

# Growth Patterns Appearing in Annual Ring Width at Different Heights in *Picea abies* KARST. and Effects of Defoliation by *Cephalcia isschikii* TAKEUCHI\*

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## I Introduction

NISHIGUCHI & MOROTO(4) reported on the defoliation by sawfly (*Cephalcia isschikii* TAKEUCHI) in Tokyo University Forest in Hokkaido. According to their report, the insect was found out in 1944 at a hedge made of Norway spruce (*Picea abies* KARST.) in the first nursery and it spread to the near planted area rapidly. In the 76th compartment of the University Forest the number of the insect increased gradually from about 1952 and considerable damage seemed to occur in some places. In 1956, the insect broke out on a large scale abruptly, and at the middle of August, the crown of Norway spruce turned red in the southern half of the compartment and the remarkable damage was observed from a distance. After that, the conspicuous damage did not occur and the number of the insect decreased quickly. It was the greatest damage at most that the upper half to one-third of a crown was eaten by the insect and in the lower crown, the damaged branch was found clearly. And such a severe damage, often reported in Europe and America, that all the leaves of a crown was eaten clearly by the insect did not occur in this break out of the insect. Therefore, it seems the mortality caused by the insect to be a little, if any. (See Abb. 2. Verteilungen der Larven im Bodem and Tab. 1. Frassgrad und Zahl der Larven im Bodem in the report of NISHIGUCHI & MOROTO(4).)

DUFF & NOLAN(1) in Canada made a precise growth analysis of the ring width of *Pinus resinosa* and proposed a original method for analysing growth pattern of trees. MOTT et al. (3), STARK & COOK (5), and YOSHIDA & KANAMITSU (6) showed the usefulness of the method for analysing growth reduction by harmful insect. In a series of our investigation to analyze the influence of external factors on the annual ring width through the long life of tree growth, we examined the change of annual ring width of Norway spruce caused by the leaf-eating insect, sawfly, following the method by DUFF & NOLAN.

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## II Materials and Methods

In June of 1980, the specimens were selected and felled down in the Norway spruce (*Picea abies* KARST.) plantation in the e-subcompartment of the 76th compartment of the Tokyo University Forest in Hokkaido where the great outbreak of sawfly had been recorded. The stand where the specimens were taken faces to southeast with the inclination angle 6 degrees. The Norway spruce stand was planted in about 1911, and the mean breast height diameter at the time of felling was 35.3 cm, mean height 29.7 m, and the stand density 640 stems per hectare. The trees at the time of the insect outbreak were about 40 years old, mean breast height diameter 23.5 cm, mean height 20 m, and the stand density 770 stems per hectare (2). The reduction of the stand density was mainly caused by the twice thinnings, one was 64 stems per hectare in 1958 and the other 63 stems per hectare in 1965.

Three specimens were selected for this examination : one with the bigger diameter, another the mean, and the other with the smaller diameter at breast height, respectively.

Bigger diameter specimen : 46.6 cm in D.B.H., 30.24 m in height

Mean diameter specimen : 34.8 cm in D.B.H., 26.80 m in height

Small diameter specimen : 26.6 cm in D.B.H., 27.78 m in height

Disks were cut out at intervals of 50 cm from the butt on each stem. The annual ring width in the disks of the upper and lower parts of the stem was measured with a precision of 0.1 mm along four cardinal directions using microscope, and the width of the other parts of the stem was measured with a precision of 0.01 mm using a machine for measuring annual ring width in Faculty of Agriculture, Nagoya University. The mean from four measurements was taken as the ring width. Although the innermost ring on each disk consisted of pith and xylem, only the xylem part was regarded as the increment of the first year.

The longitudinal section for every year of the each stem was drawn using these measurements. The height of the tree for each year was estimated by drawing a line parallel to the ring which was one year older than the year for which the height was estimated and by getting an intersection with the stem axis. The width of each ring located in the middle of an internode, i.e., the annual height increment, was calculated by regarding the figure made by two adjoining rings and two adjoining disks which contained those rings as a trapezoid. Such a calculation was made by the computer in the Computation Center of Nagoya University. The mean of three measurements thus calculated from each stem was taken as the ring width at the middle of each internode, and used first to examine the annual increment of the height and the volume and second the three different sequences of the ring width, namely oblique, horizontal and vertical sequence (1,7).

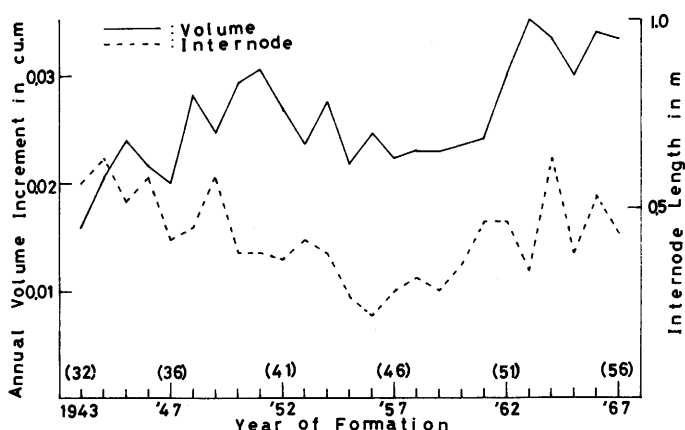


Fig. 1 Annual increment of volume and height before and after the damage of the insect  
 Each curve represents the mean of three stems  
 The number in parentheses is the tree age

### III Results

#### 1 Annual increments of the volume and the internodal length (Fig. 1)

The annual increments of the volume and the internodal length in about 1952 when the number of the insect began to increase are shown in Fig. 1. The volume increased from 1943 to 1951 and decreased from 1952 to 1957 with some fluctuations. The volume kept constant or somewhat increased from 1957 to 1961, in 1962 reached approximately the same value for 1951, and after 1963 oscillated. Therefore, the effect of the insect on the volume was considered as follows. It began to appear in 1952 and the growth decreased gradually. The effect was clearest from 1957 to 1961 and disappeared in 1962 or 1963. The internodal length decreased with some fluctuations from 1943 to 1956 and increased from 1957 to 1961, and after that, oscillated around a definite value. Although the effect of the insect is somewhat obscured by the trend of the decrease, the decrease in 1955 and the lowest value in 1956 can be interpreted as the effect of the insect. It seems that the damage was almost recovered by the increase in 1961. Damage by the insect seems to influence the volume clearer and longer than the internodal length, which agrees with NISHIGUCHI & MOROTO's description. It is generally recognized that the volume and the internodal length increase from the first to certain stage and then decrease gradually. As the volume increases over longer time than the internodal length, the growth reduction by the insect in this examination appeared more clearly in the volume increment than in the internodal length. On the other hand, the internodal length decreases earlier and the effect of the insect may be obscured by simultaneous reduction by the insect and the natural decrease. Hereafter, the examinations were made mainly from 1952 to 1962.

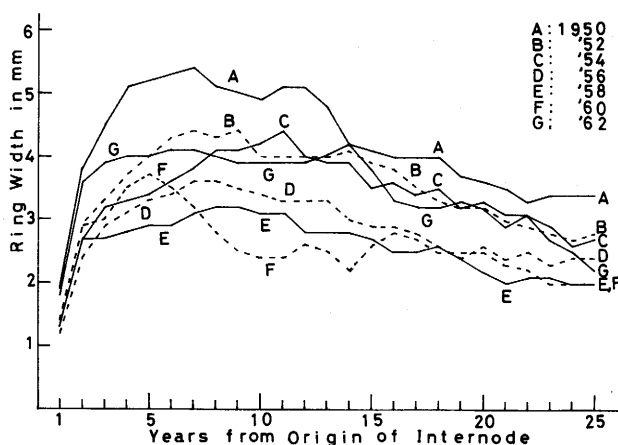


Fig. 2 Oblique sequences of the annual ring width before and after the damage of the insect  
Each curve represents the mean of three stems

The stand was thinned in 1958 and in 1965. Each of the thinning rate was at most 10 percent of 770 stems per hectare, so that the effects are considered to be a little, if any. In fact, although the volume increased slightly in 1958, the volume immediately decreased in the next year of 1967. The value of 1965 was small compared with around the values and indeed the value increased in 1966, but immediately decreased to the value of 1964, before the thinning, again. Therefore, even if these fluctuations are caused by these thinnings, those effects are considered to be little. The case of the internodal length is almost the same as the volume.

## 2 Oblique sequences (Fig. 2)

The sequence of 1950 (A) in which no effect of the insect appeared yet, displayed a trend that the value for the first year from the pith was small, rapidly increased to a maximum at 7th year, and then decreased gradually. This seems to be the same growth pattern described by DUFF & NOLAN. The ring widths of sequence 1952 (B) were smaller than those of 1950 throughout the sequence, indicating that the effect of the insect began to appear. But the shape of the curve was similar to that of 1950. The ring widths of the sequence 1954 (C) were almost the same as those of 1952 except that the maximum value somewhat delayed, i.e., 11th year from the pith. The shape of the curve from the 3rd year to the 11th year was almost straight, not smooth convex, indicating the effect of the insect. The ring widths of the sequence 1956 (D) became much smaller compared with those of 1952 and 1954. Thus the effect of the insect seemed to progress further. The pattern of increase and decrease described by DUFF & NOLAN was recognized though indistinctly. The ring widths of the sequence 1958 (E) became smaller compared with those of 1956 and the shape became almost straight from the second to 18th year and also after 21st year. When the effect of

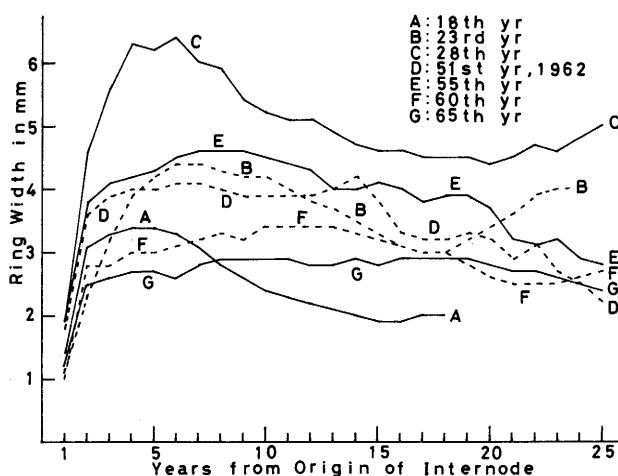


Fig. 3 Oblique sequences of the annual ring width from the 18th year to the 65th year  
Each curve represents the mean of three stems

the insect is very severe, the ring widths become very small throughout the sequence and shape becomes almost straight as designated in this curve. The recovery from the insect damage seemed to begin in 1960, because the curve of the ring widths of the sequence 1960 (F) showed a clear maximum at the fifth year, although the ring widths were almost the same as those of 1958. The recovery began first from the upper stem. The ring widths of the sequence 1962 (G) were almost the same as those of 1952 and 1954, although the shape from the third to 13th year was generally straight. Therefore, it seemed that the growth was mostly recovered in this year, or at least on the way. DUFF & NOLAN studied the growth pattern of *Pinus resinosa* of 15 to 30 years and proposed the tendency of increase and decrease during this period. Fig. 3 shows that the sequences of 18th, 23rd and 28th year have a definite pattern of increase and decrease just like DUFF & NOLAN, but in the sequences of 55th, 60th and 65th year the maximum point was unclear and gradually the shape became flat. As the sequence of 1962 corresponded to the 51th year, the growth seemed almost restored in this year.

### 3 Horizontal sequences (Fig. 4)

The year when the number of the insect began to increase was 1952, then the height of the middle of the first internode, i.e., the first year from the pith was 19.11 m. Therefore, the horizontal sequences were drawn at intervals of 8 years from 19.11 m. DUFF & NOLAN noted on the horizontal sequences the regular pattern of gradual rise, reaching a maximum and fall. The sequence of the height 19.11 m (A) was nearly horizontal from the 2nd to 7th year from the pith, or from 1953 to 1958, and also nearly horizontal though at higher level after 1961. This pattern differs from that of DUFF & NOLAN. The shape from 1953 to 1958 was nearly horizontal, presumably due to the effect of the insect. The value of the sequence

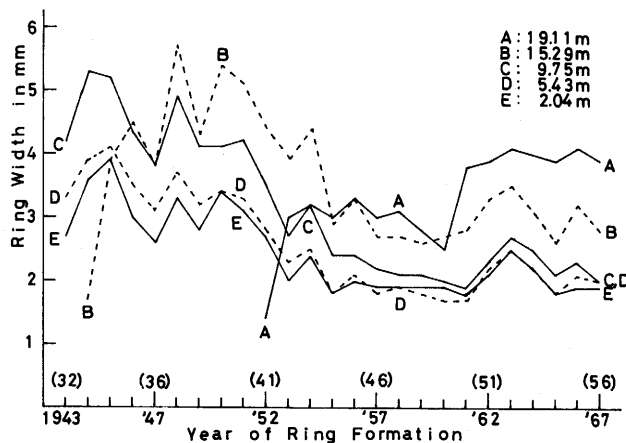


Fig. 4 Horizontal sequences of the annual ring width before and after the damage of the insect  
Each curve represents the mean of three stems  
The number in parentheses is the tree age

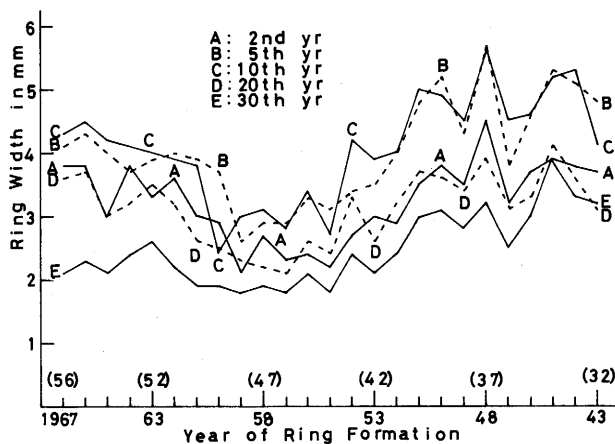


Fig. 5 Vertical sequences of the annual ring width before and after the damage of the insect  
Each curve represents the mean of the three stems  
The number in parentheses is the tree age

at the height 15.29 m (B) was small at the first year, rapidly increased to a maximum at the 5th year, 1948, then decreased just like the pattern by DUFF & NOLAN. The values from 1957 to 1961 in this sequence were small, presumably due to the effect of the insect, although somewhat obscured because of the decrease from 1948, the time of maximum, to about 1959 with fluctuations. The sequences of the heights 9.75 m (C), 5.43 m (D), 2.04 m (E) resembled one another. All the three ring width series had a trend of decrease from 1945 to 1955 with big fluctuations, followed by small but relatively constant period from ca. 1955

to 1961, and increase and decrease thereafter. The value from ca. 1955 to 1961 are considered to be affected by the insect, although the effect is obscured by the trend of decrease with fluctuations after 1945.

#### 4 Vertical sequences (Fig. 5)

The sequence of the 2nd year from the pith (A) oscillated irregularly at a certain level from 1943 to 1951, then decreased from 1952 to 1955, oscillated at another level from 1955 to 1959 followed by the graduate increase from 1960 to 1962, and oscillated at the other level after 1962. The decrease from 1952 to 1955, the oscillation from 1955 to 1959 and the increase from 1960 to 1962 are considered to be the growth reduction, stagnation caused by the insect and recovery from that, respectively. Ring widths of the 5th year (B) were apparently greater than those of the 2nd year throughout the curve but the shape of the curves resembled each other, indicating that the effect of the insect were similar to those of the 2nd year. But while the ring widths of the 2nd year oscillated from 1955 to 1959, those of the 5th year decreased smoothly from 1951 to 1959, which indicated that the ring width of the 2nd year reflected stagnation more clearly than those of the 5th year. Although the general trend of the ring width curve of the 10 year (C) resembled those of the 2nd and 5th year, it followed rather a random curve because of many fluctuations. The tendency to decrease from 1952 to 1960 indicates the effect of the insect, though it was obscured by the fluctuations. The ring widths of the 20 year (D) maintained almost the same level as those of the 2nd year but followed a different curve. The increase from 1958 to 1961 seemed to be the recovery from the growth reduction by the insect. The ring widths from 1952 to 1957 changed greatly, although those had a tendency to decrease, consequently the growth reduction by the insect was obscured. Therefore, the effect of the insect was indistinct on the whole. The ring widths of the 30th year (E) were smaller and smoother than those of the other years throughout the sequence. The ring widths fluctuated randomly at a certain level from 1943 to 1951 and also after 1962. The ring widths decreased, then increased between 1952 and 1962, although the tendency was somewhat obscured, which indicated growth reduction by the effect of the insect and the recovery from it.

### IV Discussion

The mean annual increment of the volume from 1948 to 1951 before the reduction by the insect was calculated to be  $0.028 \text{ m}^3$ , that from 1962 to 1967 after the recovery from the reduction was  $0.033 \text{ m}^3$ , while that from 1952 to 1961 under the influence of the insect was  $0.024 \text{ m}^3$  (Fig. 1). Assuming that the annual increment without the damage to be  $0.305 \text{ m}^3$  (mean of the increment before and after the damage), the total volume increment under the influence of the insect was about 80 percent of the normal increment. Namely, the period of the damage was about 10 years and the total loss was about 20 percent of normal

increment.

When the effect of the insect did not appear in the oblique sequence, its shape was the same as the pattern described by DUFF & NOLAN. When the effect of the insect began to appear, the ring widths at first became smaller throughout the sequence, then the shape from the first year to about the maximum value turned to a almost straight line. Subsequently the ring widths became futher smaller throughout the sequence but the shape noted by DUFF & NALON appeared again. When the effect of the insect appeared most intensely, the ring widths were small and the shape was almost straight. The recovery began after that, the maximum point appearing clearly in the young year from the pith. The next, the ring widths became greater but the position of the maximum point was obscure and consequently the pattern of increase and decrease described by DUFF & NOLAN was indistinct. It is conceivable that, as the recovery progresses, the shape of the sequence turns to the pattern described by DUFF & NOLAN. But it is also probable that the position of the maximum is not clear and the sequence became almost flat from the 2td or 3rd to the older year, as in the case of trees going to loss their vigor, for example, as over-matured trees.

In the horizontal sequences at the upper part of the stem, the effect of the insect was recognized by the fact that the pattern of the increase and decrease was disturbed. But it was generally difficult to analyse the effect of the insect accurately because the growth reduction by the insect was obscured by the growth trend of decrease with fluctuations.

The vertical sequence is considered to have a certain trend with random fluctuations and the shape of each sequence generally resembles one another although the random fluctuations seem to differ with year to year from the pith. The random fluctuations of the 2nd and 30th year were comparatively small and those of the 10th year were great. This difference is considered to be related to the vertical distribution of branches with living leaves and the external action. The amount of leaves of the tree in stand is little near the apex of the stem, and gradually rises downward to a maximum and falls. Then it disappears at the certain part of the stem. Thus, the amount of leave is little at the 2nd year from the pith, abundant at the 10th year, and at the 30th year the amount is about the same as or a little less than that of the 10th year. On the other hand, the branches and leaves at the 2nd and 10th year receive fully sunlight but those at the 30th year are shaded by those of adjacent trees. Therefore, even the great external changes are not reflected in the sequence of the 2nd year so much because of a few leaves, and also in the sequence of the 30th year because either the amount of the leaves are not so much or the branches and leaves not so vigorous being suppressed, or due to the external changes themselves moderated by the crown closure. Against these situations, the leaves at the 10th year are at the upper part of the tree, abundant and vigorous, so that the external changes will be reflected in the sequence of the 10th year manifestly. The fluctuations in the sequences are considered to be concerned with these situations.

In this examination, the effect of the insect appeared most clearly in the oblique



sequence and showed tendencies to be obscured by the trend of decrease in the horizontal sequence and by random fluctuations in the vertical sequence. Further, in the case of the matured tree like this specimen, the oblique sequences before the outbreak of the insect play a role of the comparative tree, so that the effect of the insect are considered to be well assessed only the damaged tree. The annual increment of the volume seemed to resemble the vertical sequence, which was considered as follows. The vertical sequence is considered to have a certain trend with random fluctuations. On the other hand, as the annual increment of the volume in this specimen was latter half of its life, without the insect damage, its trend would have been smooth curve with random fluctuations. And if both the random fluctuations are owing mainly to the same environmental changes, in many cases, it will be suggested that the annual increment of the volume is similar to the vertical sequence.

### Summary

Norway spruce (*Picea abies* KARST.) caused damage by sawfly (*Cephalcia isschikii* TAKEUCHI) was examined, following the method proposed to analyze *Pinus resinosa* Ait. in Canada by DUFF & NOLAN in 1953. The method analyses radial growth of the stem in three different directions, namely oblique, horizontal and vertical sequence. Patterns appeared in these three sequences in Norway spruce were almost the same as described for *Pinus resinosa* Ait. by DUFF & NOLAN. The effects of the insect appeared most clearly in the oblique sequence, showing the progress of the growth reduction, stagnation caused by the insect and recovery from that, and indicated tendencies to be obscured by the trend of decrease in the horizontal sequence and by random fluctuations in the vertical sequence. The growth reduction by the insect appeared more clearly in the volume increment than in the height increment. The period of the damage was about 10 years and total loss was about 20 percent of normal volume increment.

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## ドイツトウヒの高さ別年輪幅に現われる生長のパターン とオオアカズヒラタハバチの食葉の影響

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### 摘 要

DUFF & NOLAN が、レジノーサマツの生長を解析した手法を、オオアカズヒラタハバチの食葉被害をうけたドイツトウヒに適用した。この方法は、樹木の肥大生長を三方向から解析するものであるが、生長のパターンについては、彼らとほぼ同様の結果を得た。被害の影響は、斜め方向の系列に最も鮮明に現われ、被害が現われ、回復していく過程をよく示していた。水平方向の系列については、変動しながら減少していく系列の性質により、垂直方向の系列については、ランダムな変動により、害虫の影響による生長の減退は不明瞭であった。害虫の影響は、樹高生長よりも材積生長に鮮明に現われ、被害の期間は約10年間であり、総損失量は正常の生長量の約20%であった。