relationships between soil organic matter content and RBA of black pine.

4.50~5.64, 8.5~11.0me/100g in C.E.C., 8~32 ppm in $P_2O_5$, 0.30~0.70me/100g in $K_2O$, 1.5~3.4me/100g in CaO, 0.3 ~1.1me/100g in MgO, 50~80ppm in $SiO_2$, and 5.0~8.1me/100g in exchangeable hydrogen(Table 1).

By the age-trunk volume reationship (Fig. 8), the production in trunk volume of black pine was about twofold than that of red one and about fourfold than that of pitch one in the coast. The highest production of black pine was in the mid area (site III in Fig. 9). The production was decreased gradually getting near the inland. The productions of red and pitch pine, however, were increased steadly. It was observed that inland production of about 20 year-old pitch pine was superior to those of black and red pine but the growth curve of pitch pine declined gradually, thereafter. Growth of

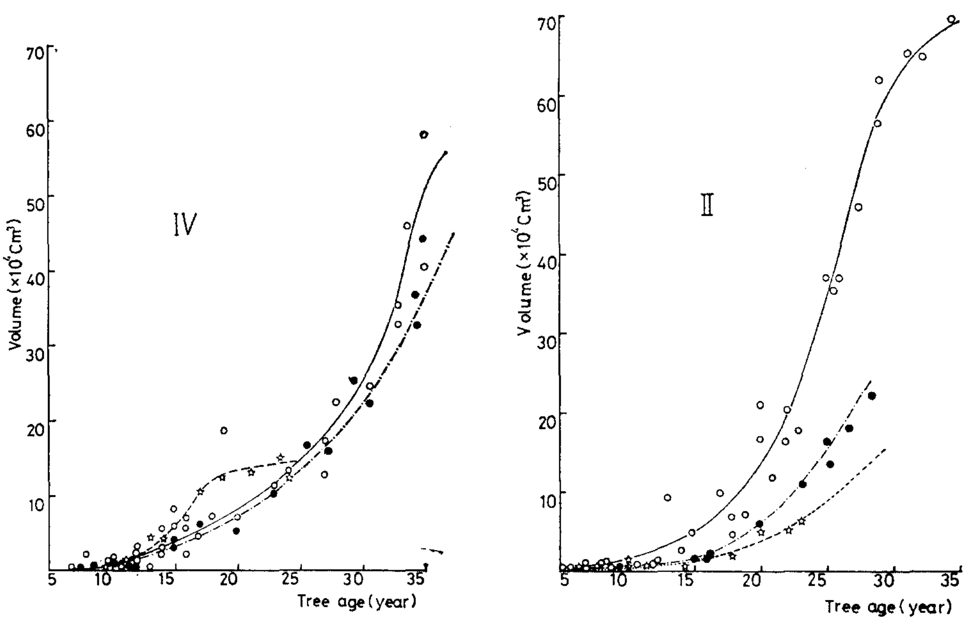


**Fig. 8.** Production curves of black (*P. thunbergii*: ○—○), red (*P. densiflora*: ●—●) and pitch (*P. rigida*: ✻—✻) pines. Right: curve of site II, left: curve of site IV.

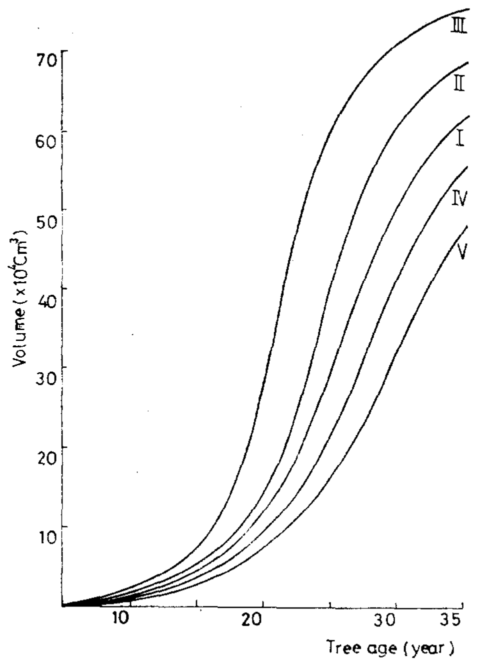


**Fig. 9.** Comparison of production curves of black pine from the various sites (I, II, III, IV, V).

pitch pine is rather inferior to those of black and red pine after about 25 year-old.

As shown in Fig. 9, phytomass curves of five sites become stunted after 35 years. It should explain that optimum rotation period of black pine is postulated to 35 years.

Site index curves illustrates that growth in elongation of red and pitch pine in coast (left of Fig. 10) were inferior to black pine but, *vice versa* in inland (right of Fig. 10), as described above the production. Growth potentiality of black pine was the best at site III(Fig. 11), that is, site index is 15.5 (Table 2) at 35 year-old.

In comparison for leaf size in length, both long and short diameter of black pine with red pine (Table 3), the former was longer than the latter, so leaf area for photosynthesis is large. And black pine is shooting out in all directions radially and the branches are spreading straight. Therefore, light interception is meager. Consequently efficiency for photosynthesis of black pine should be higher than red pine. From those reasons high production of black pine may be explanated.

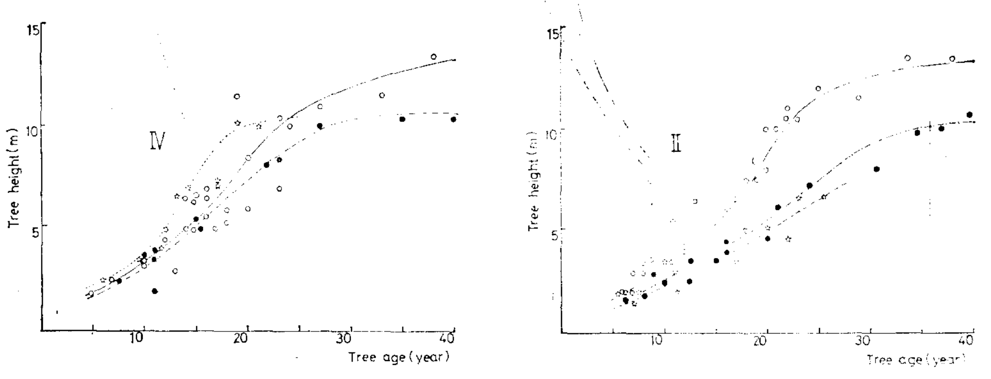


**Fig. 10.** Site index curves of black (○—○), red (●—●) and pitch (*—*) pines. Right: site II, left: site IV

**Table 1.** Analysis of the forest soil from the various stands

| Quadrat No. | RBA | Salinity % | O.M. % | pH | C.E.C. me/100g | $P_2O_5$ ppm | $K_2O$ me/100g | CaO me/100g | MgO me/100g | $SiO_2$ ppm | H me/100g |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 69 | 0.035 | 3.6 | 4.69 | 9.3 | 8 | 0.63 | 1.8 | 0.7 | 78 | 6.2 |
| 2 | 65 | 0.029 | 3.0 | 5.04 | 9.3 | 6 | 0.30 | 1.3 | 0.4 | 44 | 3.3 |
| 3 | 83 | 0.050 | 5.2 | 4.78 | 8.9 | 8 | 0.18 | 1.8 | 0.3 | 49 | 4.0 |
| 4 | 79 | 0.028 | 2.8 | 4.57 | 8.5 | 8 | 0.36 | 1.6 | 0.3 | 58 | 6.2 |
| 5 | 95 | 0.051 | 3.3 | 4.49 | 9.7 | 10 | 0.28 | 2.4 | 0.4 | 51 | 4.6 |
| 6 | 86 | 0.027 | 3.4 | 4.65 | 9.1 | 11 | 0.34 | 1.8 | 0.4 | 58 | 5.7 |
| 7 | 74 | 0.034 | 3.0 | 4.39 | 9.0 | 10 | 0.31 | 1.8 | 0.3 | 71 | 6.2 |
| 8 | 79 | 0.083 | 5.1 | 4.50 | 10.1 | 8 | 0.37 | 1.8 | 0.5 | 71 | 8.4 |
| 9 | 79 | 0.029 | 2.2 | 4.58 | 10.1 | 8 | 0.34 | 2.1 | 0.3 | 58 | 5.5 |
| 10 | 67 | 0.035 | 2.9 | 4.53 | 8.9 | 6 | 0.28 | 1.5 | 0.3 | 51 | 6.8 |
| 11 | 99 | 0.036 | 3.9 | 4.69 | 11.0 | 8 | 0.52 | 3.0 | 0.9 | 80 | 6.6 |
| 12 | 93 | 0.053 | 2.2 | 4.53 | 8.9 | 8 | 0.40 | 2.4 | 0.6 | 61 | 5.7 |
| 13 | 60 | 0.026 | 3.1 | 4.85 | 10.0 | 6 | 0.24 | 1.0 | 0.4 | 53 | 4.4 |
| 14 | 90 | 0.036 | 3.3 | 4.49 | 10.9 | 15 | 0.70 | 1.6 | 0.7 | 53 | 7.9 |
| 15 | 80 | 0.151 | 2.8 | 4.52 | 9.7 | 15 | 0.35 | 1.7 | 0.8 | 56 | 4.8 |
| 16 | 95 | 0.053 | 5.6 | 4.51 | 10.5 | 32 | 0.40 | 1.6 | 0.4 | 56 | 8.1 |
| 17 | 66 | 0.044 | 3.7 | 4.56 | 9.4 | 8 | 0.32 | 1.6 | 0.5 | 53 | 7.0 |
| 18 | 93 | 0.038 | 3.7 | 4.48 | 9.1 | 25 | 0.33 | 2.1 | 0.4 | 63 | 7.3 |
| 19 | 62 | 0.019 | 2.9 | 4.76 | 8.3 | 8 | 0.17 | 1.0 | 0.3 | 66 | 6.8 |
| 20 | 91 | 0.039 | 3.0 | 4.55 | 9.7 | 8 | 0.36 | 1.7 | 0.3 | 44 | 4.4 |
| 21 | 29 | 0.030 | 1.5 | 4.41 | 6.2 | 6 | 0.36 | 0.8 | 0.4 | 46 | 4.6 |
| 22 | 60 | 0.041 | 3.0 | 4.73 | 10.3 | 8 | 0.67 | 2.9 | 0.8 | 53 | 5.9 |
| 23 | 69 | 0.053 | 2.1 | 4.40 | 7.9 | 10 | 0.23 | 2.0 | 0.4 | 53 | 5.3 |
| 24 | 93 | 0.038 | 4.3 | 4.38 | 10.9 | 10 | 0.40 | 2.4 | 0.6 | 53 | 7.5 |
| 25 | 82 | 0.029 | 0.7 | 4.61 | 9.2 | 8 | 0.28 | 1.9 | 0.4 | 49 | 2.6 |
| 26 | 70 | 0.052 | 1.7 | 4.19 | 8.7 | 8 | 0.26 | 1.2 | 0.4 | 68 | 6.8 |
| 27 | 40 | 0.030 | 2.3 | 4.43 | 6.8 | 6 | 0.28 | 1.3 | 0.4 | 66 | 4.8 |
| 28 | 15 | 0.021 | 1.7 | 4.73 | 7.0 | 6 | 0.36 | 1.1 | 0.4 | 41 | 5.1 |
| 29 | 66 | 0.027 | 2.8 | 5.21 | 9.0 | 17 | 0.48 | 2.6 | 0.7 | 53 | 2.2 |
| 30 | 73 | 0.034 | 3.0 | 4.82 | 9.6 | 11 | 0.62 | 3.4 | 1.0 | 53 | 4.6 |
| 31 | 58 | 0.025 | 4.3 | 4.91 | 10.0 | 11 | 0.60 | 1.7 | 0.7 | 53 | 7.0 |
| 32 | 15 | 0.020 | 2.6 | 4.71 | 9.8 | 6 | 0.60 | 2.1 | 1.4 | 69 | 5.7 |
| 33 | 95 | 0.039 | 5.4 | 4.37 | 7.6 | 6 | 0.33 | 1.1 | 0.5 | 61 | 5.7 |
| 34 | 45 | 0.021 | 2.6 | 5.00 | 10.7 | 8 | 0.46 | 2.9 | 1.1 | 49 | 6.2 |
| 35 | 27 | 0.030 | 4.3 | 4.70 | 11.5 | 15 | 0.85 | 1.6 | 0.7 | 46 | 7.9 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 36 | 38 | 0.020 | 1.5 | 4.50 | 7.2 | 6 | 0.17 | 1.2 | 0.3 | 56 | 5.5 |
| 37 | 30 | 0.022 | 2.9 | 4.33 | 7.3 | 10 | 0.28 | 0.9 | 0.4 | 56 | 5.7 |
| 38 | 47 | 0.023 | 2.6 | 4.52 | 8.5 | 6 | 0.24 | 1.1 | 0.4 | 46 | 6.8 |
| 39 | 57 | 0.025 | 4.3 | 4.71 | 9.5 | 8 | 0.30 | 1.5 | 0.6 | 51 | 7.5 |
| 40 | 48 | 0.024 | 2.6 | 4.90 | 8.3 | 8 | 0.50 | 1.7 | 0.5 | 56 | 6.6 |
| 41 | 66 | 0.026 | 2.9 | 5.02 | 9.2 | 19 | 0.57 | 2.7 | 1.1 | 80 | 4.8 |
| 42 | 29 | 0.031 | 3.0 | 4.80 | 9.5 | 6 | 1.80 | 2.3 | 1.0 | 66 | 4.4 |
| 43 | 52 | 0.024 | 2.5 | 4.48 | 7.0 | 8 | 0.28 | 1.2 | 0.4 | 51 | 5.1 |
| 44 | 23 | 0.021 | 2.8 | 4.61 | 8.1 | 6 | 0.29 | 1.2 | 0.4 | 88 | 6.2 |
| 45 | 42 | 0.022 | 2.1 | 4.91 | 7.7 | 8 | 0.40 | 1.9 | 1.0 | 66 | 4.4 |
| 46 | 42 | 0.023 | 2.5 | 4.62 | 7.5 | 6 | 0.23 | 1.6 | 0.4 | 51 | 5.3 |
| 47 | 42 | 0.024 | 2.8 | 4.34 | 6.6 | 6 | 0.36 | 1.0 | 0.4 | 61 | 4.8 |
| 48 | 45 | 0.022 | 4.6 | 4.34 | 9.5 | 8 | 0.28 | 1.7 | 0.5 | 61 | 7.0 |
| 49 | 43 | 0.021 | 3.8 | 4.30 | 9.5 | 13 | 0.38 | 1.8 | 0.5 | 68 | 6.8 |
| 50 | 20 | 0.023 | 3.1 | 4.20 | 6.4 | 6 | 0.27 | 0.9 | 0.4 | 51 | 4.8 |
| 51 | 33 | 0.025 | 1.2 | 4.11 | 6.3 | 32 | 0.23 | 0.4 | 0.4 | 49 | 5.3 |
| 52 | 28 | 0.023 | 2.5 | 4.12 | 8.1 | 6 | 0.20 | 1.0 | 0.3 | 78 | 6.6 |
| 53 | 34 | 0.023 | 1.8 | 4.35 | 6.2 | 8 | 0.24 | 1.2 | 0.4 | 61 | 4.4 |
| 54 | 32 | 0.022 | 2.3 | 4.35 | 6.1 | 8 | 0.22 | 0.9 | 0.4 | 61 | 4.6 |
| 55 | 28 | 0.021 | 1.3 | 4.36 | 5.0 | 6 | 0.13 | 0.4 | 0.3 | 49 | 4.2 |
| 56 | 32 | 0.022 | 4.0 | 4.39 | 8.8 | 9 | 0.60 | 3.4 | 1.0 | 58 | 4.8 |
| 57 | 6 | 0.022 | 1.8 | 4.37 | 5.3 | 6 | 0.23 | 0.8 | 0.3 | 95 | 4.0 |
| 58 | 44 | 0.019 | 0.7 | 4.12 | 5.8 | 6 | 0.32 | 1.0 | 0.5 | 63 | 4.0 |
| 59 | 25 | 0.021 | 3.6 | 4.21 | 4.7 | 8 | 0.31 | 1.0 | 0.3 | 76 | 3.1 |
| 60 | 30 | 0.018 | 1.6 | 4.70 | 5.1 | 6 | 0.27 | 1.1 | 0.4 | 56 | 3.3 |
| 61 | 22 | 0.020 | 1.1 | 4.31 | 5.0 | 7 | 0.76 | 1.6 | 0.6 | 66 | 7.0 |
| 62 | 10 | 0.019 | 2.1 | 4.36 | 7.2 | 6 | 0.27 | 0.9 | 0.5 | 95 | 5.5 |
| 63 | 18 | 0.015 | 0.5 | 4.51 | 6.4 | 6 | 0.47 | 0.2 | 0.4 | 125 | 5.3 |
| 64 | 25 | 0.018 | 0.4 | 4.37 | 5.6 | 4 | 0.19 | 0.1 | 0.5 | 216 | 4.8 |
| 65 | 7 | 0.019 | 1.1 | 4.38 | 5.6 | 6 | 0.46 | 1.6 | 0.6 | 86 | 2.9 |
| 66 | 3 | 0.017 | 2.0 | 4.50 | 7.3 | 6 | 0.46 | 1.6 | 0.6 | 103 | 4.6 |
| 67 | 10 | 0.018 | 2.0 | 4.37 | 7.6 | 8 | 0.45 | 1.7 | 0.6 | 88 | 4.8 |
| 68 | 31 | 0.020 | 1.3 | 4.37 | 8.2 | 8 | 0.35 | 2.3 | 1.1 | 66 | 4.4 |
| 69 | 14 | 0.018 | 2.0 | 4.50 | 8.1 | 6 | 0.45 | 3.1 | 1.4 | 105 | 5.1 |
| 70 | 20 | 0.019 | 2.3 | 4.52 | 7.1 | 8 | 0.92 | 1.2 | 0.6 | 86 | 4.4 |

Note; RBA: relative basal area of black pine, O.M: organic matter content, C.E.C.: cation exchangeable capacity, H : exchangeable hydrogen

As a results, optimal habitat for black pine plantation are estimated the locality with WI 105°C·month above (Fig. 13), as the site III, Seosu district with WI 106.5°C·month (Yim and Kira, 1975).

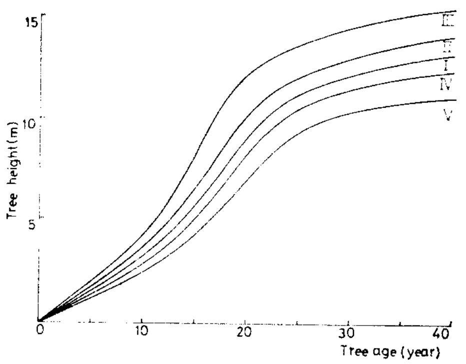


**Fig. 11.** Comparison of site index curves of black pine from the various sites (I, II, III, IV, V).

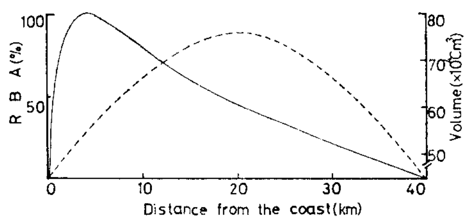


**Fig. 12.** Ecological behavior of black pine showing the response under competition. Dashed line: physiological optimum curve, solid line: ecological optimum curve. Values of X axis: environmental gradient, distance, Y axis: RBA for ecological behavior, growth in volume at 35 years for physiological behavior.

**Table 2.** Comparison of site index from the various sites

| Site | Site index (Height in meter of dominant and codominant trees at 35 years old) |
|---|---|
| I | 13.5 |
| II | 14.0 |
| III | 15.5 |
| IV | 12.8 |
| V | 10.3 |

**Table 3.** Comparison of leaf size in *Pinus thunbergii* and *Pinus densiflora*

| | Length (mm) | Long diameter (mm) | Short diameter (mm) |
|---|---|---|---|
| *P. thunbergii* | 137 | 1.40 | 0.81 |
| *P. densiflora* | 73 | 0.93 | 0.37 |

Note : Numbers are mean data of one thousand leaves

## DISCUSSION

Black pine grows well in warm area with WI 100°C·month isopleth above and with high soil salinity (Kim and Kil, 1983). The density of black pine was high

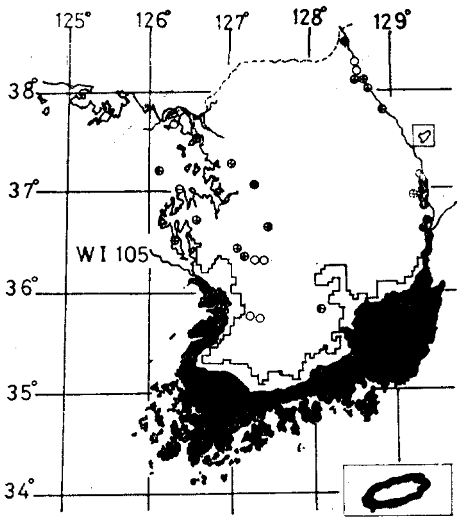


**Fig. 13.** Map showing optimum area in terms of WI for planting *Pinus thunbergii*.
○⊕● : distribution point out of northern limit line of black pine. ○ : based on field survey, ⊕ : on literatures, ● : on information from people.
□ : northern limit of black pine
■ : optimum area for planting black pine

along the coastal area. However, production and site index of black pine stand were low in both the coastal and inland areas, rather high in the mid area.

Shown as Fig. 12, the ecological behavior of black pine was deviated from the physiological behavior *i.e.* the ecological optimum of black pine is shifted unilaterally from the physiological optimum of this plant, close to the maximum. This result is similar to '2a type' of ecological behavior types of Ellenberg (1953, 1956).

Assumpted the optimal range of black pine distribution is the area with RBA =60% more, coastal area, from group I to II (Fig. 4), should be corresponded to this area. But the highest growth and production of this trees occurred at site III (Fig. 9 and Fig. 11). From these facts physiological optimum area of this plants is evaluated at site III, or mid area, while the ecological optimum area is estimated at site I.

The cold tolerance of black pine is lower than those of red and/or pitch pine, but its salt tolerance is the highest among them. The black pine, therefore, can overcome the red and/or pitch pine at the coastal area. But because of environmental condition, *i.e.* salinity, is altered at the inland area, the black pine must be replaced with the other pines. Ecological optimum habitat of same species should be determind by relationships between physiological conditions of itself and competition with the other species.

## 摘 要

韓國 海岸에 主로 分布하는 곰솔(*P. thunbergii*) 群集은 中部 以南의 海岸에서는 곳에따라 全基底面積의 最高 99%를 占하는 純群落을 이루고 있다. 그러나 內陸으로 갈수록 溫度와 鹽度 等의 影響으로 소나무(*P. densiflora*), 리기다소나무(*P. rigida*) 等과 競爭 關係에 있다.

곰솔의 生長에 關與하고 있는 土壤의 化學的 性質과 그 最適 要求水準은 鹽度 0.025

~0.151%, 有機物 3~6%, pH 4.50~5.04, C.E.C. 8.5~11.me/100g, $P_2O_5$ 8~32 ppm, $K_2O$ 0.30~0.70me/100g, CaO 1.5~3.4me/100g, MgO 0.3~1.1me/100g, $SiO_2$ 50~80ppm 그리고 置換性 水素(H) 5.0~8.1me/100g 이었다.

海岸 地域에서는 樹齡 25年의 곰솔의 生產力은 同齡 소나무의 約 2倍, 리기다소나무의 約 4倍가 記錄되었다. 또 곰솔의 最適 伐採 樹齡은 35年으로 推定되었다.

韓半島에서의 곰솔의 造林 最適地는 WI 105°C·month 以上인 地域으로 判斷되었으며 이에 의거하여 韓半島에서의 곰솔의 造林 適地圖를 만들었다.

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