

Comparison of mensuration methods for annual shoot elongation
with adjacent bud scale marks on shoot
of Siberian dwarf pine (*Pinus pumila* REGEL)

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ハイマツ幹年枝長測定法の比較

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I. Introduction

Siberian dwarf pine (*Pinus pumila* Regel) is a subalpine species with a dwarf form. It has a discrete distribution in the higher mountains of Honshu and Hokkaido, and forms large and small communities on the slopes under varied climatic and edaphic conditions. Most of the communities of this pine are protected by laws because of ecological importance. This pine shows a wide variation in size of trees forming a community with differing conditions of each site (Araki *et al.*, 1993b). Therefore, biomass of the communities varies widely (Araki *et al.*, 1993a), but in most cases, standing crop of leaves is more than (Shidei, 1963) or nearly equal to (Kajimoto, 1994; Araki *et al.*, 1993a) that of common coniferous forests (Tadaki, 1976). Especially, an extremely high dry matter density is observed (Kira *et al.*, 1967; Araki *et al.*, 1993a) in this pine community. It is considered for this reason that the community shows very different community architecture from those of common tree species as follows: tops of stems and all branches are mostly erected upward, a characteristic specific to this species. Therefore, there is an assumption that light environments surrounding each shoot (stem and branch) are not so different from each other. Application of stratified clipping method to verifying this assumption is impossible, because the major communities of this pine are in the conservation areas of national parks. However, we are able to determine annual shoot elongation during the last twenty one years (Sano *et al.*, 1977) or the last fifteen years (Okitu, 1988), with measurement of lengths between two adjacent bud scale marks on shoots (the length is abbreviated as LAS). Therefore, it is possible to analyze the effect of specific community architecture on extremely high dry matter density, by the measurement of LAS. This measurement is very difficult owing to the shortness of LAS, and flexibility and shape of the shoot. There is no comparative discussion on the methods of measurement of LAS. Further there is no explanation of the methods in previous studies (Sano *et al.*, 1977; Okitu, 1988).

The purpose of this study was to investigate a practical and simple method for measurement of LAS and to clarify general growth characteristics of LAS. Authors wish to thank the staff of the Management Office of Chubusangaku National Park, and officials of Nagano and Yamanashi Prefectures for their kind assistances in collecting data.

II. Sampling site and term of data sampling

Data of LAS were collected from two communities, one near the Corona Observatory on the top of Mt. Norikuradake (summit altitude 3,026m), and the other in the shoulder (alt. 2,510m) of Mt. Asahidake (summit alt. 2,579m) in Oku-chichibu mountains. The community of Mt. Norikuradake was growing on a slope with an inclination of 30° and direction of S-86°-W, whereas the other community was growing on a slope with an inclination of 28° and direction N-64°-E. Outlines of the communities are shown in Table-1. Measurement of LAS was done from the 1st of July to the 23th of August in 1991.

III. Methods of measurements

1. Main stem and top part of shoot with leaves (TSL)

Siberian dwarf pine is a dwarf form. Therefore, we need to measure many more size factors to define tree size and shape than in common trees. Names and explanations of each size factor was published previously (Araki *et al.*, 1993b). Names discussed in this paper are as follows. 1) First stem indicates the creeping stem and the erecting stem in the lump. 2) First branch indicates a branch which ramifies directly from the 1st stem and is rather erect in the top part. 3) Second stem indicates a stem which is ramified from the 1st stem, creeping and clearly stouter than the common branches. There were 3rd stems in some cases.

Basal part of the creeping stem is usually contacted to the ground surface. This part develops roots and becomes buried under the soil following growth of the stem, ramifying part of the stem will be buried too. Therefore, it seems unlikely that 2nd stems or 3rd stems of same tree are 1st stems of another tree. It was observed that LAS of the 1st stem is longer than that of 2nd or 3rd stem. Therefore, measurements should be made on the 1st stem. The best way to distinguish the 1st stem, is to uncover soil on the under ground part of creeping stem. However, this method can't be used because of protective laws mentioned above. In this investigation, a shaking method was applied as follows: when a stem was

Table-1 Some dimensions of sample communities

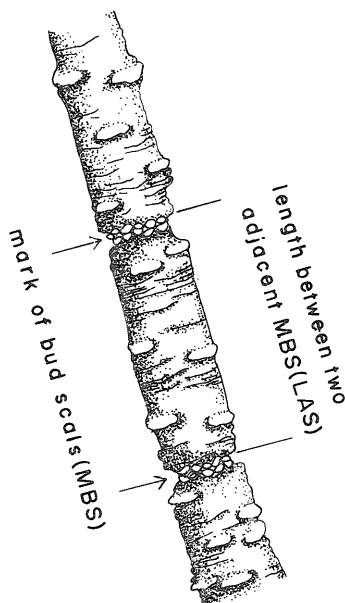
	Mt. Norikuradake	Mt. Asahidake
Plot area (m ²)	10	8
Density (nos. of stem/m ²)	12.7	2.1
Mean community height (m)	0.54	1.35
Mean basal diameter of stem (cm)	2.2	4.49

shaken by hand, if other stems showed synchronous shaking, they were judged as cohorts. As an alternative, the longest stem in a clump is defined as the 1st stem (Kajimoto, 1985).

The 1st stem recognized as top of a clump of trees by the shaking method was chosen for measuring and named as the main stem. Most main stems, didn't show zig-zag bending with ramifying 2nd stems. Here, the word tree is used for convenience. Because, there is a possibility that trees completely dissociated now, might have been one individual (clone) in the past. The ramified part of the creeping stem buried under the soil might have decayed over time. Branches directly ramified from 1st branches are named 2nd branches, and those from 2nd branches are named 3rd branches. Top parts of shoots with leaves are named TSL.

2. Length between adjacent bud scale marks on shoot (LAS)

Bud scales of this pine detach from the base of winter bud after elongation of new shoot. A meshy mark of bud scales (abbreviated as MBS) is formed on the shoot every year. Shoot elongation type of this pine is one flush in a year (Sano *et al.*, 1977), therefore prominent growth of shoots only occurs in early June, and the winter bud is formed from late July (Sano *et al.*, 1977) to mid-August (this measurement). In Fig.- 1 a schema of LAS described above is shown. Many bud scale marks (MBS) on a TSL were named as follows; first



Figure— 1 Schema of LAS

one from the top formed in 1991 as MBS_0 , second one as MBS_1 , third one as MBS_2 , and so on. A shoot from MBS_0 to MBS_1 is stratified as one year old shoot or shoot of age class 1 (abbreviated as YS_1), and a shoot from MBS_1 to MBS_2 is YS_2 , and so on. The length between two adjacent MBS of succeeding years (LAS) were measured. Each LAS is equal to annual shoot elongation. Leaves on current shoots (YS_0) had not expanded to full size in many TSL at the time of measurement, therefore LAS of YS_0 were not measured.

3. Differences in LAS by four measuring methods (Measurement I)

1) Methods

The basal part of a stem of the pine creeps on the surface of the ground, and the stem often touches the soil surface. Middle part of the stem lays obliquely with a very small angle of inclination above ground. The end of the middle part of the stem forms a bending part. Above the bent part, the stem stands with a concave shape. The top part of the stem is rather erect. Most TSL have a concave curvature. To measure LAS, a vernier caliper must be used for the reason that follow. 1) TSL shows concave curvature. 2) TSL is very flexible. 3) TSL have many needle fascicles. 4) Length of TSL is very short. It is very difficult to measure LAS by the reason of flexibility of shoot (TSL), especially when the TSL is shaken by wind. Therefore, in practical measurements, the TSL must be fixed. This is accomplished by pinching the top of TSL with fingers and stretching TSL (abbreviated as method FX). Then, there is a possibility that the value of LAS obtained by FX method is longer than LAS obtained by other measuring methods.

Comparative discussions are made here between FX method and other complicated methods, to clarify values obtained by FX method.

2) Measurements

Ten main stems were sampled from the Mt. Norikuradake community. LAS of the TSL were measured for YS_1 to YS_5 . The four methods of measurement applied are illustrated in Fig.-2. Measurements of LAS were done with vernier caliper in millimeters to the first decimal point.

- ① Fix(FX): Length between two adjacent meshy bud scale marks (MBS) was measured by fixing method mentioned above. Values by this method can be said to be the stretched length.
- ② Inside(IN): Chord length between two adjacent MBS was measured from chord side of TSL.
- ③ Outside(OU): Chord length between two adjacent MBS was measured from arc side of TSL.

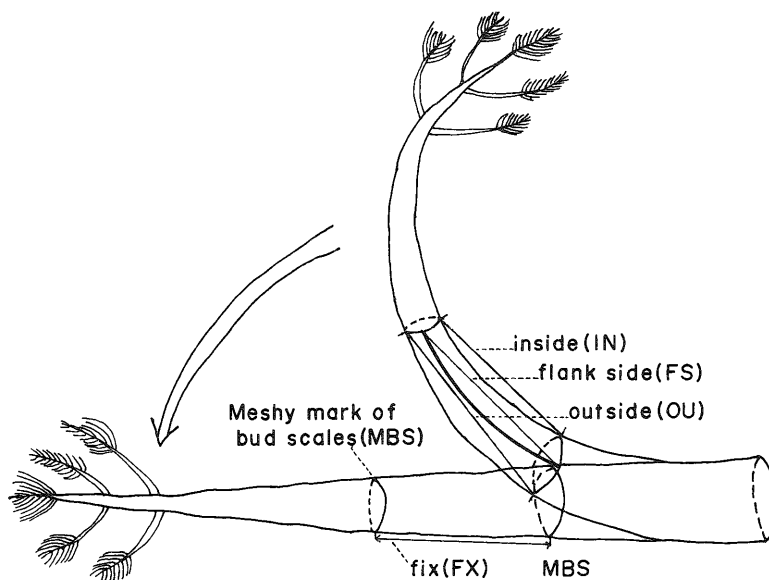


Figure — 2 Illustration of four methods for measurement

- ④ Flank side (FS): Shortest length between each center of two adjacent MBS on flank side of TSL was measured. In this case it was defined that FS of two flank sides (this and opposite) were the same length.

Values obtained by the four methods are different from each other. By IN · OU · FX methods, measured length is not arc length but cord length.

4. Clarification of growth characteristics of LAS (Measurement II)

1) Methods

Each LAS of YS_1 , YS_2 , YS_3 and so on in the same TSL are not equal because of differing climatic conditions in past years. Annual variation of LAS in shoot age classes occurred. In other words, the yearly patterns of LAS (abbreviated as PLAS) are performed on TSL. Then, similarity of PLAS on shoots of main stems, 1st branches and 2nd branches are examined and variation of LAS in branching order is studied.

2) Measurements

The following four measurements were carried out in the community at Mt. Asahidake mentioned above, using FX method.

- ① LAS of TSL in shoot age class from YS_1 to YS_{10} were measured for ten main stems sampled at random.
- ② LAS of TSL in $YS_1 \sim YS_5$ for ten 1st branches per every ten main stems were measured.

- The main stems were separately sampled in ①. The ten branches were collected by census sampling from the base of each stem. In this case LAS of stems were measured too.
- ③ LAS of TSL in $YS_1 \sim YS_5$ for all 1st branches of one main stem sampled from ② were measured. In this case LAS of stems were measured too.
- ④ LAS of TSL in $YS_1 \sim TS_5$ for all 2nd branches of one of the lowest 1st branches of one main stem sampled from ③ were measured.

IV. Results and discussions

1. Difference of LAS on stems among measuring method (Measurement I)

It can be said that the values of LAS obtained by three methods, IN · OU · FS, are approximations of shoot elongation value but are not true lengths, because TSL shows concave shape as in Fig.- 2. The true values can be obtained by measurement of the concave length along the center axis of the flank side, as the thick line in Fig.- 2. However, this measurement is impossible. On the other hand, FX method is the easiest method as mentioned above. Therefore, values of LAS on stems obtained by the other three methods in ten main stems were compared to the values by FX method. In other words, discussions based on the FX method as the standard were done.

1) Analysis of variance for values of LAS

Here, variation in LAS values obtained by each method was determined by analysis of variance. Analysis of variance used was three-way layout without replication, setting the three factors as ten main stems, five shoot age classes and four measuring methods, with two hundred values of LAS. The results showed a significant difference at 0.1% probability in main stems and in shoot age classes as shown in Table- 2. It can be said as matter of course that the variances among main stems and among shoot age classes are large (variance ratio in the Table- 2 are high), because the values of LAS vary with tree size, growth conditions due to climate in the previous year (Okitu, 1988) and etc.. On the other hand, there was no significant difference in measuring methods.

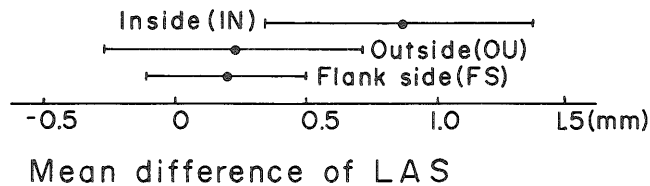
2) Comparison of mean LAS obtained by each measuring method

The mean of fifty values of LAS obtained by FX method was 17.0mm. The differences between value of LAS obtained by FX method and values obtained by the other three (IN · OU · FS) methods were calculated for every ten main stem and every five shoot age classes, as FX minus IN and so on. Fig.- 3 shows values of interval estimation for the differences, calculated with significant levels at 5%, and with pooled data for main stems and shoot age

Table— 2 Analysis of variance of length between two adjacent marks of bud scale, main stems shoot age classes and measuring methods

Factor	S.S.	D.F.	M.S.	F
Main stem (S)	3550.21	9	394.47	53.52***
Shoot age class (A)	1706.08	4	426.77	57.91***
Measuring method (M)	17.19	3	5.73	0.77
S · M	60.91	27	2.26	0.31
A · M	9.90	12	0.83	0.47
Error	1061.22	144	7.37	
Total	6406.51	199		

Note)***=Significance level at 0.1%.



Figure— 3 Interval estimation for differences among measuring method

Note) Difference between two LAS are obtained by $IN = FX - IN$, $OU = FX - OU$ and $FS = FX - FS$ respectively.

confidence limits are given with significant level at 5% probability.

classes. Each value for interval estimation was in the plus range. Fx method gave longer values than the other three methods. The value of IN is significantly shorter than that of FX. In other words, in applying the FX method the inside of TSL is elongated 5.1% and flank side 1.1%. However, values obtained by the three methods are not true values as mentioned above. It can be said that, the values obtained by FX method are nearest to the true value, because values obtained by the other three (IN · OU · FS) methods, even by FS method, are chord length and not are arc length.

3) Conclusion

It is very difficult to measure LAS in the field without fixing by pinching and stretching of TSL. In spite of this there has been no discussion before of measuring methods for LAS on TSL. FX method is the easiest and most practical method when compare to the other three methods. It is clear that TSL especially the inside length (IN) is elongated significantly by use of the FX method. The value obtained by FX method is the nearest to the true

length of annual shoot elongation, because FX method gives values that are even longer than the FS method. Therefore it can be concluded that the FX method has satisfactory accuracy in practical application.

2. Clarification of some characteristics of LAS (Measurement II)

Here, variation of LAS among branching order was elucidated, and synchronization of PLAS among main stems, among 1st branches and 2nd branches were analyzed, using the data II-①~④ obtained by FX method.

1) Difference of LAS depending on branching order

Difference of LAS caused by branching order are discussed here, using the data of II-①②③④, containing twenty stems, ninety 1st branches and forty six 2nd branches. Mean values of LAS for every branching order and every shoot age class, and values of interval estimation were significant at 5%. The results show that LAS of stems is the longest, LAS of 1st branches is next and that of 2nd branches is the shortest in each shoot age class as shown in Table- 3. Part of reason for small confidence limits in 1st branches is based on a small t-value applied to the 1st branches, because the number of that was twice or four times as many as the others. Analysis of variance was done to separate effects of branching order and effect of shoot age class on LAS, with mean value of LAS calculated for every branching order and every shoot age class. The results indicate that branching order has an effect with significant at 0.1%. The effect of shoot age class on LAS showed no significance. Collection of 2nd branches from one 1st branch does not cause any problems, because it was observed that LAS of 1st branches are longer than LAS of all 2nd branches ramifying from the 1st branch.

Table- 3 Differences in length between two adjacent marks of bud scale on stem and branch for one to five shoot age classes

S.A.C.	Stem	1 st Branch	2 nd Branch
1	65.2±6.1	25.4±2.2	17.8±3.6 (mm)
2	71.5±5.3	28.5±2.1	16.3±4.4
3	82.1±6.7	28.7±2.3	16.1±5.3
4	72.9±5.2	28.2±2.0	15.5±5.5
5	69.5±5.8	27.3±2.4	13.1±4.8

Note) S.A.C=shoot age class. First numerals are mean, and second one are confidence limit calculated at 5% sig. level. Sample number is as follows; Stem=20, 1 st Branch=90, 2 nd Branch=46.

2) Synchronization of PLAS among shoot classes

a. Synchronization of PLAS among main stems

If the correlation coefficient between any two PLAS is high, this is called a high synchronization of PLAS after Okitu (1988). Correlation coefficient among all possible combinations of PLAS on TSL of each main stem were calculated as shown in Table- 4 using the data II-①. For example, in a case of main stem No. 1 (independent variable), the coefficients between five main stems of No. 2 · 3 · 5 · 7 · 10 showed significance less than 5% probability. Main stem No. 1 showed high growth synchronization as compared to many others. For example, correlation coefficient between main stem No. 1 and No. 2 is equal to that between No. 2 and No. 1. For the analysis the same coefficients are written in two places in Table- 4. The number of stems of each main stem showing high growth synchronization with a significance of 5% probability are summed in the total column. Since, there are thirty two out of ninety combinations of main stems reaching over 5% level, it can be said that 36% of combinations show high growth synchronization in these samples. For another sample as II-②, the same analysis was done. The degree of growth synchronization is summarized as 31 % of the total combinations. At the same time, there are some cases showing negative values for the coefficients. The reasons for this will be discussed after more data has been collected.

Table — 4 Growth synchronization of yearly patterns of length between two adjacent marks (PLAS) on bud scales, among ten main stems

	DV 1	2	3	4	5	6	7	8	9	10	Total
ID 1		0.693*	0.739*	-0.018	0.752*	0.561	0.719*	-0.121	0.110	0.848*	5
2	0.693*		0.758*	0.290	0.723*	0.694*	0.485	-0.096	0.633*	0.749*	6
3	0.739*	0.758*		0.112	0.742*	0.830*	0.503	-0.141	0.367	0.807*	5
4	-0.018	0.290	0.112		-0.196	0.366	0.116	0.125	0.693*	-0.019	1
5	0.752*	0.723*	0.742*	-0.196		0.361	0.219	-0.123	0.243	0.845	4
6	0.561	0.694	0.830*	0.366	0.361		0.590	-0.075	0.459	0.650*	3
7	0.719*	0.485	0.503	0.116	0.219	0.590		0.028	0.025	0.436	1
8	-0.121	-0.096	-0.141	0.125	-0.123	-0.075	0.028		0.331	-0.065	0
9	0.110	0.633*	0.367	0.693*	0.243	0.459	0.025	0.331		0.212	2
10	0.848*	0.749*	0.807*	-0.019	0.845*	0.650*	0.436	-0.065	0.212		5
Total	5	6	5	1	4	3	1	0	2	5	32

Note) Numerals in the Table indicate correlation coefficient of PLAS among main stems. Vertical column shows number of main stem set as an independent variable (ID), and horizontal one as dependent variable (DV). Total indicates total number of main stems that have significant correlation coefficients at 5% probability.

b. Synchronization of PLAS between stem and 1st branch

Growth synchronization among PLAS of TSL in stems and those in every 1st branch ramified from the same stem were analyzed using the data II-③. One main stem and twenty four 1st branches ramifying from the same main stem were treated. PLAS on stem was an independent variable of correlation as the standard, and that on 1st branch was dependent variable. Correlation coefficient between PLAS on stem and PLAS on the lowest 1st branch was calculated as 0.81. In the same way as above, the coefficients between PLAS of stem and PLAS of all 1st branches were calculated. At a 10% probability, the rate of 1st branches showing high growth synchronization to stem is 21% of the total. Nearly the same analysis was done on ten main stems of sample II-②. In these cases only ten of the 1st branches were sampled according to branching order from ground. Nevertheless, relation between rate of 1st branches showing high growth synchronization to all in each stem and number of stems was as follows; 30% for one stem, 20% for three, 10% for four and 0% for two. Overall the growth synchronization of PLAS on TSL between stems and 1st branches is recognized as 14% of 1st branches.

c. Synchronization of PLAS between 1st branch and 2nd branch

Degree of growth synchronization of PLAS on TSL between 1st branch and 2nd branch was analyzed with the data II-④, as all eight 2nd branches used ramified from the lowest 1st branch. Correlation coefficients of PLAS on TSL between 1st branch as independent variable, and TSL of 2nd branch as dependent variable were calculated. The growth synchronization (10% probability) was recognized as 25% even in eight of the 2nd branches.

3) Conclusion

It is clear that the mean length of LAS in stems is the longest, that in 1st branches is next and 2nd branches is the shortest. Growth synchronizations of PLAS on TSL are recognized as follows; 1) main stems with rates of 31~36%, 2) between stem and 1st branch ramifying from same stem with rates of 14~21% (in the maximum case the rate raises up to 30%), 3) between 1st branch and 2nd branches ramifying from same 1st branch with rate of 25%.

V. Considerations

In four methods for measuring lengths between two adjacent marks of bud scale on shoots, the value obtained by a practical method designated the FX method gives the value nearest to the true value of annual shoot elongation. In this investigation, synchronization of

yearly patterns of LAS are recognized at rates of 14~36% in three kinds of shoot order. These values are not so high, nevertheless it can be said that these values did not appear by chance. Therefore, it is considered that measurement of LAS of shoots can be one technique to analyze community architecture of Siberian dwarf pine communities.

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和 文 要 旨

ハイマツ群落は、匍匐し矮小な樹体群から形成されるにもかかわらず、亜高山帯針葉樹林と同程度かそれ以上の落量を保有する。また、地上部現存量密度が極めて高いことも特徴である。これらの特徴の発現原因は、その特殊な群落構造にあると考えられる。ハイマツ群落の大部分が国立公園等の保護地域内に生育するため、構造解析に常法である層別刈り取り法の使用は殆ど不可能である。そのため、別の手法として幹・1次枝・2次枝の年枝長の利用を試みたい。一方、す

で年枝長の地理的変化・気候条件による変動などが論じられている。しかし、ハイマツのシュートは湾曲し非常に柔軟で測定が困難であるにもかかわらず、年枝長の測定法に関する論議は無い。そこで、軸の先端を指で摘まんで引張・固定しながら隣り合う2つの芽鱗痕の間隔を測るという実際的な方法(FX法)と、自然状態のままで軸が湾曲している内側(IN法)・外側(OU法)・側面(FS法)で芽鱗痕の間隔を測るという時間・労力・風条件などから現地では適用し難い数種の方法によって年枝長調査を試みた。そして、各種の手法によって測定法の相互比較を行った。その結果、①主軸・年枝階・測定法について年枝長の分散分析を行うと測定法には有意差がないこと、②平均値から見ると実際的な方法(FX法)によった値は他のどの測定法の値より長く最も真値に近い値を与えられることが判った。すなわち、FX法の持つ意味が明らかになった。また、③主軸・1次枝・2次枝の年枝長の比較するとこの順に長いこと、④年枝長の年変化パターンは主軸間あるいは主軸・1次枝間や1次枝・2次枝間で14~36%の出現頻度をもって高い同調性を示すことが判った。この頻度は、偶然に生じたとは考えにくい。すなわち、ハイマツ群落が示す特殊な構造を解明する手法にこの年枝長の測定・解析法が使用できる。