The Estimation of Population Density of the Pine Caterpillar, *Dendrolimus spectabilis* Butler*

Kihachiro KIKUZAWA** and Tooshu FURUNO***

マツカレハ幼虫の密度推定法

菊沢喜八郎・古野　東洲

Contents

Résumé

Three density estimation methods of larval population of pine caterpillar, namely (1) faecal pellets counting, (2) shaking off insects and (3) sampling trees were comparatively studied at two Japanese red pine forest stands.

(1) The mean number of faecal pellets collected by ten traps (each of 1 m^2 in area) were divided by the mean number of pelletts produced by an individual to provide the mean larval density. The densities estimated were 114000/ha and 126000/ha in stands A and B, respectively.

(2) The numbers of larvae shaken off from trees on the traps were converted into the densities as 139000/ha and 29000/ha in stands A and B.

(3) The larval densities estimated by the regression between the numbers of larvae on a tree and its diameter were 126000/ha and 80000/ha in stands A and B.

The weight of leaves consumed by the larval populations was estimated at 5.5 ton/ha and 2.3 ton/ha in live weight in stands A and B.

---

* Contributions from JIBP-PT No. 34
This is carried out as The Special Project Research supported by the Ministry of Education "Studies on the Dynamic Status of Biosphere".
** Forest Ecology Laboratory, Faculty of Agriculture, Kyoto University, Kyoto, Japan.
*** School Forest of Kyoto University, Kyoto, Japan.

要　　旨

2つのアカマツ林分に生息するマツカレハ幼虫個体群を対象にして，3つの密度推定法により密度を推定し結果を比較した。方法は(1)糞数法，(2)振い落し法，(3)伐倒法である。

(1)：面積 $1 m^2$ の受布を林内に設置して落下糞を集めて数えた。一方，個体飼育によって個体当りの排糞数を求めた。この両者より生息密度を推定したところ，スタンドAでは，114000/ha，スタンドBでは 126000/ha であった。

(2)：設置した受布の周囲の木を強く振動させ，木に付着している幼虫を落下させた。受布内に落下した幼虫を数え，密度を推定した。スタンド A では 139000/ha，スタンド B では 29000/ha であった。

(3)：試料木を伐倒し，付着している幼虫数とその木の直経との回帰を求め，これを利用して幼虫密度を推定した。この結果はスタンド A で 126000/ha，スタンド B で 80000/ha であった。

(4)試料木の葉量から林分当りの葉量を推定し，幼虫個体群による葉の消費量を推定した。その結果は生重量で，スタンド A では 5.5ton/ha，スタンド B では 2.3ton/ha であった。

Introduction

In view of the many studies progressing on production ecology, it becomes very necessary to give proper estimation of the amount consumed by the natural insect population inhabiting forest stands. The density estimation as well as the amount of consumption by an individual is the basic information necessary for this purpose.

The pine caterpillar, chosen for this study, is one of the most important defoliators of pine trees in Japan. Several investigators, therefore, have paid much attention to this insect: FURUNO,[1] for example, studied the food consumption by an individual larva; KOKUBO[2] investigated the mortality factors of eggs, larvae and pupae, while KANAMITSU[3] drew suvivourship curves of the insect in a nursery. However, few investigations have been made on the density estimation in the forest of this insect. On the other hand, several methods have been deviced to assess forest crown insects other than the pine caterpillar. MORRIS[4], TINBERGEN[5], KLOMP[6], for example, sampled the twigs or branches of the forest trees and estimated the population density of insects. Several investigators[5,7~11], used the faecal pellets as a population index. The method, if feasible and precise, could be used for the estimation of long term density fluctuations. We used the BHC smoking method for the estimation of absolute density.[12,13]

In the present study, three methods, namely (1) faecal pellet counting, (2) shaking off insects and (3) sampling tree, were applied to the larval populations of pine caterpillar at two Japanese red pine forest stands and estimations of the leaf consumption by the population were also made. The results of the density estimation were compared on the basis of the absolute term of density per unit ground area.

The authors are pleased to acknowledge the assistance of various members of the Ibaragi Prefectural Forest Experimental Station, especially Mr. Tetsutaro FUKASAKU the chief of the Institute and Mr. Hideaki KONDO the chief of Division of Forest Protection of the same Institute. They also wish to express their thanks to Miss Keiko HIRAMOTO for correcting the English text. Finally, their thanks are due to Prof. Tsunahide SHIDEI and the members of the Forest Ecology Laboratory of Kyoto University for their critical discussion.

Sampling Site

The investigations were carried out in a Japanese red pine (*Pinus densiflora*) forest near Yatabe town Ibaragi prefecture, Japan.

The forest was composed of two stands, stand A and stand B, of different tree densities and heights. The tree density and the mean tree height in stand A were about 4500 trees/ha and about 6.0 m, respectively; while those in stand B were about 3000 trees/ha and 7.5 m respectively.

The investigations were carried out from the 19th to 23th in June of 1967.

Three and four plots in stand A and stand B of 200–400 m^2 in area were measured out, and the diameter at breast height (D) of every tree in each of the plots was measured.

Methods

The three methods applied for the density estimation of the insects, were the faecal-pellets counting, shaking off insects and sampling tree.

(1) Faecal pellet method

Ten traps each of 1 m×1 m of surface area were set ramdomly in each stand to collect the fallen faecal pellets of the insects. These traps were made of cloth to form an inverse funnel.[13] The faecal pellets in the traps were collected twice after 24 hours and 48hours, and brought back to the laboratory. The number of faecal pellets were counted, oven-dried and weighed in the laboratory.

In addition, ten larvae were collected in each stand and put into separate polyethylene bags. They were fed with pine needles. The bags used as breeding cages were 30 cm in width and 70 cm in length, and many perforations were made by needles to facilitate the circulation of air. After 24 and 48 hours, the faecal pellets in the bags were collected, counted and brought back to the laboratory to be weighed.

(2) Shaking off method

After the faecal pellets counting, the shaking off method was conducted utilizing the same traps used previously. The pine treees near the traps were heavily shaken. The larvae shaken from the trees which fall on the traps were collected, preserved in bottles with 80% alcohol and brought back to the laboratory. The head width of the larvae having been measured in the laboratory, they were oven-dried and weighed.

(3) Sampling tree method

After considering the results of the diameter measurement, seven and ten representative trees in stands A and B respectively were selected for cutting. Spreading large sheets on the ground, the trees were cut so that they fell on the sheets. Immediately after the cutting, the larvae and cocoons on the fallen trees were collected. They were preserved and brought back to the laboratory and measured, oven-dried and weighed.

The diameter at breast height of the fallen trees was measured. The old and the new leaves were weighed separately. Random samples of each part were brought back to the laboratory, oven-dried and weighed.

Results and Discussion

(1) The head width and body weight of the larvae

The frequency distribution of the head width of the larvae is shown in Figure 1. The frequency distribution shows a similar bimodal pattern in both stands A and B, indicating that the population of both stands were composed of larvae of similar stages, though somewhat larger

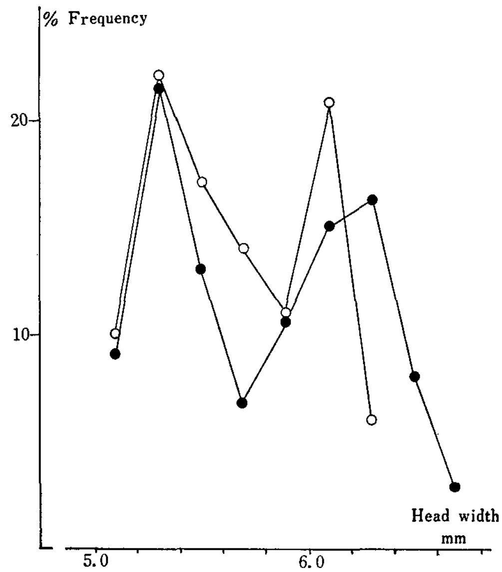

Figure 1. Per cent frequency distribueion of head width of the larvae
○ Stand A
● Stand B

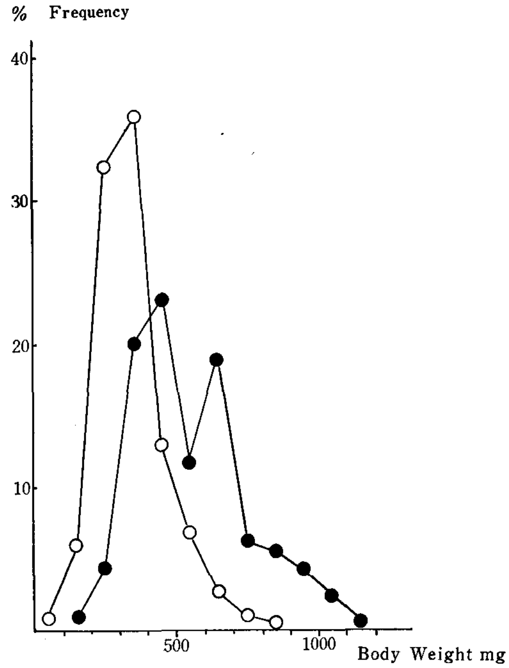

Figure 2. Per cent frequency distribution of body weight of the larvae
○ Stand A
● Stand B

larvae were found in stand B. According to AINO et al[14], these head width correspond to the 8th or the 9th larval stage. The distributional patterns of the frequency of the larval body weights

Table 1. Numbers and weights of faecal pellets collected by traps in each stand

Trap No.	Stand A				Stand B			
	1st day		2nd day		1st day		2nd day	
	number /m²	weight mg/m²	number /m²	weight mg/m²	number /m²	weight mg/m²	aumber /m²	weight mg/m²
1	173	963	173	1134	220	2212	181	1799
2	173	1204	200	1656	160	1561	151	1405
3	192	1187	200	1533	173	2377	157	1754
4	132	739	146	910	324	4774	330	3418
5	113	725	140	1155	176	2190	99	812
6	83	385	84	439	195	2202	215	2534
7	127	781	157	817	257	3672	222	2083
8	157	966	170	1028	101	1012	74	564
9	95	416	78	445	136	1687	113	1059
10	148	763	133	786	157	1663	118	1180

shown in Figure 2, however, were significantly different between the two stands. The mean individual body weights were 377 mg (oven-dry) and 625 mg in stand A and B, respectively. This indicates that some factors other than larval stage affected the larval weights, especially in stand A.

(2) Density Estimation

a. Faecal pellet method

The number and weight of faecal pellets per square meter per day are shown in Table 1. The mean number and weight of faecal pellets were 144 pellets/m^2·day, 902 mg/m^2·day in stand A and 174 pellets/m^2·day, 200 mg/m^2·day in stand B. On the other hand, the mean value of the number and weight of faecal pellets by individuals per day estimated by the breeding experiments were 12.7 pellets/individual·day, 123 mg/individual·day in stand A and 14.2 pellets/individual·day and 115 mg/individual·day in stand B, respectively.

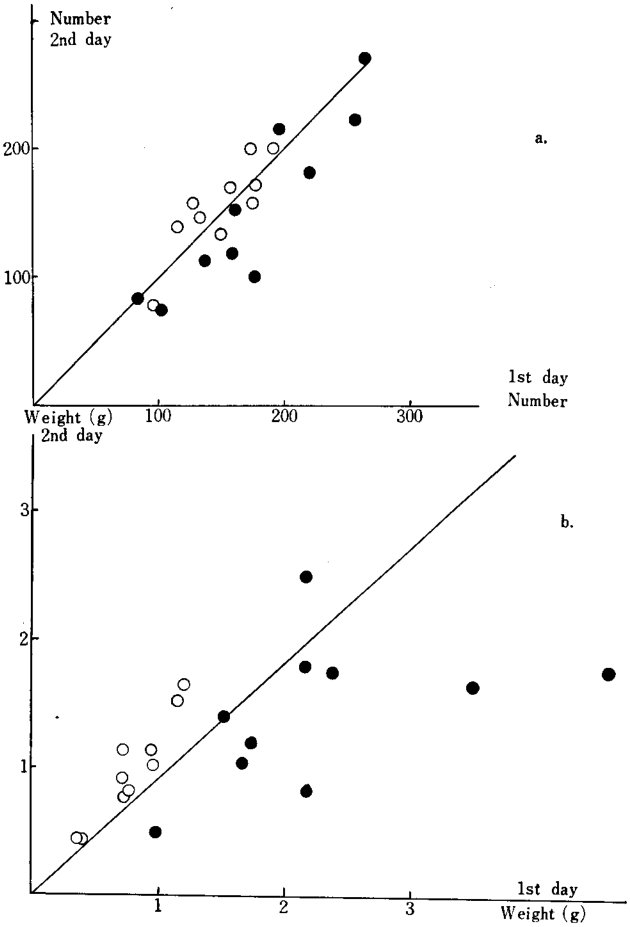

Figure 3. The relation between faecal petlts collected at the first day and those at the second day a. Number b. Weight
○ Stand A ● Stand B

The next problem was to determine which parameter, the number or weight of faecal pellets, should be used for density estimation. To solve this problem, the stabilities of the number and weight of faecal pellets in each of the traps between two successive sampling days were examined as shown in Figure 3-a and -b. As shown in Figure 3, the variation between the two days seems to be larger in faecal weight than in number, and, therefore, the number was adopted as the parameter for density calculation.

Though there were great variations of faecal number among traps and among breeding bags, the mean larval density can be easily calculated by dividing the mean number in the traps by the mean number by individuals.

The mean densities calculated thus were 11.4/m^2 and 12.6/m^2 in stands A and B, respectively. These correspond to 114000/ha and 126000/ha in stands A and B. The 95% confidence intervals were calculated as 94900–132800/ha and 96000–157000/ha in stands A and B.

b. Shaking off method

The individual numbers of larvae fallen on the traps by shaking were shown im Table 2. The mean larval numbers were 13.9/m^2 and 2.9/m^2 in stand A and stand B, corresponding to 139000/ha and 29000/ha, respectively. The 95% confidence intervals were 128000–150000 for stand A and 19000-39000 for stand B.

Table 2 Number of larvae shaken on the traps (each of 1 m² in area)

Trap No.	Stand A	Stand B
1	17	4
2	20	4
3	12	4
4	13	5
5	11	2
6	10	4
7	16	2
8	32	0
9	11	2
10	15	2

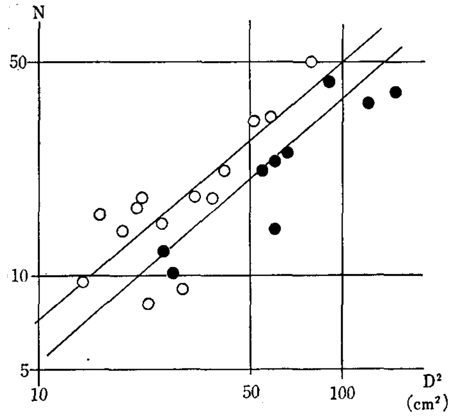

Figure 4. The relationship between the numbers of larvae (N) on a tree and its diameter (D)
○ Stand A ● Stand B

c. Sampling tree method

The relationships between the diameter at breast height (D) of the sample tree and individual number of larvae on it (N) are shown in a double logarithmic scale (Figure 4). The regression lines were determined by the least square method in the two stands as;

in stand A

$$\log N = 0.8313 \log D^2 + 0.0209$$

in stand B

$$\log N = 0.7931 \log D^2 - 0.0741$$

The regression line in stand A is significatly different from that in stand B, that is to say, more larvae lived on the similar diametered tree in stand A than in stand B.

The larval densities were calculated at 126000/ha and 80000/ha in stands A and B respectively by substituting the values of diameter of all trees in both stands into D in the above equations. The 95% confidence intervals of the mean larval numbers per hectare were: 102200-133000 in stand A and 66800-95300 in stand B.

d. The number of cocoons

The number of cocoons can not be counted by the faecal pellets method or shaking method. The ratio of cocoons to larvae obtained by samples taken from the cut trees, then multiplied to the estimated larval density per hectare, provided cocoon density per hectare. The number of cocoons per hectare estimated thus were 29700/ha and 20400/ha in stands A and B, respectively.

e. The biomass of larvae

The biomass of larvae was estimated by using the relationship between the diameters of trees and the weight of the larvae on the trees. As shown in Figure 5, these relationships were not significantly different between the two stands. That is to say, the weight of larvae on trees of the same size in both stands was similar. This relationship was calculated by the least square method as;

$$\log w = 1.0340 \log D^2 - 0.0720$$

where w is weight of larvae on a tree and D is diameter of the tree. The larval biomass was calculated as 47.5 kg/ha and 51.9 kg/ha in dry weight in stand A and B, respectively.

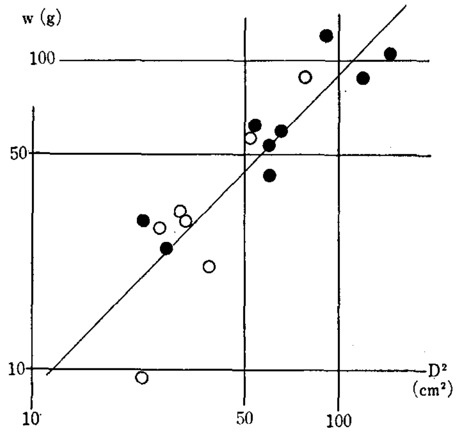

Figure 5. The relationship between the weight of the larvae (W) on a tree and its diameter (D)
○ Stand A ● Stand B

Table 3 The 95% confidence intervals of the mean larval density per hectare estimated by the three methods

Method	Stand A	Stand B
Sampling tree	102200-133000	67000- 95000
Shaking off	128000-150000	19000- 39000
Faecal pellet counting	95000-133000	96000-156600

f. Comparison of the results

The 95% confidence intervals of the mean larval densities in terms of individual numbers per hectare estimated by the above three methods are shown in Table 3 for comparison. In stand A there were no significant differences in estimated larval numbers, while in stand B, significantly different numbers were obtained by the three methods. As mentioned before, the shaking off method is not suited to forests of large trees, since it is difficult to shake all insects off trees successfully as in the case of stand B.

The density values of larvae estimated by the shaking off and sampling tree methods were higher in stand A than in stand B, while those estimated by the faecal pellet method were, conversely, higher in stand B than in stand A. These variations seem to be due to over estimation in stand B or under estimation in stand A or both. As shown before, the mean individual weight in stand A became smaller and, accordingly, the amount of faeces, both in number and weight, might become less due to high density and the lack of available food in stand A. While in stand B, the larval density might not have been so high to affect the individual weight or amount of faeces. These assumptions may explain the reasons for the different estimation of density by the faecal pellet method.

In addition to the density effect, other factors affect the precision of faecal pellet method such as temperature, moisture, quantity of food and natural enemies were pointed out by several authors.[10)15)16)] Beside these, there are still other kind of sources of errors in using this method if applied to natural forest stands, such as faeces being caught by spider's webs or the lower branches and leaves; the difficulties of identification of faeces if other species exist.

(3) Estimation of leaf consumption by the population

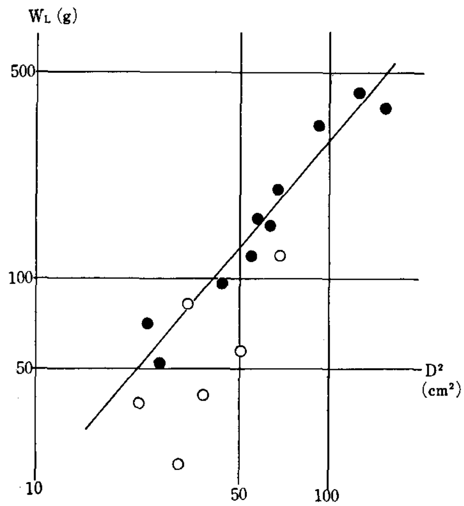

Figure 6. The relationship between the weight of leaves (W_L) of a tree and its diameter (D)
○ Stand A ● Stand B

The biomass of leaves were estimated using the regression between the leaf weight of an individual tree and its diameter. As shown in Figure 6, in the relationship between the leaf weight and square of diameter, there were great variation among the trees in stand A. This may be due to heavy ingestion by large number of larvae. The leaf biomass in stand A was estimated using the leaf weight-basal area ratio. The biomass of old and new leaves were calculauted by multipling the old and new leaf ratio of the sample to the total leaf biomass. The leaf biomass was 3.5 ton/ha in stand A and 7.4 ton/ha in stand B in live weight. According to SATOO[17)] the leaf biomass of the Japanese red pine forest is generally about 12 ton/ha in live weight. Compared with this, the values estimated in the present study was too small presumably due to ingestion by insects.

The present study was carried out in June, however, it was still the growing season of the new leaves, and moreover, pine caterpillar attacked the old leaves first. Therefore, to use only the old leaves for the calculation of the leaf biomass loss was adequate. The old leaf biomass were estimated at 1.2 ton/ha and 4.4 ton/ha in live weight in stands A and B, respectively. The old leaf biomass of a Japanese red pine forest of similar age and stand density to the stands of the present study was assumed by SATOO[17)] to be about 6.7 ton/ha. The old leaf biomass loss, therefore, can be calculated by subtracting 1.2 and 4.4 ton/ha from 6.7 ton/ha in stands A and B respectively; 5.5 and 2.3 ton/ha. The values used in the above calculation were based upon rather uncertain estimations or hypotheses, and, therefore, the values obtained above may remain the rough estimate of consumption. Further investigation, such as seasonal fluctuations of population density as well as other factors affecting the food consumption of individuals would be necessary.

Literature

1) FURUNO, T.: On the Feeding Quantity of the Pine Caterpillar (*Dendrolimus spectabilis* BUTLER), J. Jap. For. Soc., **45**, 368～374, (1963)**
2) KOKUBO, A.: Population Fluctuations and Natural Mortalities of the Pine-Moth, *Dendrolimus spectabilis*, Res. Popul. Ecol., 7, 23～34, (1965)
3) KANAMITSU, K.: Survival Curves of the Population of *Dendrolimus spectabilis* BUTLER (Lep., Lasiocampidae)., Res. Popul. Ecol., **4**, 60～64, (1962)
4) MORRIS, R. F.: The Development of Sampling Techniques for Forest Insect Defoliators, with particular Reference to the Spruce Budworm, Canad. J. Zool., **33**, 225～294, (1955)
5) TINBERGEN, L.: The Natural Control of Insects in Pinewoods, 1 Factors Influencing the Intensity of Predation by Song Birds, Arch. Néel. Zool., **13**, 266～344, (1960)
6) KLOMP, H.: The Dynamics of a Field Population of the Pine Looper, *Buparus piniaris* L. (Lep., Geom.), in Advances in Ecological Research, 3, edited by J. Cragg, 207～305, (1966)
7) BEAN, J. L.: Frass Size as an Indicator of Spruce Budworm Larval Instars, Ann. Ent. Soc. Amer, **52**, 605～608, (1959)
8) MORRIS, R. F.: Sampling Insect Populations, Ann. Rev. Ent., **5**, 243～264, (1960)
9) NOLTE, H. W.: Über den Kot von Fichten und Kieferninsekten, Tharander Forst. Jahrb., **90**, 740～761, (1939)
10) GÖSSWALD, K.: Über die Frasstätigkeit von Forstschädlingen unter dem Einfluss von Altersuntershieden und der Einwirknng verschiedener Temperature und Luftfeuchtigkeit und ihre praktishe und physiologische Bedeutung, 1. Unterschung an *Dendrolimus pini* L. Z. ang. Ent., **21**, 183～207, (1934)
11) CAMPBELL, R. W.: The Analysis of Numerical Change in Gypsy Moth Populations, For. Sci. Monogr. **15**, 1～33, (1967)
12) KIKUZAWA, K. & T. SHIDEI: On the Sampling Technique to Estimate the Density and the Biomass of the Forest Arthoropods, Jap. J. Ecol., **16**, 24～28, (1966)**

13) ——, ——: On the Biomass of Arthropods of the Japanese Red Dine Forest in the Vicinity of Kyoto, Bull. Kyoto Univ. For., 39, 1~8, (1967)**
14) AINO, S., F. YAMADA, I. KOBAYASHI and S. YAMAZAKI: Studies on the Ecology of pine Caterpillar (5) The Relation between Growth and Head Width, Rec. Meet. Jap. For. Soc., 74, (1963)*
15) SOUTHWOOD, T. R. E.: *Ecolcgical Methcds*, London, pp. 391, (1966)
16) ESCHERICH, K.: *Die Forstinsekten Mitteleuropas*, Berlin, pp. 825, (1931)
17) SATOO, T., K. NAKAMURA and M. SENDA: Materials for the Studies of Growth in Stands, I. Young Stands of Japanese Red Pine of Various Density, Bull. Tokyo Univ. For., 48, 65~90, (1955)**

---

* in Japanese
** in Japanese with English Summary