Relationship between shoot elongation and tree-ring growth varies with the positional environment in Pinus pumila
Relationship between shoot elongation and tree-ring growth varies with the positional environment in *Pinus pumila*

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Abstract
This study examined the relationship between tree-ring growth and shoot elongation in *Pinus pumila*. Previous studies have reported that, in *P. pumila*, shoot elongation is positively correlated and tree-ring width is negatively correlated with the summer temperature in the previous year. This information seems contradictory because shoot elongation and tree-ring width generally increase simultaneously; however, there are no previous studies comparing these two parameters. Therefore, in this study, we compared the tree-ring width and shoot elongation of *P. pumila* growing at Mt. Hiragadake, central Japan. Our average results indicated a positive correlation between shoot elongation and tree-ring width. However, the individual results show varying relationships between tree-ring width and shoot elongation. Tree-ring width and shoot elongation showed positive correlation in some trees, negative correlation in some, and no correlation in some others. We thought that the negative relationship caused by competition with surrounding plants. This occurrence in turn may have resulted in a trade-off for the efficient use of this product with either tree-ring growth or shoot elongation occurring in such plants.

Introduction

*Pinus pumila* (Japanese stone pine) is a very-slow-growing pine (*Natori and Matsuda 1966; Sano et al. 1977*) that grows into a pure dwarf scrub. It is found on the uppermost areas of high mountains in Japan, from central Honshu to Hokkaido (Ishizuka 1974). A literature survey revealed that studies have been conducted on the biomass and productivity (Shidei 1963; Okitsu 1981), annual shoot elongation (Sano et al. 1977), and the diameter growth of the trunks (*Natori and Matsuda 1966*) of *P. pumila*. Shoot elongation of *P. pumila* has been reported to be positively correlated with the summer temperatures of the preceding year (Sano et al. 1977; Okitsu 1988; Takahashi 2003–a). However, these studies examined the relationship between climatic conditions and shoot growth over short periods (15–20 years) because shoot elongation trace marks older than 20 years cannot be distinguished. Such short chronologies cannot provide robust results to determine the nature of the trees; hence, it is necessary to get a record growth of more years. Measurement of the radial growth (tree rings), on the other hand, can be traced back for many more years and hence can offer information about the growth history of trees in general.

Few studies have been conducted on tree rings of the stone pine mainly because most *P. pumila* trees are distributed across the national park and are protected. Moreover, core survey is not suitable for *P. pumila* since its trunk is too thin. Therefore, the association between the shoot elongation growth and radial growth is not well known.

In a previous paper (Yasuda and Okitsu 2007), the stone pines were cut down and the relationship between tree-ring growth and climatic factors was examined. The authors reported that radial growth of *P. pumila* slowed when the temperature rose. However, a shoot elongation study in *P. pumila* in Japan showed that shoot elongation was positively correlated with summer temperatures in the previous year (cf. Sano et al. 1977; Okitsu 1988; Kajimoto et al. 1996; Takahashi 2003). Contrarily, tree-ring growth and shoot elongation growth generally occur jointly. Hence, in this paper, we examined the relationship between the tree-ring growth and the shoot elongation of *P. pumila*.

Material and methods

Study site
This study was carried out on the summit of Mount Hiragatake (37°00’ N, 139°10’ E; summit elevation, 2141 m above sea level) in central Japan. The summit of Mount Hiragatake has a gentle convex topography with a distribution of bog and other vegetation (Fig. 1). The bog species that dominate here include *Nephrhythmium crista-galli*, *Molinopsis japonica* (Hack. Hayata.), Carex spp., and *Sphagnum* spp.

The *P. pumila* shrubs grow around the bog. Occasionally, *P. pumila* shrubs form a small community in the small convex in the bog. *Sasa kurilensis* grasslands and *P. pumila* shrubbery grow abundantly along the outskirts of the bog vegetation, while a coniferous forest consisting of *Abies mariesii* predominates along the outskirts.

The mean annual temperature at the study site was determined to be 0.0°C, which was estimated from the temperature recorded at the Yamanohana visitor centre of Gunma prefecture (1405 m above sea level, approximately 10 km south from the study site) by using the standard lapse rate of -0.6°C for each +100 m altitude. The mean monthly temperature in January (the coldest month) and August (the hottest month) were estimated to be -11.7°C and 12.4°C, respectively.
Sampling and measurement

The investigation was conducted on September 20, 2004. First, we investigated the vegetation surrounding the study site. Then, we selected trees for sampling. In some P. pumila trees, the above-ground stems are connected to those of adjacent individual P. pumila trees (Kajimoto 1992). In this study, we used a vibration method (Araki 1993) to select 10 trees that were not connected to other trees under the ground in order to prevent influence from other tree. The stems of the selected trees were cut off at a height of 10 cm from the ground level. The entire cut-off sections of the trees were taken to the laboratory as samples. The annual shoot elongation was determined using these samples by measuring from the bud scars using a ruler (Fig.2). Then, 1-cm thick disks were cut from each sample. These disks were dried and sanded, and the tree-ring widths were measured to 0.01 mm under a microscope by using a measurement stage.

Data comparison

The span of shoot elongation chronologies varied from 14 to 35 years among the 10 examined shoots because of the large variation in shoot length. We set '2004' as most recent year of the shoot growth and the outermost tree-ring growth. Then, we calculated the coefficient of correlation for shoot growth and tree-ring growth.

Results and Discussion

Table 1 shows the measurements and correlation coefficients of the tree rings and shoot elongation, and Fig. 3 shows the fluctuation in tree-ring width and shoot elongation. The graph was limited to 34 years, which was the maximum shoot elongation recorded. In addition, the number of tree rings on the samples was a minimum of 53 and a maximum of 96.

Table 2 shows the correlation between measured data; the average tree-ring width and the average shoot elongation showed a positive correlation with the total length of shoot elongation. In addition, a positive correlation was observed between the average tree-ring width and the average shoot elongation. In other words, a positive correlation was observed between shoot elongation and tree-ring width.

From Fig. 3, tree-ring growth and shoot elongation seemed to be synchronized in some samples, but not in others. In Table 1, samples 1, 3, and 9 show a positive correlation; samples 5, 7, 8, and 10 show a negative correlation; and samples 2, 4 and 6 did not show any correlation between tree-ring width and shoot elongation.

The samples not showing any correlation between tree-ring width and shoot elongation might have lost synchronization of shoot growth.
Yasuda and Okitsu: Relationship between shoot elongation and tree-ring growth varies with the positional environment in *Pinus pumila*. An arrows shows a bud scars.

Fig. 2  Measurement of annual shoot elongation of *Pinus pumila*. An arrows shows a bud scars.

Table 1  The measurement result and correlation coefficient between tree-ring and shoot.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Surrounding Vegetation</strong></td>
<td><strong>Type</strong></td>
<td><strong>Bog</strong></td>
<td><strong>Shrub of <em>P. pumila</em></strong></td>
<td><strong>S. kurilensis grassland</strong></td>
<td><strong>Dwarf <em>A. mariesii</em> forest</strong></td>
<td><strong>Edge of snow patch</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hight (cm)</strong></td>
<td>10</td>
<td>15</td>
<td>30</td>
<td>25</td>
<td>50</td>
<td>60</td>
<td>100</td>
<td>140</td>
<td>5</td>
<td>150</td>
</tr>
<tr>
<td>Number of shoot bud scars</td>
<td>34</td>
<td>23</td>
<td>21</td>
<td>16</td>
<td>35</td>
<td>14</td>
<td>20</td>
<td>18</td>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td>Total length (mm)</td>
<td>402</td>
<td>568</td>
<td>432</td>
<td>232</td>
<td>210</td>
<td>519</td>
<td>842</td>
<td>783</td>
<td>429</td>
<td>538</td>
</tr>
<tr>
<td>Average length (mm)</td>
<td>11.8</td>
<td>24.7</td>
<td>20.6</td>
<td>14.5</td>
<td>6.0</td>
<td>37.1</td>
<td>42.1</td>
<td>43.5</td>
<td>23.8</td>
<td>31.6</td>
</tr>
<tr>
<td>Number of tree-rings</td>
<td>54</td>
<td>63</td>
<td>82</td>
<td>38</td>
<td>84</td>
<td>79</td>
<td>49</td>
<td>79</td>
<td>96</td>
<td>82</td>
</tr>
<tr>
<td>Total width (mm)</td>
<td>17.8</td>
<td>41.1</td>
<td>17.5</td>
<td>14.5</td>
<td>34.6</td>
<td>41.8</td>
<td>32.7</td>
<td>36.0</td>
<td>43.5</td>
<td>17.6</td>
</tr>
<tr>
<td>Average width (mm)</td>
<td>0.336</td>
<td>0.664</td>
<td>0.389</td>
<td>0.372</td>
<td>0.416</td>
<td>0.537</td>
<td>0.680</td>
<td>0.462</td>
<td>0.457</td>
<td>0.346</td>
</tr>
</tbody>
</table>

Correlation coefficient between tree-ring and shoot:

- 0.457**
- 0.346
- 0.592**
- 0.253
- 0.433*
- 0.613*
- 0.168

Table 2  Correlation coefficient between each measurement items of all samples.

<table>
<thead>
<tr>
<th>Total length of shoot elongation</th>
<th>Number of shoot bud scars</th>
<th>Average length of shoot elongation</th>
<th>Length of pith to bark</th>
<th>Number of tree-rings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of shoot bud scars</td>
<td>−0.380</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Average length of shoot elongate</td>
<td>0.909**</td>
<td>−0.677*</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Length of pith to bark</td>
<td>0.329</td>
<td>−0.116</td>
<td>0.368</td>
<td>—</td>
</tr>
<tr>
<td>Number of tree-rings</td>
<td>−0.030</td>
<td>−0.053</td>
<td>0.090</td>
<td>0.433*</td>
</tr>
<tr>
<td>Average width of tree-rings</td>
<td>0.613*</td>
<td>−0.211</td>
<td>0.528*</td>
<td>0.675*</td>
</tr>
</tbody>
</table>

* Significance level of 0.05 or less  ** Significance level of 0.01 or less
Fig. 3 Fluctuation of the tree-ring width and shoot elongation of *Pinus pumila*. Bar indicates tree-ring width and line indicates shoot elongation.
and tree-ring growth because of the disappearance of tree-rings or bud dormancy.

A typical relationship can be seen in Fig. 4 and Fig. 5. We believe this variation depends on the positional environment. The samples listed in Table 1 are categorized on the basis of vegetation type. Moreover, the samples are listed in the order of the vegetation height (except number 9, which was a bare ground). The results suggest that trees growing on positions surrounded by higher vegetation show negative correlation between tree-ring width and shoot elongation.

Kibe and Masuzawa (1992) examined seasonal changes in the carbohydrate content in P. pumila and suggested that carbohydrate gained from photosynthesis during summer is stored in the branches and needles as sugar during winter and used for growth in the following year. It is likely that the photosynthetic product of the previous year is used for growth in the subsequent year. If the tree has an adequate store of photosynthetic product, this product is used for both elongation growth and tree-ring width, which will thus show a positive correlation. If the competition between plants to get the sunlight becomes aggressive, the plant will need to accelerate shoot growth. Therefore, the photosynthetic product will be used for shoot elongation, and tree-ring growth will

![Fig. 4](image)

**Fig. 4** The relationship between tree-ring width and shoot elongation in sample No.3

![Fig. 5](image)

**Fig. 5** The relationship between tree-ring width and shoot elongation in sample No.8
be suppressed. In other words, a trade-off will occur. Usually, *P. pumila* grows in sunny areas with low soil moisture (Okitsu 1988). An environment of excessive moisture, such as that in a bog, is unsuitable for *P. pumila*. This is particularly the case in locations with excessive soil moisture, such as a bog. In such locations, the oxygen in the soil has been depleted, and sulphide and metal ions, such as Fe$^{2+}$ and Mn$^{2+}$, are generated by the action of anaerobic bacteria (Larcher 1999). The toxicity of these ions results in the failure of the root system, consequently reducing the moisture content of the leaves and lowering the rate of photosynthesis (Armstrong et al. 1996; Drew 1990; Hiron and Wright 1973; Larcher 1999; Pezeshki et al. 1991). Our study area consisted of a bog with a wet environment not suitable for the growth of *P. pumila*. Hence, the rate of photosynthesis in our sample trees was estimated to be low. In such situations of low photosynthesis rate, the occurrence of a trade-off is more likely.

**Conclusion**

Tree-ring width and shoot elongation of *P. pumila* showed a positive correlation in some trees and a negative correlation in some others. We found that this relationship varies depending on competition between plants, which determines the allocation of photosynthetic product to organs. Thus, in future studies of the tree rings of *P. pumila*, it is important to understand the effects of the competition with other plants on the individual trees.

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**References**


