

A STUDY OF SOME FACTORS INFLUENCING THE  
ABUNDANCE OF ADELGES COOLEYI (GILL.) ON DOUGLAS FIR.

by

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## ABSTRACT

A study was carried out to determine factors which influence the abundance of Adelges (Chermes) cooleyi Gill. on Douglas fir. This was done through the observation of populations in the field, supported by some laboratory work designed to show that certain influences are important. The work was done during the summer of 1960 in a young stand in Totem Park near Marine Drive and Agronomy Road on the U.B.C. campus, Vancouver.

The following items were investigated: 1.) Inter tree differences, 2.) Intra tree variations, 3.) Population changes with time, 4.) Mortality of the insect.

Abundance was affected by extrinsic influences on the trees, such as location and exposure and intrinsic factors such as time of bud opening and twig length.

Within a tree the abundance of Adelges cooleyi was affected mostly by microclimatic factors, resulting in high abundance of the insect in the peripheral part of the lower crown.

The average number of living insects decreased with time rectilinearly in generation 1 (Sexuparae and Progredientes) and logarithmically in generation 2 (Neosistens). A critical period during establishment of generation 2 caused the logarithmic changes.

Mortality estimates by direct counts were subject to a large error because many of the dead insects fell off.

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INTRODUCTION.

The cooleyi spruce gall aphid Adelges (Chermes) cooleyi (Gill.), as a pest of Douglas fir and Sitka spruce, varies in abundance from year to year, place to place, and even between trees in the same locality. It is so variable in numbers as to merit examination of the factors influencing its abundance.

The insect and its secondary host, Douglas fir, Pseudotsuga Menziesii var. Menziesii (Mirb.) Franco, offer a unique opportunity for the study of environmental influences on an insect. The insect lends itself well to observation and sampling because it is sessile during most of its life, and is thus suitable for quantitative work. Douglas fir is so variable in its phenology that a wide range of phase relations between it and A. cooleyi may be found.

The cooleyi spruce gall aphid was named and described by Gillette in 1907. He called the generations on spruce: Chermes cooleyi, and generations on Douglas fir Chermes cooleyi var. cowenii. In 1914 Chrystal's (6) experiment proved that, Gillette's Chermes cooleyi var. cowenii is the colonici stage of Chermes cooleyi. Annand changed the name of the subfamily to which the species belongs in 1928, from Chermisinae to Adelginae, because the former name had been earlier used for the psyllids groups (7).

No detailed work has been done about the factors influencing the abundance of A. cooleyi on Douglas fir. The fact has been stated by Chrystal (7) and Cameron (4), that Adelges cooleyi is more abundant on young trees in

the nursery and just after plantation (23). Chrystal (7) mentioned that in a dense wood of Douglas fir the cooleyi spruce gall aphid was found chiefly on the trees near the margin and was not present in the centre of the plantation. He has also stated that the insects were more frequent on the lower and middle branches of the trees. Both in England and Germany it has been established that, Pseudotsuga Menziesii var. glauca (Beissn) Franco is more resistant to A. cooleyi than the Pseudotsuga Menziesii var. Menziesii (Mirb.) Franco.

The main biotic factors - affecting the abundance of A. cooleyi - are the natural enemies. According to the present knowledge the insect is attacked by comparatively few enemies. Two species of Syrphidae were found by Cumming (10) which attack the exposed forms on Douglas fir, and eggs of Syrphidae were also found in one gall cavity on spruce. The yellow and black Ladybird beetle is known to feed on Adelges on Douglas fir (7). Several authors have noted large numbers of Spiders and Red-Spider-Mites feeding on A. cooleyi. Gyorfi (17) has mentioned that Hymenopterous parasites of the family Chalcididae attack certain species of European Adelges.

Heavily infested Douglas firs are not killed directly by Adelges, but are so reduced in vigour that they are more susceptible to attack of secondary insect and disease. The cumulative effect of the attack probably reduces the rate of growth, reducing the active surface of assimilation, resulting in reduced food supply (12, 13). Although the trees are not killed by Adelges, it is recommended that Douglas fir and Sitka spruce mixture not be planted on unsuitable site or localities. The most critical stage in the life both of Douglas fir and Sitka spruce is just after the plantation has been made (7).

## MATERIALS AND METHODS

### 1. The Insect:

Two generations of the A. cooleyi were the main material of the experiment, established to examine the factors influencing their abundance. Adelges cooleyi prefers two different species of host-trees in its complete life cycle. In the Pacific Coast the primary host is Sitka spruce (Picea sitchensis (Bong.) Carr.), and the secondary host is Douglas fir (Pseudotsuga Menziesii var. Menziesii (Mirb.) Franco). The complete life cycle of A. cooleyi consists of 5 "generations" (Fig. 1):

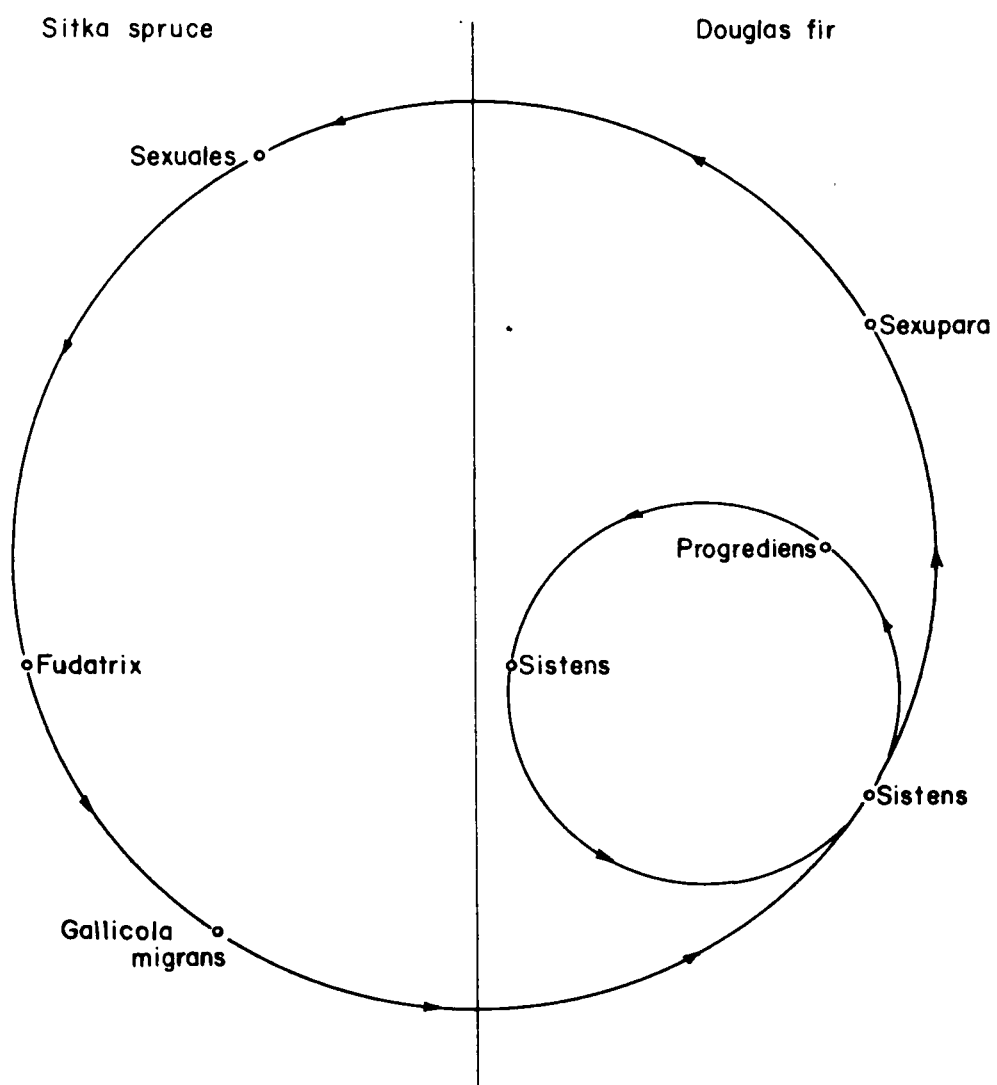
#### Fundatrix Generation:

The first-stage larva of fundatrix overwinters on a Sitka spruce terminal twig adressing its body to the twig, and sunking its stylet deeply into the tissue through bark fissures. Passing through the winter in this stage, they become active in the first part of April, and begin to feed. The fundatrices are reported to have three larval instars (9, 10). These larval stages are present for a relatively short time in the spring.

The first-instar larvae are dark brown with slightly greenish colour. The general appearance the second-instar larvae resemble the adults, having thinner cuticle. The adults are dark brown with a green tinge (10). The body of the adult or stem-mother is covered with a white wax-mass, under which she lays a large number of eggs (150-350) (10) at the end of April.

#### Gallicola Migrans:

The gallicolae migrantes are the gall-forming generation on spruce. This generation is the progeny of fundatrices. This summer generation hatches about 10 - 15 days after the eggs are deposited by the stem-mothers, and migrates to the inner bases of young needles, which are just breaking from the bud at this time. As soon as they have settled, they begin to feed, and galls begin to develop, caused by some stimulation, induced by the feeding



**Fig. 1 The life cycle of *Adelges cooleyi***

insect (14). This stimulant is supposed to be an auxin (1, 26).

The gall varies in length from 1 - 5 inches, varying with the vigour of the twig attacked (18). The number of chambers within the gall ranges from 40 to 200, the number of young in each chamber varying from 1 to 15, with an average of 5 (6).

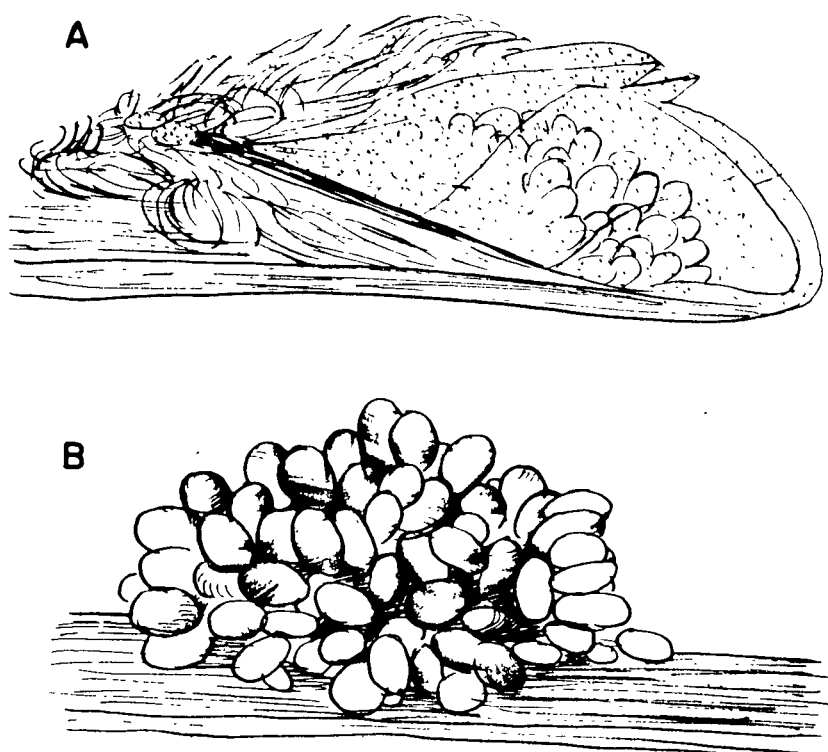
The larvae go through four instars within the galls (9, 10). The reddish-brown coloured larvae are covered with a fine powdery wax. The wing pads can be seen at the third-instar. They emerge from the galls in the fourth-instar and settle on the needles, and moult to the adult stage. The parthenogenetic adults are reddish-brown with a well sclerotized thorax. They fly to the Douglas fir, where being settled for a few days, they secrete wax from the anterior margin of the head and the abdomen. The wax from the abdomen and the wings protects the eggs which they lay. The average number of eggs laid was found to be 65 of 10 counts (9, 10) (Fig. 2).

#### Sistens (Fundatrix spurial):

The sistens are the overwintering stage on Douglas fir. They are progeny of the gallicola migrans or progeny of the second generation of wingless females, staid on Douglas fir on the previous summer. Chrystal (6) says that the sistens hatch 6 - 7 days after the oviposition. This period has been stated by Cumming (10) as about three weeks. In the present study the time required in 1960 was 2 or  $2\frac{1}{2}$  weeks. The youngs settle on the lower surface of Douglas-fir needles, and pass the winter in this stage. This dormant form of sistens generation used to be called neosistens (Fig. 4).

This generation was one subject in the experiment, and was sampled 8 times during the summer of 1960. This generation will be called generation 2 in the further part of the thesis.

The neosistens are light-brown with a darker prothorax and head. It is unlikely that this stage feeds before going into the dormant condition.



**Fig. 2** A, *Gallicola migrans* with wings closed laying eggs on fir needle (X 20)

B, Egg-mass produced by *Gallicola* or *progrediens* (X 30)



However, they move from the needle after being hatched, looking for suitable needles to overwinter, where they press their bodies to the underside of the needles, inserting their stylets into the mesophyll tissue. This insertion is believed to afford additional anchorage, rather than providing food. When settled, they secrete a fringe of white wax around the edge of the body.

The first moult occurs in the spring. The body of the second-instar larvae is covered with wax. The adults are similar to the second-instar larvae but with more wax. The adults are parthenogenetic females, laying from 30 to 40 eggs (6).

There are two kinds of progeny of the sistens:

a.) The progredientes, being wingless parthenogenetic females.

They remain on Douglas fir.

b.) The sexuparae, being winged parthenogenetic females. They migrate to spruce.

The proportion of these two forms varies widely. Chrystal (6) found that about 50% of the brood was sexupara in Stanley Park in 1915. Three counts are given by Cumming (10) from the Kananaskis Forest Experiment Station (Table 1).

Table 1. Relative numbers of sexuparae and progredientes on Douglas fir in three counts.

Date	Number counted			Per cent of Sexuparae
	Sexuparae	Progredientes	Doubtful <sup>1</sup>	
6 - VII - 55	63	5	16	75
15 - VII - 55	72	4	0	95
3 - VII - 57	84	76	11	49

The Sexuparae and Progredientes:

They hatch about a week after oviposition. Hatching begins about the time when the buds start to open. After hatching they move to the needles

<sup>1</sup>Larva too small to distinguish form.

and develop into winged adults (Sexuparae) or wingless adults (Progredientes). The larvae and the seasonal development resemble generation 2, being light yellow-brown, but become darker and darker as they pass through the moults. The larvae resemble those of the gallicolae, but the gallicolae have more glands. Wax can be found on the dorsal and ventral surfaces of the head during the larval stage.

There are four larval instars, three of them similar in morphology of the two forms. Wing pads are present on the fourth instar larvae of sexuparae.

The generation of sexuparae and progredientes was also material of the experiment, being sampled 5 times during the summer of 1960. The progredientes and sexuparae were not observed separately, because there was no reason to treat them separately for the subject of the experiment. This generation will be called as generation 1 in the further part of the thesis.

#### Sexuparae:

The adults of sexuparae are winged parthenogenetic females (Fig. 3). Wax is present on all parts of the body, except the ventral surface of the abdomen, the adults are heavily sclerotized. The eyes, head and metathorax are dark grey-black, and the remainder of the body is brown. The wings are grey with green bases and greenish-gray costa.

They migrate back to spruce, settle on the needles, then lay 5 - 20 eggs (10). The eggs are protected by wax and the folded wings of the female.

#### Progredientes:

The adults of progredientes are wingless parthenogenetic females (Fig. 4), resembling the sistens. They stay on Douglas fir. The number of eggs laid by Progredientes is variable. Chrystal (6) has stated that they lay 30 - 40 eggs. The average number of eggs is given as 15 with a range from 3 to 25 in 11 counts by Cumming (10). Fifteen egg-clusters were counted in Totem

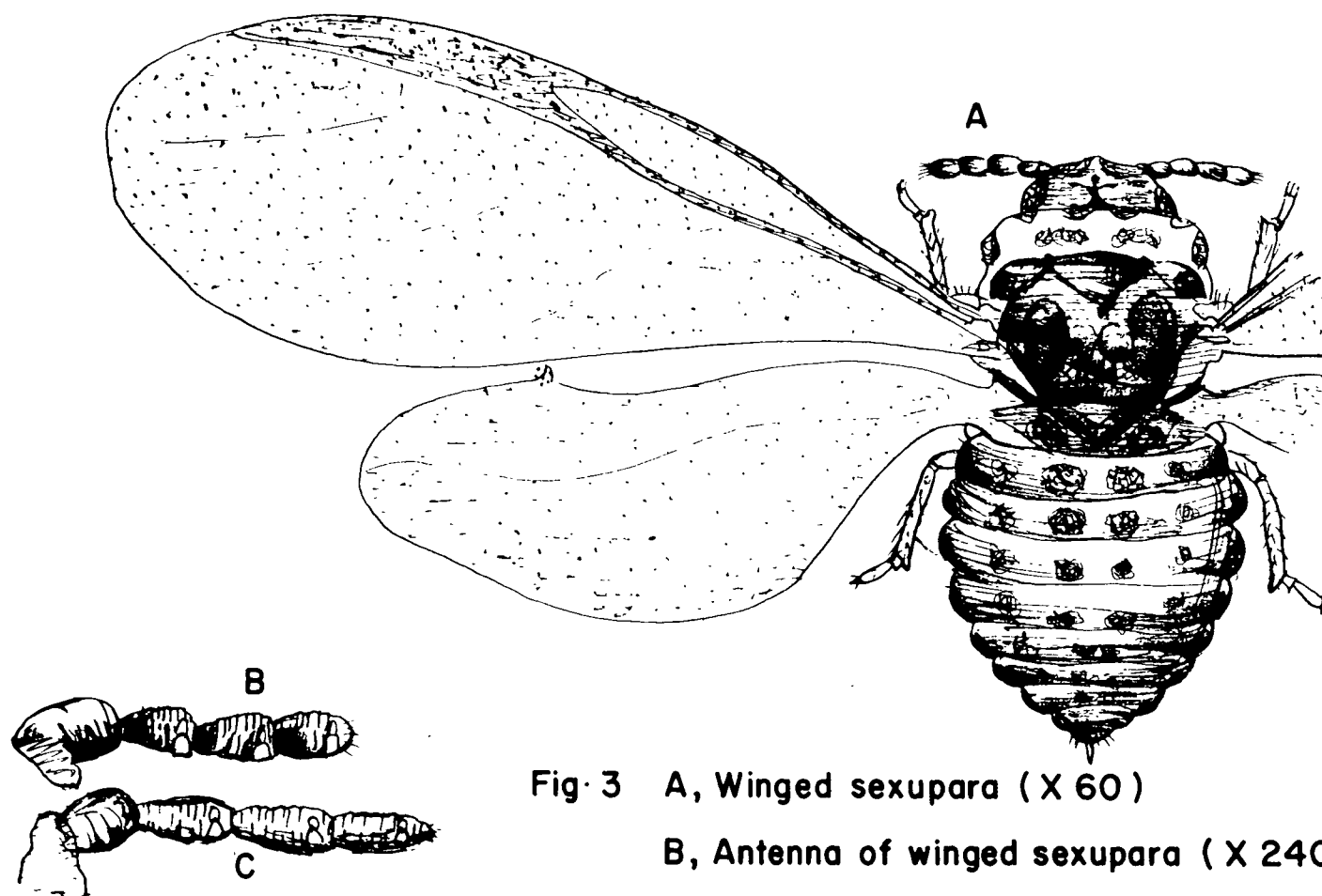


Fig. 3 A, Winged sexupara (X 60)

B, Antenna of winged sexupara (X 240)

C, Antenna of winged gallicola (X 210)  
(After Chrystal)

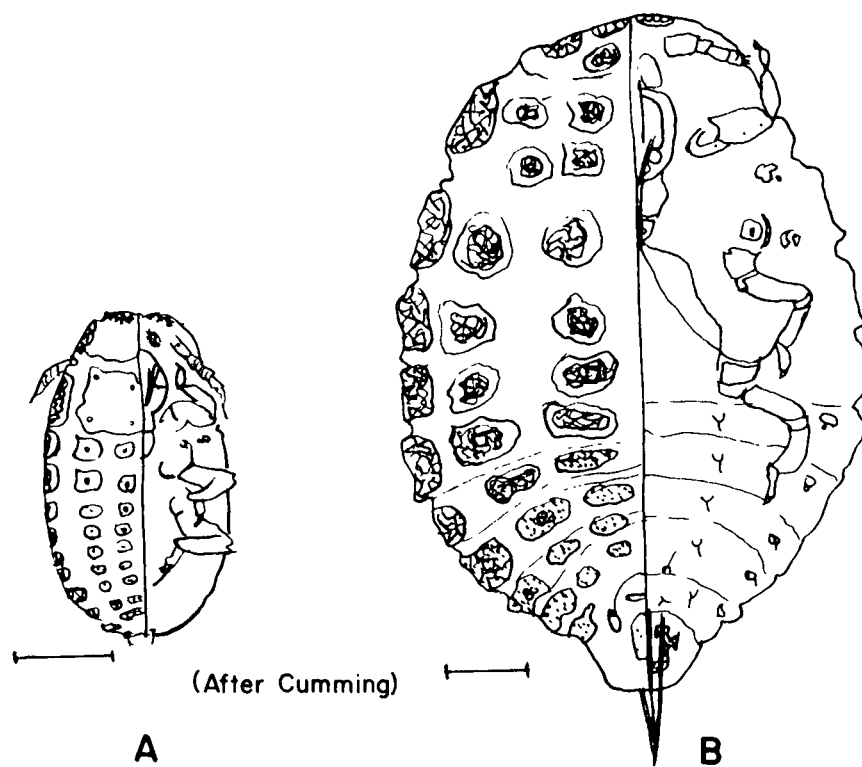


Fig. 4 A, *Sistens* nymph, first instar

B, *Progrediens* adult

Park on June 25, 1960. The average of these was 27, with a range from 5 to 43.

Progredientes hatch 2 - 3 weeks after oviposition, and overwinter in this undeveloped stage (Neosistens). Consequently a subcycle of the life cycle can be found on Douglas fir (Fig. 1), consisting of two generations: Sistens (Neosistens) and Progredientes (Sexuparae) (28). This means that the Adelges cooleyi can develop without its primary host.

#### Sexualis Generation:

This is the one generation of the Adelges cooleyi where sexual reproduction occurs. This generation is not described well in most of the literature. Chrystal (6) did not observe this generation in B. C., but later (7) he found the generation in Britain. Still later Annand in California, Cameron (4) in Britain, Francke-Grosmann (14) in Germany and Cumming (10) in Alberta recorded the sexual generation.

The most detailed report on this generation was given by Cumming (9, 10). According to him they hatch a week or more after the oviposition of the sexuparae. Chrystal (6), and Cameron (4) found 5 larval instars. Cumming (10) distinguished 3 only. It is possible that the first two instars can be so similar, that they were not distinguished (10).

The colour of the larvae is reddish-brown. The adults move back from the present year growth to the old growth, as far as 4 - 5 years-old twigs. This habit of moving back helps them in the mating, helping the male find the female. They lay eggs between the old bud scales and twigs. The female secretes wax, which surrounds but does not cover completely the egg. It is believed that the female lays only one egg (10, 14).

#### Morphology of Adelges cooleyi:

The description of the generations presented here will not be complete, only the differences between the generations will be pointed out. The most

remarkable differences can be seen in the gland facets, in their shapes and sizes. There are also differences in the arrangement of the plates on which the gland facets occur. The ventral plates are slightly sclerotized, and always have small round gland facets. The dorsal plates are heavily sclerotized, being in three pairs, showing a single transverse row on each segment. This row is arranged from the mesothorax to the sixth or seventh segment of the abdomen. Two rows can be found on the head and prothorax. The central pair of glands on the dorsal surface is called "mesial", the one beside them "pleural", and the lateral one is "marginal" (10).

#### Fundatrix:

All the dorsal gland facets of the first-instar larvae are angular in form, and everyone is well outlined except those on the sixth and seventh segments of abdomen. The posterior plates of the adults have a higher proportion of round gland facets. They also have angular gland facets which are not so large as those of the sistens and progredientes (10).

#### Gallicola Migrans:

The first-instar larvae have only setae on the thoracic and abdominal segments. These larvae are the smallest of all generation of Adelges cooleyi. The number of gland areas increases instar after instar. The fourth-instar resembles the adult, but the gland areas are smaller on the abdomen. The gland facets of the dorsal surface of the adult are round. The gland areas of the head and thorax are constant. These areas vary on the abdomen. The mesial areas of the abdomen are fused at the centre line, and the pleural areas are broken up into small groups of gland facets. The hamuli on the hind wing varies from 2 to 5.

#### Sexupara:

The first-instar larva has setae surrounded by small plates. The adults have large variation in the number and arrangement of gland areas on the

abdomen. The antennae are shorter than those of the gallicola (Fig. 3).

The hamuli on the hind wing is varying from 1 to 4 (10).

#### Sistens and Progrediens:

The first-instar sistens larva can be distinguished by the appearance of the plates. Two sclerotized areas cover the head which are separated at the centre line. Gland facets can be found on these areas anteriorly and laterally. On each side of the prothorax a large sclerotized area can be found, each of them is fused from four plates. The mesial, pleural and marginal areas of the mesothorax, metathorax and the abdominal segments, from 1 to 4 have rectangular plates. Gland facets can be seen on the fifth, sixth and seventh abdominal plates. The gland facets resemble those of the fundatrix larvae.

The larvae of the progrediens resemble the sistens, but they have more glands at the lateral margins and the reticulations are more conspicuous.

The separation of the sistens and progredientes can be done by the gland facets on the anterior mesial plate of the prothorax and by the pleural plate of the first abdominal segment. The sistens has smaller number of gland facets in both areas than the progrediens, and the whip of the antenna is shorter than in that of the progrediens. More sistens have gland area on the hind coxa than progredientes (10).

#### Sexualis:

The male and female cannot be distinguished in the first-instar. The last-instar female has a wax gland at the posterior end. The adults are smaller than any of the generations. Setae are present on the head thorax and abdomen of the male, where gland areas can be seen on the other forms.

## 2. The Stand:

The place of the experiment was Totem Park and its surrounding planted stand. The main component of the stand is Douglas fir. Three age classes can be found: most of the trees are 24 - 26 years old, but some 20 and 28 - 29 years old trees are also present. The oldest class seems to be natural regeneration, and the two younger classes are planted. The main material of the plantation was Douglas fir, with some Sitka spruce. Some other tree species are also present as a result of natural regeneration. The vegetations of three layers of the forest, as tree crown layer (A), shrub layer (B) and ground vegetation (C) are the follows:

### The Vegetation of the Forest:

A level: crown closure: 95%

*Pseudotsuga Menziesii*

*Thuja plicata*

*Tsuga heterophylla*

*Picea sitchensis*

*Taxus brevifolia*

*Alnus rubra*

*Acer macrophyllum*

*Prunus* sp.

B level: closure 20 - 25%

*Gaultheria shallon*

*Sambucus pubens*

*Rubus spectabilis*

*Rubus vitifolius*

*Rosa gymnocarpa*

*Rubus parviflorus*

*Symphoricarpus rivularis*



*Vaccinium parviflorum*

*Physocarpus capitatus*

C level: closure 25 - 30%

*Polystichum nunitum*

*Pteridium aquilinum*

*Sorbus sitchensis*

*Dryopteris austriaca*

*Sambucus pubens*

*Claytonia silirica*

*Trientalis latifolia*

*Galium triflorum*

*Dicentra formosa*

*Pseudotsuga Menziesii*

*Tsuga heterophylla*

*Acer macrophyllum*

In the southern part of the forest most of the B and C level vegetation has been removed. The soil of this part is tramped down, having a thick level of raw humus.

Generally the soil of the forest has been developed on sandy deposits of the Fraser River, to a podzolic soil. The surface layers of the soil are: A<sub>0</sub>, 1 inch, A<sub>1</sub>, 2 inches, and A<sub>2</sub>, 1½ inches.

The "B" or depositional layer is also present but it was too deep to dig down to "C" or basic layer to measure "B". It appears that the forest type - indicated by the site index, soil and vegetation - is a disturbed Douglas fir - Moss association (11).

### 3. Description of Sample Trees and Sampling Methods:

Twenty-five trees were sampled during the period of study, from June to the end of September. These trees were marked with numbered tags from 1 to

25. The trees were chosen with regard to two things:

1. Location of the tree; three classes were established:

- a.) Trees growing at the center of the forest.
- b.) Trees growing at the different margins of the forest.
- c.) Open-growth trees.

Eight of the 25 trees were chosen at the center of the forest, 13 of them at the margins and 4 of them were open growing.

2. Time of bud-opening: considerable differences occurred in the time of opening of buds of Douglas fir (16). Three classes were established to differentiate the trees:

- a.) Early (E): the buds were open before May 15.
- b.) Medium (M): the buds opened from May 15 to May 21.
- c.) Late (L): the buds opened later than May 21.

Ten of the 25 trees were early-opening, 4 of them were medium, and 11 were late-opening.

The trees were chosen, as much as possible, with regard to height, D.B.H., crown class and age. The opportunity for selecting for these variables was limited, because the forest consists of planted trees of limited variation in these factors.

Both of the progrediens and sistens (Neosistens) settled on the current year's growth, consequently the new growth of foliage was sampled. The basic sample unit was established as a needle. Samples were drawn from three levels of the living crown of each tree. The living crowns of the trees were visually separated into three levels (Low, Medium, High), and the samples were drawn from the middle of each level (Appendix E). North, East, South and West sides of the trees were sampled in each level. The samples were drawn from the outer part of the crown. Consequently 12 sample twigs were cut from a normal tree. Some of the trees are not normal in crown shape

(Appendix L), lacking some part of the crown. Most of the trees on the margins are of this kind. In these cases the 12 samples could not be drawn from one tree. Some of the sample trees were very high, and difficult to sample with safety in the high level and sometimes even in the medium level. These levels were sampled only three times during the summer.

The frequency of sampling was varied according to circumstances. The trees were sampled once per week from June 4, to August 6, and after this time only once per two weeks or once per three weeks. The change of the length of sampling period was suggested by the low activity of insects after August 6, because by this time most of the neosistens were established on the needle preparatory to overwintering.

Prunners were used to cut the sample twigs from the lower trees, and in the lower levels of the higher trees. Two prunners were used, one of the two was 8 feet in length, and the other one consisted of three 15 - feet - long pieces, working telescopically. This second prunner was not useful over 30 - 35 feet in length, because it was very flexible.

For sampling the higher trees a ladder was used, which could be extended to 34 feet from which pole prunners could be operated. Beyond the reach of prunners, samples were obtained by climbing the tree.

The cut twigs were placed in nylon bags, in which the samples were taken to the laboratory, where the living and dead insect<sup>s</sup> were counted on ten randomly chosen needles of each twig. Differentiation between dead and living larvae was made with the aid of a microscope. The information was kept separately for living and dead insects (Appendix A, B).

The different stages and instars of the insects were observed at the same time, when they were counted. The progrediens and sexupara were the material of the sampling from June 4 to July 2, and the neosistens generation was the material from July 9 to September 24 (Appendix F).

The trees, No. 4, 10 and 25, were specially sampled to establish the distribution of the Adelges cooleyi horizontally and vertically within a tree. The samples by height were drawn from every 5 feet of the outer part of the living crown, from four sides of the tree (North, West, South and East). The samples radially out from the stem to the outer part of the crown were drawn from every 3 feet, to four directions from the stem (North, West, South and East) in the low level of the crown. This special sampling was repeated 3 times during the summer, with sampling of the progrediens and sexupara generation on June 5, and the neosistens generation on July 25 and on September 26 (Appendix G). Five twig lengths were also measured in each sampling place on September 26 (Appendix G).

The current year growths of the 25 sample trees were measured 2 times during the summer, on June 4 and September 26. Ten twigs were measured in each sampling location on the 25 trees (Appendix J).

The growth of foliage was also recorded once per week on two trees, on tree No. 14 (early opened) and on tree No. 15 (late opened) (Appendix H).

The crown shapes of the 25 trees were studied and three typical shapes were drawn from two different views (Appendix L).

Owing to lack of equipment, the meteorological data were not measured. The data presented as Appendix K are from the U.B.C. Meteorological Station. The place of observation of these data was within 300-400 yards of Totem Park.

The natural enemies of Adelges cooleyi were observed, but lack of time did not permit measurement of mortality attributable to them.

#### 4. Processing of data:

To determine the relationships between the abundance and factors, most of the data were subjected to statistical analyses. The detailed processing of data will be discussed in the next chapter.

Some of the measured data were not analysed, but they will be used to

explain the effect of several factors.

## EXPERIMENTAL RESULTS:

Six trees - No. 1, 2, 10, 11, 14 and 20 - of the 25 could be sampled in each level and at every cardinal points. The abundance of the living insects on these 6 trees was analyzed by three factors: level, exposure (cardinal points) and bud-opening time (Appendix M), separately for the two generations (Table 2 and 3).

Table 2. Analysis of variance for generation 1.

Source	Degrees of freedom	Net sum squares	Mean sum squares	Variance ratio (F)	Significance at 0.05 level
Levels (L)	2	0.74	0.37	7.40	H.S.*
Exposures (E)	3	0.03	0.01	-	N.S.
Bud opening (B)	2	1.21	0.61	12.20	H.S.
L x E	6	0.05	0.01	-	N.S.
L x B	4	0.14	0.04	-	N.S.
E x B	6	0.08	0.01	-	N.S.
L x E x B	12	0.10	0.01	-	N.S.
Residual	36	1.94	0.05		
Total	71	4.29			

\* H.S.=highly significant, S=significant, N.S.=Not significant.

The levels and the bud-opening times show significant differences.

In table 3 the bud-opening times show also significant difference, the levels do not, but the "F" value of levels is very close to the significance level. Examining the factors in table 2 and 3, the average numbers of living insects per needle were greater at the low level (0.31 in generation 1 and 0.39 in generation 2) than at the medium level (0.24 in generation 1 and 0.28 in generation 2), and it was greater at the medium level than at the high level (0.07 in both generations) of the living crown. The average number of living insects was also greater on the early bud-opening trees (0.38 in

Table 3. Analysis of variance for generation 2.

Source	Degrees of freedom	Net sum squares	Mean sum squares	Variance ratio (F)	Significance at 0.05 level
Levels (L)	2	1.26	0.63	3.15	N.S.
Exposures (E)	3	0.19	0.06	-	N.S.
Bud opening (B)	2	3.56	1.78	8.90	H.S.
L x E	6	0.07	0.01	-	N.S.
L x B	4	0.75	0.19	1.00	N.S.
E x B	6	0.34	0.06	-	N.S.
L x E x B	12	0.12	0.01	-	N.S.
Residual	36	7.31	0.20		
Total	71	13.60			

generation 1 and 0.56 in generation 2) than on the medium (0.17 in generation 1 and 0.09 in generation 2) and late bud opening trees (0.07 in generation 1 and 0.09 in generation 2).

Both of the analyses of variance indicate that there is no significant difference between exposures, consequently the data of the four cardinal points will not be treated separately in the further analyses.

#### 1. Population changes with time:

The first five sampling time of the 13 covered the generation 1, and the remainder covered the generation 2.

##### a. Population changes with time in generation 1:

First, the correlation between number of insects per needle and time was tested for the 6 trees mentioned. The average number of insects per needle was plotted by time (Fig. 5). The numbers of dead and living insects were plotted separately. The points suggested the calculation of linear-regression equations for both numbers of living and numbers of dead insects (Table 4, 5).

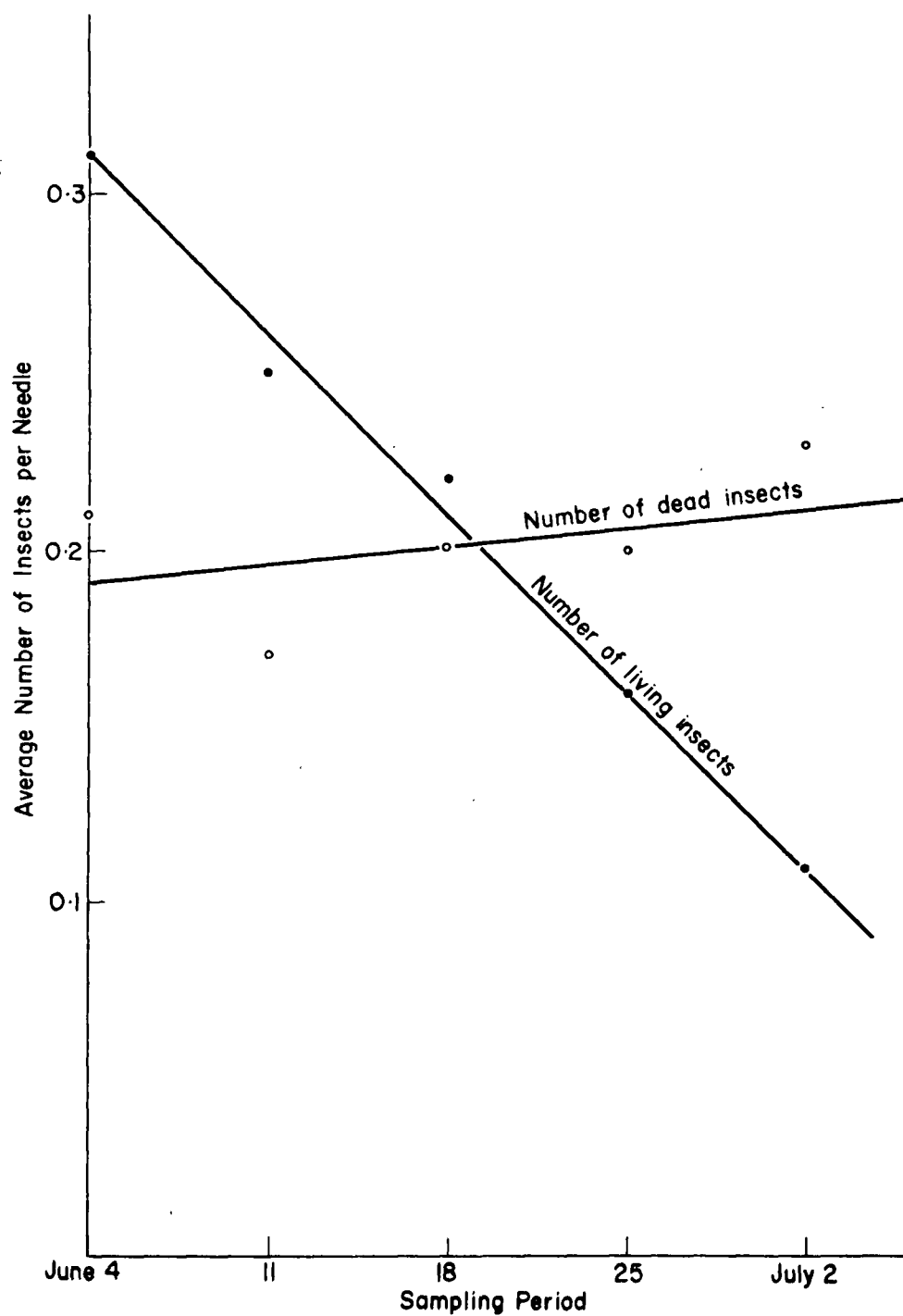


Fig. 5 Number of living and dead insects per needle in generation I for different periods



Table 4. Calculation of the equation and correlation coefficient of variables by period and average number of living insects per needle.

	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
	0	0.31	0	0.0961	0.00
	1	0.25	1	0.0625	0.25
	2	0.25	4	0.0484	0.44
	3	0.16	9	0.0256	0.48
	4	0.11	16	0.0121	0.44
Total	10	1.05	30	0.2447	1.61
Ave.	2.0	0.21			

X = period, Y = average number of insects per needle,  $b = -0.049$ ,  $a = 0.31$ ,  $r = -0.998$ ,  $t = -26.97$ ,  $S_b = 0.00257$ ,  $-0.057 \leq i \leq -0.041$ .

Where:  $b$  = sample regression coefficient.

$a$  = intercept.

$r$  = correlation coefficient.

$t$  = "t" test for correlation coefficient.

$S_b$  = standard deviation for regression.

$i$  = confidence intervals.

The equation of the regression line is:  $Y = -0.049X + 0.31$

The correlation is significant between the average number of insects and periods. The values of " $r$ " and " $t$ " are highly significant. The average number of insects per needle decreased linearly with time.

There is no significant correlation between the average number of dead insects per needle and time (Table 5), but points fit well to the line. The insignificant result probably was caused by the small sample size.

Logically, the slope of the mortality line should be the reverse of the line of living insects, but this is not so, for two reasons:

- i. about 50% of the insects of this generation develop into winged

Table 5. Calculation of the equation and correlation coefficient of variables by period and average number of dead insects per needle.

	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
	0	0.21	0	0.0441	0.00
	1	0.17	1	0.0289	0.17
	2	0.20	4	0.0400	0.40
	3	0.20	9	0.0400	0.60
	4	0.23	16	0.0529	0.92
Total	10	1.01	30	0.2059	2.09
Ave.	2.0	0.20			

X = periods, Y = number of dead insects per needle,  $b = 0.007$ ,  $a = 0.19$ ,  $r = 0.51$ ,  $t = 1.02$ ,  $S_b = 0.00686$ ,  $-0.015 \leq i \leq +0.029$ .

The equation of the regression line is  $Y = 0.007X + 0.19$

adults, and fly to spruce. The number of winged adults could not be observed because of their flight.

ii. Some of the dead insects could not be observed, because many of them fell off, and also many of them were eaten by predators.

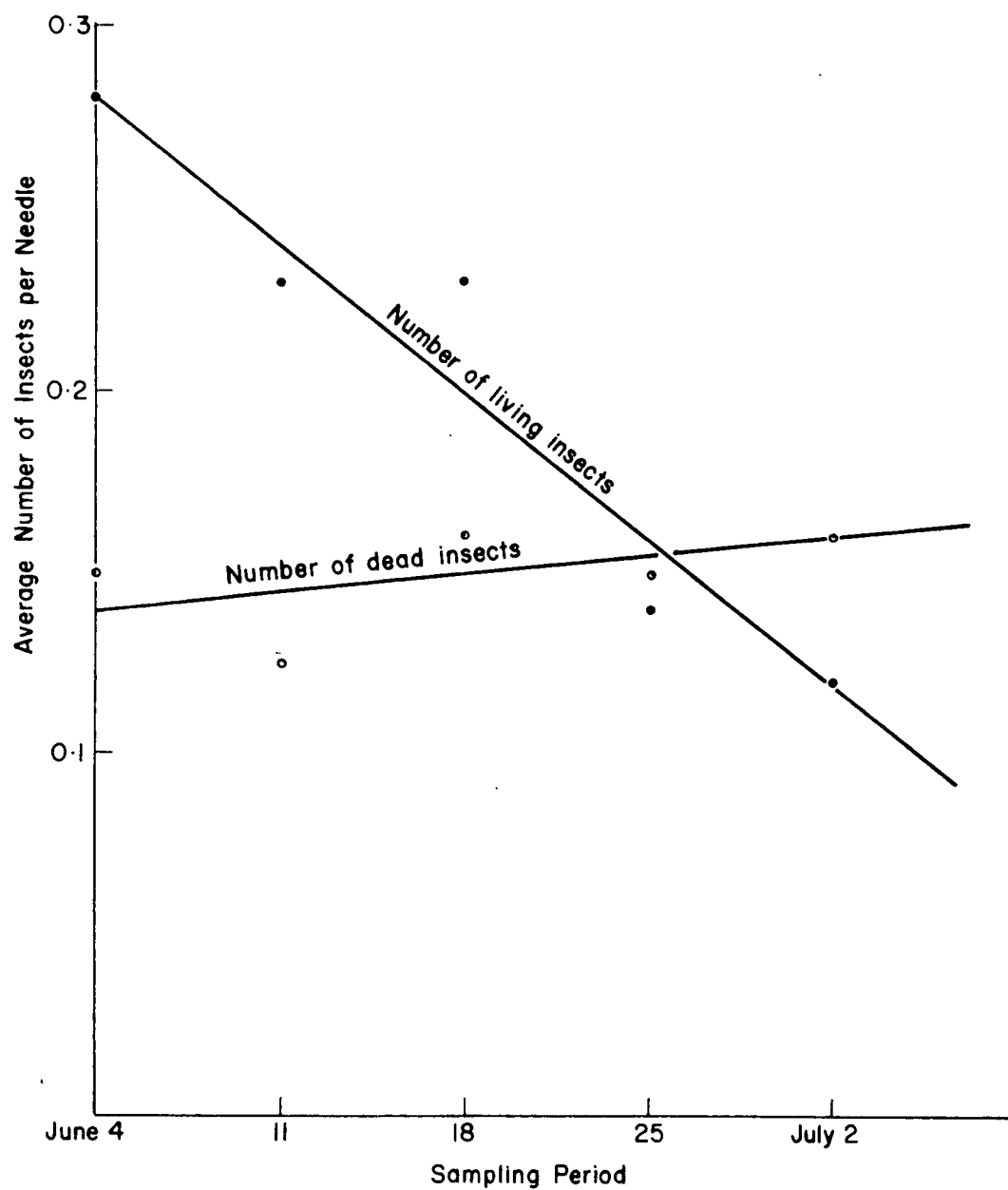
The correlation between number of insects per needle and period, was extended for every tree sampled. The average numbers of insects at the lower crown level of the trees were used, because they were most abundant there (Fig. 6) (Appendix C) (Table 6, 7).

The "t" and "r" show that (Table 6) the correlation is significant between the number of living insects per needle and time.

The lack of correlation (Table 7) between the number of dead insects per needle and time probably is caused by the small sample size.

#### b. Population changes with time in generation 2:

Eight samples out of 13 were drawn from generation 2. The data of these samples were treated in the same way as in generation 1. First the average



**Fig. 6** Number of living and dead insects per needle in generation I for different periods at the low level of the living crown

Table 6. Calculation of the equation and correlation coefficient of the number of living insects per needle at low crown level of the trees on period.

	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
	0	0.28	0	0.0784	0.00
	1	0.23	1	0.0529	0.23
	2	0.23	4	0.0529	0.46
	3	0.14	9	0.0196	0.42
	4	0.12	16	0.0144	0.48
Total	10	1.00	30	0.2182	1.59
Ave.	2.0	0.20			

X = periods, Y = numbers of insects per needle,  $b = -0.041$ ,  $a = 0.28$ ,

$r = -0.960$ ,  $t = -5.89$ ,  $S_b = 0.00775$ ,  $-0.063 \leq i \leq -0.019$

Equation:  $Y = -0.041X + 0.28$

Table 7. Calculation of the equation and correlation coefficient of the number of dead insects per needle at low level of the trees on period.

	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
	0	0.15	0	0.0225	0.00
	1	0.12	1	0.0144	0.12
	2	0.16	4	0.0256	0.32
	3	0.15	9	0.0226	0.45
	4	0.16	16	0.0256	0.64
Total	10	0.74	30	0.1106	1.53
Ave.	2.0	0.15			

X = periods, Y = numbers of insects per needle,  $b = 0.005$ ,  $a = 0.14$ ,  $r = 0.48$ ,

$t = 0.95$ ,  $S_b = 0.00606$ ,  $-0.012 \leq i \leq 0.022$

Equation:  $Y = 0.005X + 0.14$

numbers of insects per needle of the 6 trees mentioned were plotted against

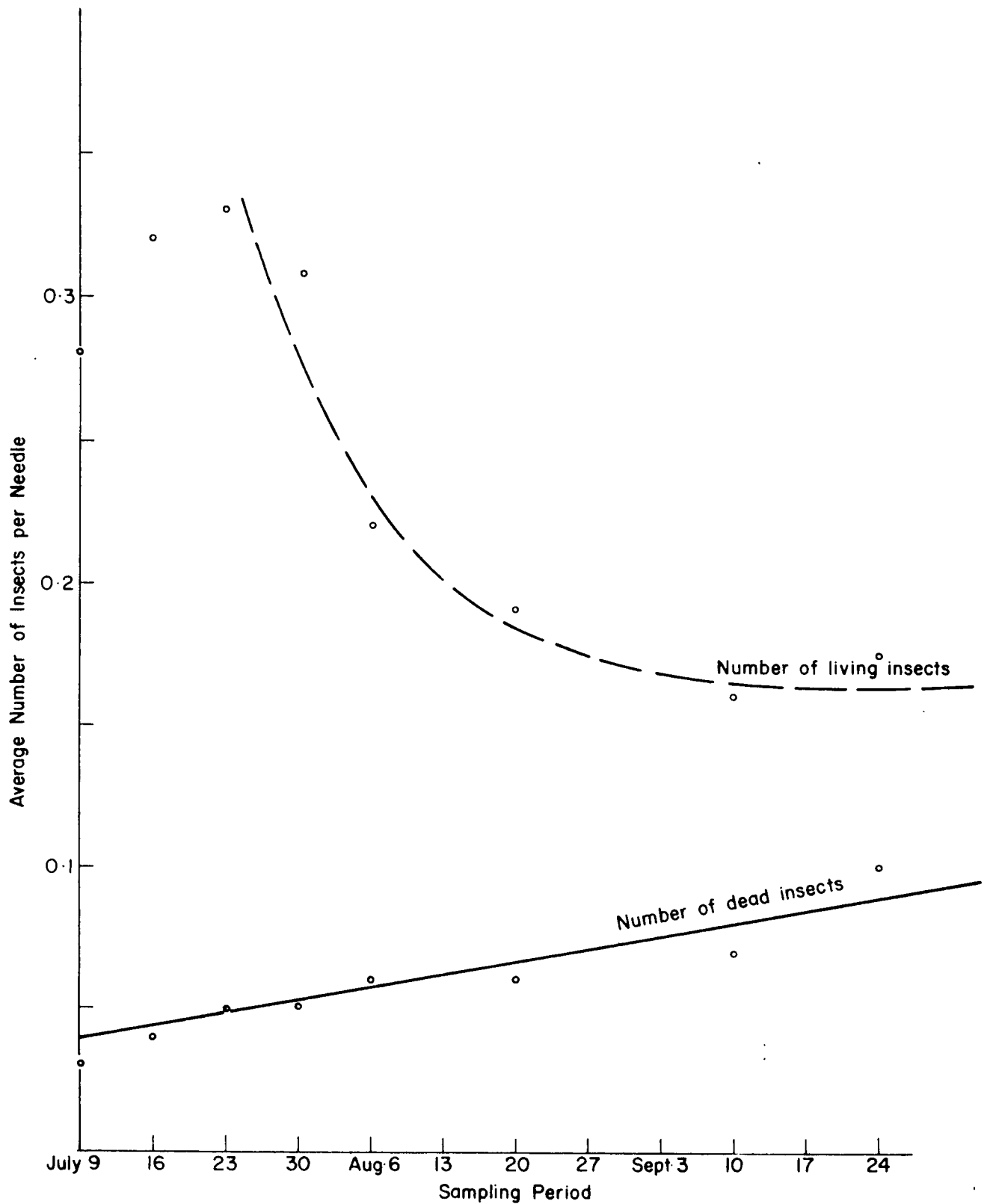
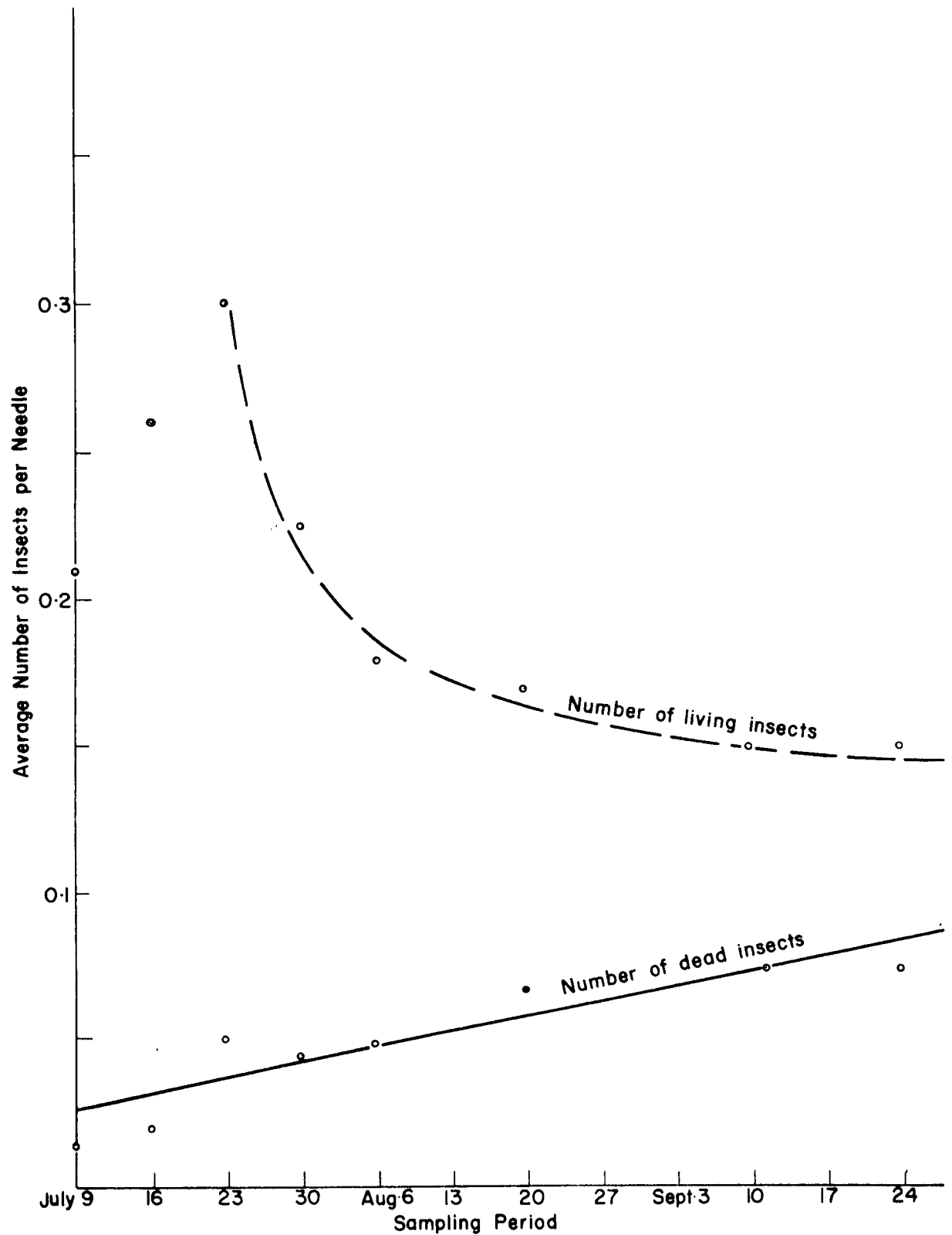


Fig. 7 Number of living and dead insects per needle in generation 2 for different periods



**Fig. 8** Number of living and dead insects per needle in generation 2 for different periods at the low level of the living crown

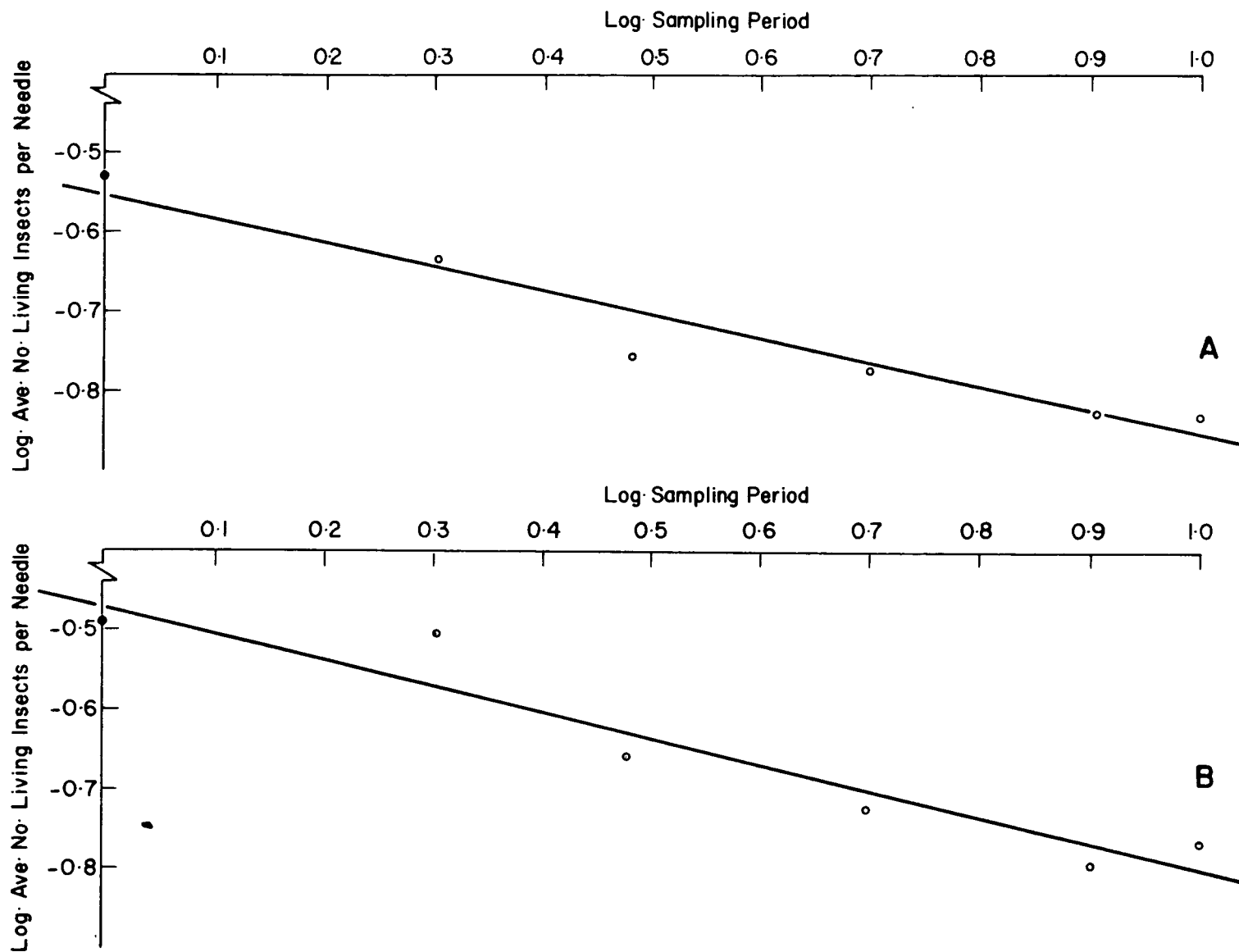


Fig. 9 Transformed curves of fig. 7 (B) and fig. 8 (A)

time (Fig. 7). Between the first and second and between the second and third sampling periods the line of the living insects is increasing, because these periods were the hatching time. From the third point, the line starts to decrease. The manner of the points suggested to leave out the first two points. The remaining points show a curve, which was transformed to logarithms. Both the X and Y were changed to logarithms (Table 8) (Fig. 9).

Table 8. Calculation of the equation and correlation coefficient of average number of living insects per needle on time.

X	Y	logX	logY	(logX) <sup>2</sup>	(logY) <sup>2</sup>	(logX)(logY)
1	0.33	0.000	-0.481	0.0000	0.2314	0.0000
2	0.31	0.301	-0.509	0.0906	0.2591	-0.1532
3	0.22	0.477	-0.658	0.2275	0.4330	-0.3139
5	0.19	0.699	-0.721	0.4886	0.5198	-0.5040
8	0.16	0.903	-0.796	0.8154	0.6336	-0.7188
10	0.17	1.000	-0.770	1.0000	0.5929	-0.7700
T* 29	1.38	3.380	-3.935	2.6221	2.6698	-2.4599
A* 4.83	0.23	0.563	-0.656			

T\* = Total

A\* = Average

X = periods, Y = numbers of living insects per needle,  $b = -0.339$ ,  $a = 0.465$ ,  
 $r = -0.963$ ,  $t = -6.80$ ,  $S_b = 0.049$ ,  $-0.203 \leq i \leq -0.465$

Equation:  $\log Y = -0.339 \log X - 0.465$

Both the values of "r" and "t" give significant correlation between the transformed "Y" and "X", meaning that the correlation is logarithmic between the average number of living insects per needle and time.

The equation of the regression line was also calculated for number of dead insects per needle in the generation 2 (Fig. 7) (Table 9).

Significant correlation was found between the average number of dead



insects per needle and time.

The correlation analysis between number of insects per needle and period was extended to include all of the 25 trees sampled. The average number of insects at the low level of each tree was used, because insects were most abundant there (Appendix C, D).

Table 9. Calculation of the equation and correlation coefficient of average number of dead insects per needle on time.

	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
	0	0.03	0	0.0009	0.00
	1	0.04	1	0.0016	0.04
	2	0.05	4	0.0025	0.10
	3	0.05	9	0.0025	0.15
	4	0.06	16	0.0036	0.24
	6	0.06	36	0.0036	0.36
	9	0.07	81	0.0049	0.63
	11	0.10	121	0.0100	1.10
Total	36	0.46	268	0.0296	2.62
Ave.	4.5	0.06			

X = periods, Y = numbers of dead insects per needle,  $b = 0.005$ ,  $a = 0.04$ ,

$r = 0.948$ ,  $t = 7.29$ ,  $S_b = 0.00069$   $0.003 \leq i \leq 0.007$

Equation:  $Y = 0.005X + 0.04$

The average numbers of living insects had to be tested the same way as in table 8. The first two points were omitted and both X and Y were transformed to logarithms (Fig. 8, 9) (Table 10).

A significant correlation was found between X and Y, meaning that the numbers of living insects decreased logarithmically with time (Table 10).

Table 10. Calculation of the equation and correlation coefficient of average number of living insects per needle on time.

	X	Y	logX	logY	(logX) <sup>2</sup>	(logY) <sup>2</sup>	(logX)(logY)
	1	0.30	0.000	-0.523	0.0000	0.2735	-0.0000
	2	0.23	0.301	-0.638	0.0906	0.4070	-0.1920
	3	0.18	0.477	-0.745	0.2275	0.5550	-0.3554
	5	0.17	0.699	-0.770	0.4886	0.5929	-0.5382
	8	0.15	0.903	-0.824	0.8154	0.6790	-0.7441
	10	0.15	1.000	-0.824	1.0000	0.6790	-0.8240
Total	29	1.18	3.380	-4.324	2.6221	3.1864	-2.6537
Ave.	4.83	0.20	0.563	-0.721			

X = periods, Y = numbers of living insects per needle,  $b = -0.303$ ,  $a = -0.551$ ,  
 $r = -0.9684$ ,  $t = -8.07$ ,  $S_b = 0.013$ ,  $-0.267 \leq i \leq -0.339$

Equation:  $\log Y = -0.303 \log X - 0.551$

Table 11. Calculation of the equation and correlation coefficient of average number of dead insects per needle on time.

	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
	0	0.014	0	0.0002	0.000
	1	0.019	1	0.0004	0.019
	2	0.050	4	0.0025	0.100
	3	0.044	9	0.0019	0.132
	4	0.048	16	0.0023	0.192
	6	0.067	36	0.0045	0.402
	9	0.074	81	0.0055	0.666
	11	0.074	121	0.0055	0.814
Total	36	0.390	268	0.0228	2.325
Ave.	4.5	0.049			

X = periods, Y = numbers of dead insects per needle,  $b = 0.005$ ,  $a = 0.0026$ ,  
 $r = 0.898$ ,  $t = 5.045$ ,  $S_b = 0.00126$ ,  $0.002 \leq i \leq 0.008$

Equation:  $Y = 0.005X + 0.026$

The results (Table 11) show significant correlation between X and Y, meaning that the numbers of dead insects per needle increased with time.

## 2. Inter Tree Differences:

The numbers of living and dead insects were summarized by tree, generation and level in tree (Appendix N). Analysis of variance was carried out for the living insects (Table 12).

Table 12. Analysis of variance among trees, levels and generations.

Source	Degrees of freedom	Net sum squares	Mean sum squares	Variance ratio (F)	Significance at 0.05 level	Components of Variance
Tree (T)	24	3.770	0.1571	39.27	H.S.	0.02364
Level (L)	2	0.600	0.3000	75.00	H.S.	0.00575
Generation (G)	1	0.001	0.0010	-	N.S.	-0.00008
T x L	48	0.960	0.0200	5.00	S.	0.00800
T x G	24	0.330	0.0138	3.45	S.	0.00326
L x G	2	0.010	0.0050	1.25	N.S.	0.00004
T x L x G	48	0.190	0.0040			0.00400
Total	149	5.861				

Table 12, shows a highly significant difference among trees, and among levels. These results indicate the possibility of significant components of variance. The significant interactions indicate that the factors are not independent and there is no good biological explanation of the interactions.

The most economical sample numbers could be calculated from the components of variance for the factors. Minimum variance would be obtained if we take a large sample in a large stratum, a large sample when the stratum

Table 13. Differences among trees by abundance of Adelges cooleyi.

Generation 1.

I	14	22	4	5	2	15	8	13	12	3	11	23
II	0.62	0.24	0.23	0.21	0.21	0.18	0.17	0.16	0.15	0.15	0.15	0.14
III	19.44	4.37	3.97	3.56	3.56	1.98	1.59	1.19	0.79	0.79	0.79	0.40
IV	H.S.	S.	S.	S.	S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
V	M	O	M	M	M	M	M	M	M	M	O	O

I	10	6	1	21	20	9	7	24	19	18	16	17	25
II	0.14	0.11	0.11	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.02	0.01
III	0.40	-0.79	-0.79	-3.57	-3.57	-3.57	-3.57	-3.97	-3.97	-3.97	-3.97	-4.37	-4.76
IV	N.S.	N.S.	N.S.	S.	S.	S.	S.	S.	S.	S.	S.	S.	S.
V	O	M	M	I	I	M	M	I	I	I	I	I	I

Generation 2.

I	14	4	5	22	3	23	2	1	8	6	12	15
II	1.03	0.25	0.22	0.22	0.17	0.16	0.14	0.14	0.13	0.12	0.10	0.10
III	22.28	2.97	2.23	2.23	0.99	0.74	0.25	0.25	0.00	-0.25	-0.74	-0.74
IV	H.S.	S.	S.	S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
V	M	M	M	O	M	O	M	M	M	M	M	M

I	11	7	9	10	19	20	21	24	16	18	13	17	25
II	0.09	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.00
III	-0.99	-2.23	-2.23	-2.23	-2.23	-2.49	-2.49	-2.49	-2.72	-2.72	-2.97	-2.97	-3.22
IV	N.S.	S.	S.	S.	S.	S.	S.	S.	S.	S.	S.	S.	S.
V	O	M	M	O	I	I	I	I	I	I	M	I	I

Generation 1 + 2.

I	14	4	22	5	2	3	23	8	15	12	1	11
II	1.56	0.48	0.46	0.43	0.35	0.32	0.30	0.30	0.28	0.25	0.25	0.24
III	21.55	3.41	3.10	2.64	1.40	0.93	0.62	0.62	0.31	-0.16	-0.16	-0.31
IV	H.S.	S.	S.	S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
V	M	M	O	M	M	M	O	M	M	M	M	O

I	6	10	13	7	9	19	20	21	24	18	16	17	25
II	0.23	0.18	0.17	0.08	0.08	0.07	0.07	0.07	0.06	0.05	0.05	0.03	0.01
III	-0.47	-1.24	-1.40	-2.79	-2.79	-2.95	-2.95	-2.95	-3.10	-3.26	-3.26	-3.57	-3.88
IV	N.S.	N.S.	N.S.	S.	S.	S.	S.	S.	S.	S.	S.	S.	S.
V	M	O	M	M	M	I	I	I	I	I	I	I	I

Key for table 13: I = tree No.

II = average number of living insects per needle.

III = value of "t".

IV = significance at 0.05 level.

V = location of the trees.

I = inside growth tree

M = margin growth tree

O = open-growth tree

variance is high (trees) and a small sample when the stratum cost is high (level). Because of the high cost of sampling at the several locations above reach from the ground and adequate estimates of variance were obtained from the ground, further sampling probably should be concentrated on providing estimates of tree-to-tree variation at the ground level of sampling.

The differences between trees were examined by the "t" test. Table 13 shows that most of the highly populated trees are edge trees, and the lower populated trees are inside the stand. By these results, the trees were separated into three populations, interior, marginal and open trees. The average numbers of living insects per needle of each tree population were tested against each other by the "t" test (Table 14).

Table 14. Influence of position of tree in the stand on abundance of Adelges cooleyi.

Location of trees.	Values of t		
	Interior	Marginal	Open
Interior	--	--	--
Marginal	21.48 H.S.	--	--
Open	5.19 S.	2.13 N.S.	--

Table 14 shows that the abundance of the Adelges cooleyi on growing within a stand is significantly different from those on the stand edge, or grown

Table 15. Differences among trees by abundance of Adelges cooleyi. The trees were treated as two population, separated by location.

Generation 1. Margin growth trees.

	7	9	1	6	3	12	13	8	15	5	2	4	14
I	0.04	0.04	0.11	0.11	0.15	0.15	0.16	0.17	0.18	0.21	0.21	0.23	0.62
II	-3.65	-3.65	-1.82	-1.82	-0.78	-0.78	-0.52	-0.26	0.00	0.78	0.78	1.30	11.41
III	S.	S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	H.S.
IV	L	L	M	E	L	E	M	E	L	E	L	E	E

Inside growth trees.

	25	17	16	18	19	24	20	21
I	0.01	0.02	0.03	0.03	0.03	0.03	0.04	0.04
II	-5.71	-2.86	0.00	0.00	0.00	0.00	2.86	2.86
III	S.	S.	N.S.	N.S.	N.S.	N.S.	S.	S.
IV	L	L	E	M	E	L	M	E

Generation 2. Margin growth trees.

	13	9	7	15	12	6	8	1	2	3	5	4	14
I	0.01	0.04	0.04	0.10	0.10	0.12	0.13	0.14	0.14	0.17	0.22	0.25	1.03
II	-2.48	-2.06	-2.06	-1.24	-1.24	-0.97	-0.83	-0.69	-0.69	-0.27	0.41	0.83	11.58
III	S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	H.S.
IV	M	L	L	L	E	E	E	M	L	L	E	E	E

Inside growth trees.

	25	17	18	16	24	21	20	19
I	0.00	0.01	0.02	0.02	0.03	0.03	0.03	0.04
II	-2.15	-1.07	0.00	0.00	1.07	1.07	1.07	2.15
III	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
IV	L	L	M	E	L	E	M	E

Generation 1 + 2. Margin growth trees.

	9	7	13	6	1	12	15	8	3	2	5	4	14
I	0.08	0.08	0.17	0.23	0.25	0.25	0.28	0.30	0.32	0.35	0.43	0.48	1.65
II	-2.21	-2.21	-1.53	-1.07	-0.92	-0.92	-0.69	-0.53	-0.38	-0.15	0.46	0.84	9.77
III	S.	S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	H.S.
IV	L	L	M	E	M	E	L	E	L	L	E	E	E

Inside growth trees.

	25	17	16	18	24	21	20	19
I	0.01	0.03	0.05	0.05	0.06	0.07	0.07	0.07
II	-4.60	-2.30	0.00	0.00	1.15	2.30	2.30	2.30
III	S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
IV	L	L	E	M	L	E	M	E

Key: I, II, III, IV = as in table 13.

V, = Bud opening time.

E = Early

M = Medium

L = Late

in the open. No significant difference was found between open and margin growth trees.

Then the trees were separated into two groups, interior and edge trees, omitting the open trees and differences between trees were sought, differences were indicated by the "t" test (Table 15).

Slight differences can be seen between trees within the separated tree populations (Table 15). Most of the trees, which were significantly more populated than the average were early bud-opening trees, and most of those which were significantly less populated were late bud-opening trees. Slight differences were shown by "t" test between the late and early-opening trees (significant at 0.3 level) in respect to the abundance of Adelges cooleyi. The test of differences between late-opening and medium-opening trees, and between medium-and early-opening trees could not be carried out, because of the small number of medium-opening trees.

The 13 marginal trees had been chosen so 3 of them faced North, 3 East, 3 South and 4 West (Appendix O). These trees were analysed in relation to exposures and levels, leaving out one (No. 5) of the West trees (Table 16, 17 and 18).

Table 16. Average numbers of living insects per needle, by exposures and levels for the marginal trees.

Level	North	South	West	East
Low	0.56	0.44	0.51	0.91
Medium	0.33	0.15	0.23	0.87
High	0.04	0.04	0.04	0.32
Totals	0.93	0.63	0.78	2.10
Ave.	0.31	0.21	0.26	0.70

Both the levels and exposures show significant differences (Table 17). The relationship between number of living insects per needle and height level

Table 17. Analysis of variance among exposures and levels.

Source	Degrees of freedom	Net sum squares	Mean sum squares	Variance ratio (F)	Significance at 0.05 level
Exposure (E)	3	0.4506	0.1502	15.98	H.S.
Level (L)	2	0.4938	0.2469	26.27	H.S.
L x E	6	0.0566	0.0094		
Total	11	1.0010			

on the living crown will be examined later. The differences between exposures were shown out by the least-significant-range test (Table 18).

Table 18. Differences between differently exposed trees by the abundance of Adelges cooleyi.

Exposures	Ranges	Significantly different from
North	0.69-1.17	S, E
South	0.39-0.87	N, E
West	0.54-1.02	E
East	1.86-2.34	N, S, W

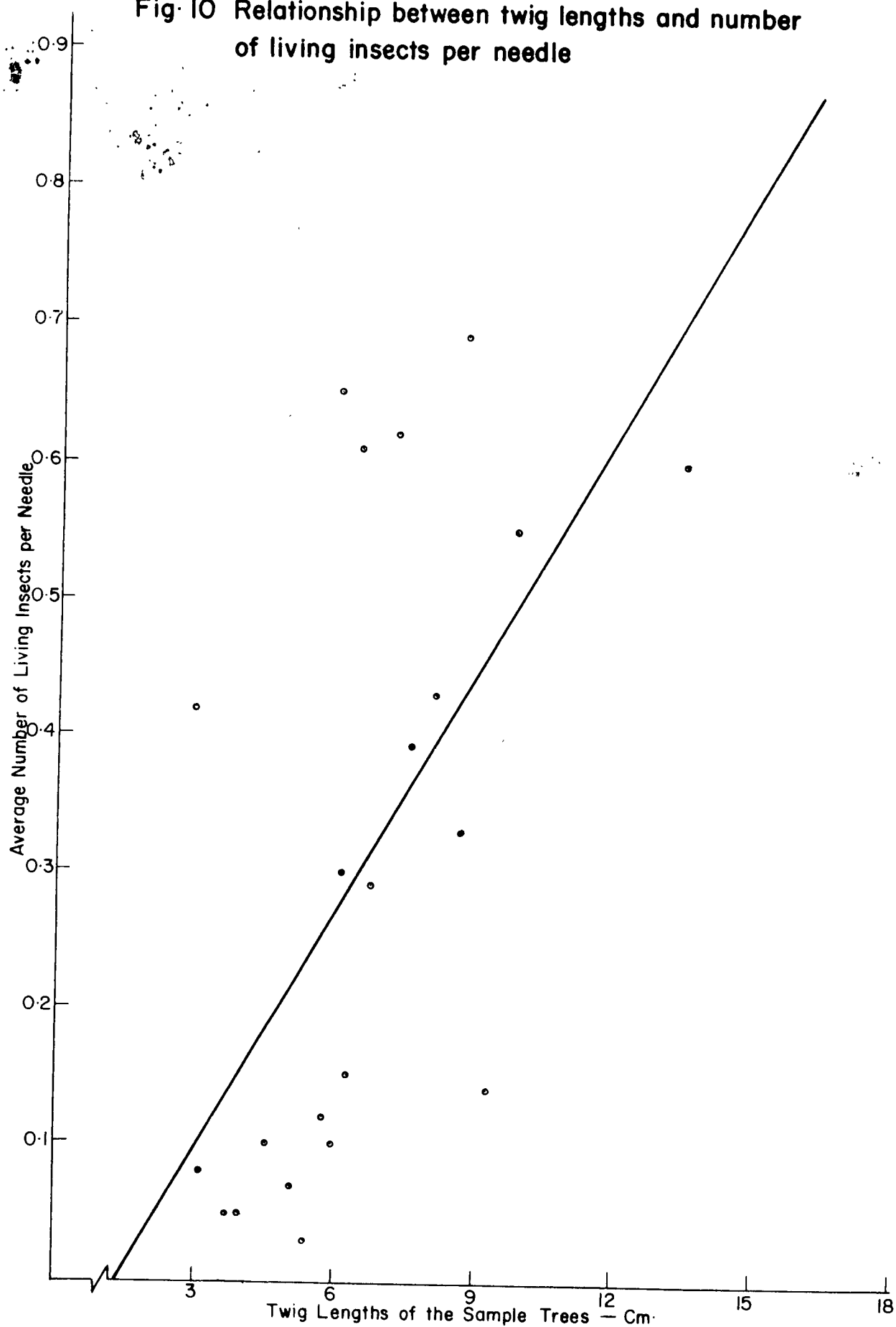
The abundance of Adelges cooleyi was examined in relation to length of twigs, which showed a high degree of variation between trees. The average numbers of living insects per needle from the low level of the living crown of the trees were plotted over the average length of twigs from the low level of the living crown (Appendix J) (Fig. 10). The data measured on September 26 were used for calculating the average twig length. It is given by the calculation of the equation of regression line that (Appendix I):

$$b = 0.0023, a = 0.225, r = 0.228, t = 0.112, S_b = 0.02013, -0.019 \leq i \leq 0.065$$

As shown by the values of "r" and "t", no significant correlation was found between number of living insects per needle and twig length. One of the trees, No. 14, shows a very high insect population on relatively short twigs,



Fig. 10 Relationship between twig lengths and number of living insects per needle



and another of the trees, No. 10, has very long twigs with a relatively small number of insects on it. Another calculation was carried out without these two trees (Appendix I), where:

$$b = 0.058, a = -0.08, r = 0.680, t = 4.25, S_b = 0.01375, 0.30 \leq i \leq 0.086$$

$$\text{Equation: } Y = 0.058X - 0.08$$

This second calculation shows significant correlation, meaning that the Adelges cooleyi usually is more abundant on the longer-twigged trees.

The factors D.B.H. (X1), height (X2), age (X3), crown width (X4), length of clear stem (X5), proportion of living crown to total height (X6), bud-opening time (X7) and location (X8) of the trees were related to the average number of living insects per needle (Y) by analysis of linear - multiple - regression. This was carried out by the Alwac III electronic computer (Appendix O) (Table 19).

Table 19. Influence of 8 factors on the average number of living insects per needle.

Variable	X1	X2	X3	X4	X5	X6	X7	X8
Means	6.54	45.20	22.80	14.68	14.80	68.37	2.04	4.44
Standard deviations	3.39	20.01	5.80	6.60	12.16	19.99	0.94	3.14
Minimum value	0.6	2	4	2	0	36.5	1	1
Maximum value	12.8	69	29	32	41	99.9	3	9
Correlation coefficients	0.131	0.343	0.269	0.125	0.482	0.513	0.268	0.261
% of influence of each factor	5.73	28.31	0.58	-8.82	-45.57	89.63	12.00	-19.27

$$R^2 = 0.625 \quad (R = \text{multiple correlation coefficient})$$

$$SE_e = 0.197 \quad (SE_e = \text{standard error of estimate})$$

$$\begin{aligned} \text{Equation: } Y = & -0.042X_1 - 0.013X_2 - 0.001X_3 + 0.034X_4 + 0.025X_5 + 0.028X_6 - \\ & - 0.155X_7 - 0.076X_8 - 0.993 \end{aligned}$$

Examining the correlation coefficients, only two factors show significant

correlation with number of insects: the length of clear stem and the percentage of live crown. The meaning of these two significant results is related to the location of trees. In other words the clear stems are longer on the interior trees, consequently these trees have smaller percentages of living crown.

### 3. Intra Tree Variations:

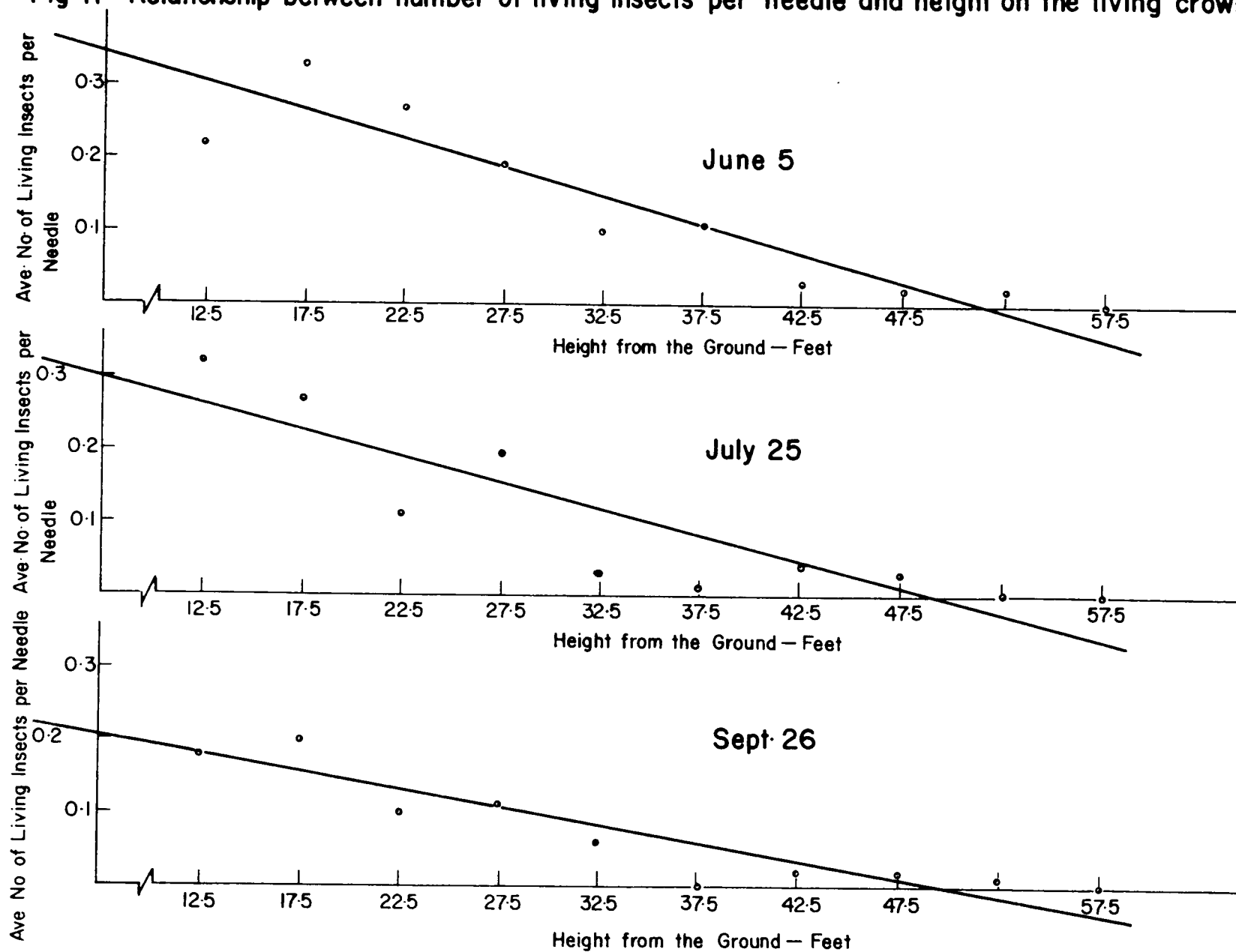
The analyses of variance in table 2 and 3 did not show significant differences among the cardinal points, meaning that no further analysis is needed for this factor.

Significant differences were found among the different levels of the trees (Table 2, 12 and 17). The numbers of living insects were summarized and averaged for the three specially sampled trees (No. 4, 10 and 25) and the calculated average numbers of living insects per needle were plotted by height levels (Appendix G) (Fig. 11). The linear-regression equations were calculated separately for the three sampling times (June 5, July 25, September 26) (Table 20, 21 and 22).

Table 20. Calculation of the equation and correlation coefficient of average number of living insects per needle on height from the ground (data of June 5).

	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
	12.5	0.22	156.25	0.0484	2.750
	17.5	0.37	306.25	0.1369	6.475
	22.5	0.27	506.25	0.0729	6.075
	27.5	0.19	756.25	0.0361	5.225
	32.5	0.10	1056.25	0.0100	3.250
	37.5	0.11	1406.25	0.0121	4.125
	42.5	0.03	1806.25	0.0009	1.275
	47.5	0.02	2256.25	0.0004	0.950
	52.5	0.02	2756.25	0.0004	1.050
	57.5	0.00	3306.25	0.0000	0.000
Total	350.0	1.33	14312.50	0.3181	31.175

Fig. II Relationship between number of living insects per needle and height on the living crown



X = height from the ground, Y = number of insects per needle,  $\bar{x} = 35.00$ ,

$\bar{y} = 0.13$ ,  $b = -0.0075$ ,  $a = 0.39$ ,  $r = -0.901$ ,  $t = -6.07$ ,  $S_b = 0.0013$ ,

$-0.0105 \leq i \leq -0.0045$

Equation:  $Y = -0.0075X + 0.39$

Table 21. Calculation of the equation and correlation coefficient of average number of living insects per needle on height from the ground (data of July 25).

	$\bar{x}$	Y	$x^2$	$y^2$	XY
	12.5	0.32	156.25	0.1024	4.000
	17.5	0.27	306.25	0.0729	4.725
	22.5	0.11	506.25	0.0121	2.475
	27.5	0.19	756.25	0.0361	5.225
	32.5	0.01	1056.25	0.0009	0.975
	37.5	0.01	1406.25	0.0001	0.375
	42.5	0.04	1806.25	0.0016	1.700
	47.5	0.03	2256.25	0.0009	1.425
	52.5	0.00	2756.25	0.0000	0.000
	57.5	0.00	3306.25	0.0000	0.000
Total	350.0	1.00	14312.50	0.2270	20.900
Ave.	35.0	0.10			

X = as in table 20, Y = as in table 20,  $b = -0.0068$ ,  $a = 0.34$ ,  $r = -0.871$ ,

$t = -5.03$ ,  $S_b = 0.0014$ ,  $-0.100 \leq i \leq -0.0036$

Equation:  $Y = -0.0068X + 0.34$

Each of the three analyses (Table 20, 21, 22) show significant correlation between average numbers of living insects per needle and height from the ground. The insect numbers decreased with height in every instance.

The change of twig lengths with height on crown was also studied. The

Table 22. Calculation of the equation and correlation coefficient of average number of living insects per needle on height from the ground (data of September 26).

	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
	12.5	0.18	156.25	0.0324	2.250
	17.5	0.20	306.25	0.0400	3.500
	22.5	0.10	506.25	0.0100	2.250
	27.5	0.11	756.25	0.0121	3.025
	32.5	0.06	1056.25	0.0036	1.950
	37.5	0.00	1406.25	0.0000	0.000
	42.5	0.02	1806.25	0.0004	0.850
	47.5	0.02	2256.25	0.0004	0.930
	52.5	0.01	2756.25	0.0001	0.525
	57.5	0.00	3306.25	0.0000	0.000
Total	350.0	0.70	14312.50	0.0990	15.280
Ave.	35.0	0.07			

X = as in table 20, Y = as in table 20,  $b = -0.0045$ ,  $a = 0.23$ ,  $r = -0.907$ ,  
 $t = -6.05$ ,  $S_b = 0.0007$ ,  $-0.0061 \leq i \leq -0.0029$

Equation:  $Y = -0.0045X + 0.23$

lengths of twigs were summarized and averaged for two trees (No. 4 and 10) by 5 feet intervals (Appendix G). Then the average twig lengths were plotted by height levels from the ground (Fig. 12). The plotted points show a curve rather than a straight line. For further analysis twig length was transformed to logarithms (Fig. 12) (Table 23).

The curvilinear correlation is significant between the height levels and twig lengths (Table 23).

The trees No. 4, 10 and 25 were also examined horizontally at 3-foot intervals radially from the bole at the middle of the low level of the living

Fig. 12 Relationship between twig length and height on the living crown

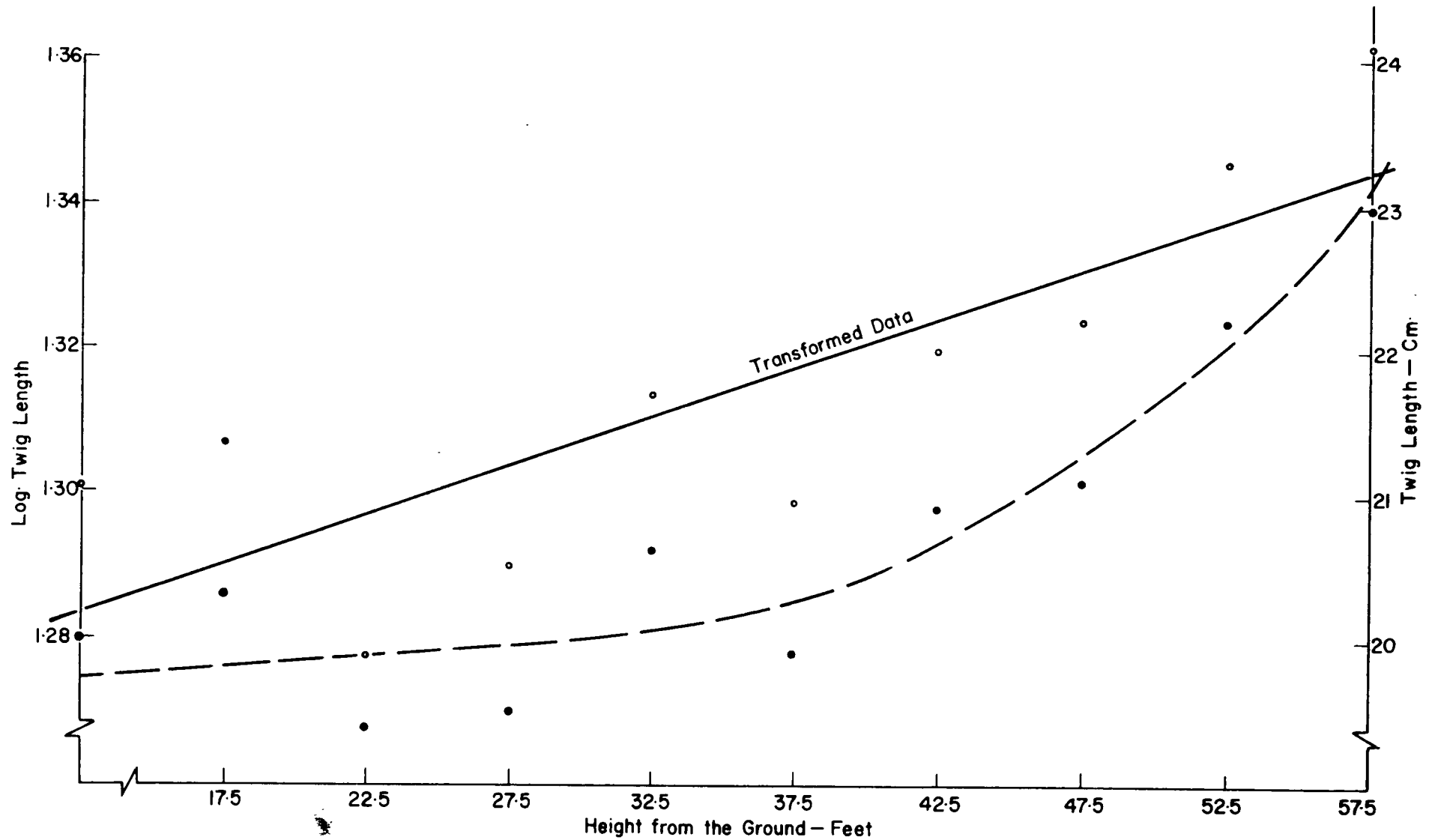


Table 23. Calculation of the equation and correlation coefficient of average twig length on height from the ground.

	X	Y	logY	X <sup>2</sup>	(logY) <sup>2</sup>	X(logY)
	12.5	20.0	1.301	156.25	1.693	16.26
	17.5	20.3	1.307	306.25	1.708	22.87
	22.5	19.4	1.278	506.25	1.633	28.76
	27.5	19.5	1.290	756.25	1.664	35.48
	32.5	20.6	1.314	1056.25	1.727	42.71
	37.5	19.9	1.299	1406.25	1.687	48.71
	42.5	20.9	1.320	1806.25	1.742	56.10
	47.5	21.1	1.324	2256.25	1.752	62.89
	52.5	22.2	1.346	2756.25	1.812	70.67
	57.5	23.0	1.362	3306.25	1.855	78.32
Total	350.0	206.9	13.141	14312.50	17.273	462.77
Ave.	35.0	20.7	1.314			

X = height from the ground, Y = average twig length of the height level,

b = 0.00137, a = 1.266, r = 0.986, t = 16.08, Sb = 0.0000695,

0.00121 ≤ i ≤ 0.00153

Equation:  $\log Y = 0.00137X + 1.266$

crowns. The numbers of insect found were summarized, and averaged (Appendix G). Then the average numbers of living insects per needle were plotted over the distances from the stem (Fig. 13), and the regression analyses were carried out separately for the three different sampling times (June 5, July 25, September 26) (Tables: 24, 25 and 26).

The correlations are not significant at the 0.05 level in tables 24 and 25, which might also be caused by the small sample sizes. Significant correlation was found in table 26 between the numbers of living insects per needle and distances from the stem.



Fig. 13 Relationship between number of living insects per needle and distance from the stem at the low level of the living crown

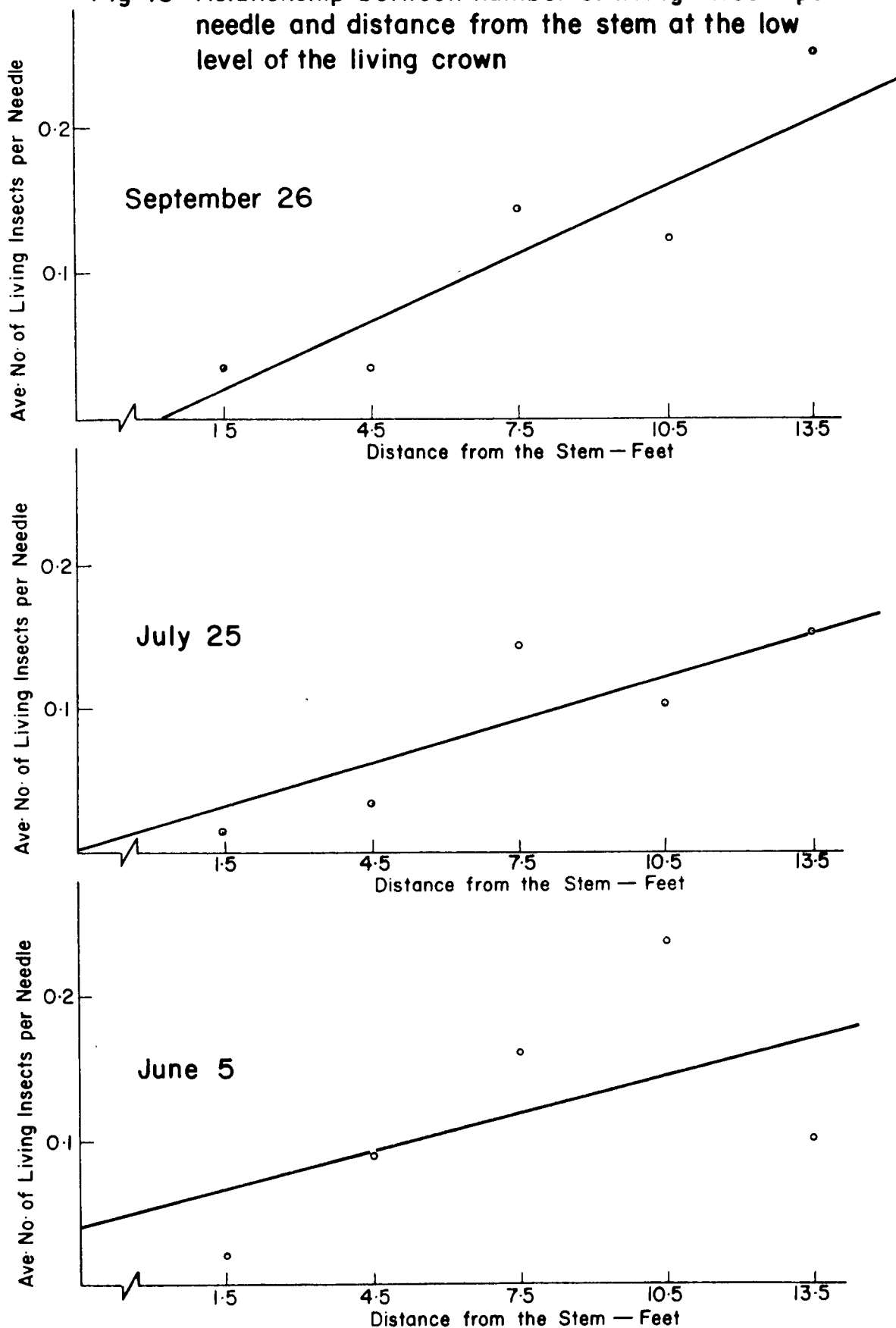


Table 24. Calculation of the equation and correlation coefficient of average numbers of living insects per needle on distances from the stem (data of June 5).

	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
	1.5	0.02	2.25	0.0004	0.030
	4.5	0.09	20.25	0.0027	0.405
	7.5	0.16	56.25	0.0256	1.200
	10.5	0.24	110.25	0.0576	2.520
	13.5	0.10	182.25	0.0100	1.310
Total	37.5	0.61	371.25	0.0963	5.505
Ave.	7.5	0.12			

X = distances from the stem, Y = numbers of living insects per needle,  $b = 0.010$ ,  $a = 0.04$ ,  $r = 0.664$ ,  $t = 1.54$ ,  $S_b = 0.00675$ ,  $-0.011 \leq i \leq 0.031$

Equation:  $Y = 0.010X + 0.04$

Table 25. Calculation of the equation and correlation coefficient of average numbers of living insects per needle on distances from the stem (data of July 25).

	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
	1.5	0.01	2.25	0.0001	0.015
	4.5	0.03	20.25	0.0009	0.135
	7.5	0.14	56.25	0.0196	1.050
	10.5	0.10	110.25	0.0100	1.050
	13.5	0.15	182.25	0.0225	2.025
Total	37.5	0.43	371.25	0.0531	4.275
Ave.	7.5	0.09			

X = as in table 24, Y = as in table 24,  $b = 0.012$ ,  $a = 0.00$ ,  $r = 0.861$ ,  $t = 2.93$ ,  $S_b = 0.00421$ ,  $-0.001 \leq i \leq 0.025$  Equation:  $Y = 0.012X$

Table 26. Calculation of the equation and correlation coefficient of average number of living insects per needle on distances from the stem (data of September 26).

	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
	1.5	0.03	2.25	0.0009	0.045
	4.5	0.03	20.25	0.0009	0.135
	7.5	0.14	56.25	0.0196	1.050
	10.5	0.12	110.25	0.0144	1.260
	13.5	0.25	182.25	0.0625	3.375
Total	37.5	0.57	371.25	0.0983	5.865
Ave.	7.5	0.11			

X = as in table 24, Y = as in table 24, b = 0.018, a = -0.03, r = 0.914, t = 3.96, Sb = 0.00435,  $0.004 \leq i \leq 0.032$

Equation:  $Y = 0.018X - 0.03$

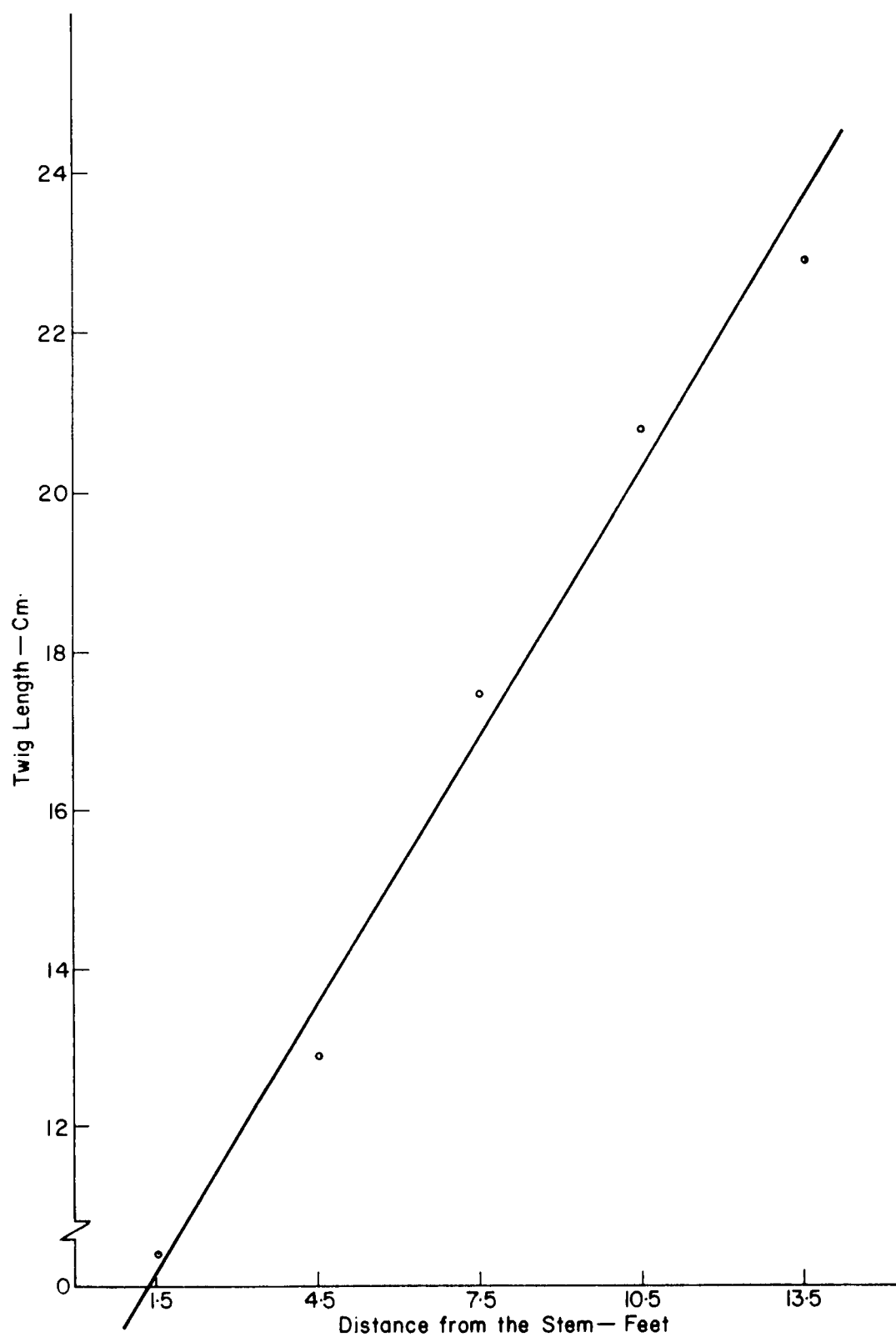
Table 27. Calculation of the equation and correlation coefficient of average lengths of twigs on distances from the stem.

	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
	1.5	10.4	2.25	108.16	15.60
	4.5	12.9	20.25	166.41	58.05
	7.5	17.5	56.25	306.25	131.25
	10.5	20.8	110.25	432.64	218.40
	13.5	22.9	182.25	524.41	309.15
Total	37.5	84.5	371.25	1537.87	732.45
Ave.	7.5	16.9			

X = distances from the stem in feet, Y = average lengths of twigs, b = 1.096, a = 8.7, r = 0.993, t = 14.56, Sb = 0.0765,  $0.853 \leq i \leq 1.339$

Equation:  $Y = 1.096X + 8.700$

Fig. 14 Relationship between twig length and distance from the stem at the low level of the living crown



The twig lengths were also measured every 3 feet horizontally from the stem, at the middle of the low level of the living crowns (Appendix G). The average twig lengths were plotted over distances from the stem (Fig. 14) (Table 27). Significantly linear relationships were found between the twig lengths and distances from the stem.

#### 4. Mortality:

As mentioned, the accurate numbers of dead insects could not be counted, because many of them fell off the needles, and a large proportion of them was eaten completely by predators. Assuming that the probability of loss of dead insects was similar everywhere, the analysis of data will give some information about the factors influencing mortality.

Trees No. 1, 2, 10, 11, 14 and 20 were examined by two analyses of variance, separately for generation 1, and generation 2 (Appendix M) (Tables 28 and 29).

Table 28. Analysis of variance of dead insects among trees levels and exposures (generation 1).

Source	Degrees of freedom	Net sum squares	Mean sum squares	Variance ratio (F)	Significance at 0.05 level
Level (L)	5	0.19	0.095	23.75	H.S.
Exposure (E)	3	0.02	0.007	1.75	N.S.
Tree (T)	5	3.20	0.640	160.00	H.S.
L x E	6	0.07	0.012	3.00	S.
L x T	10	0.12	0.012	3.00	S.
E x T	15	0.10	0.007	1.75	N.S.
L x T x E	30	0.13	0.004		
Total	71	3.83			

Both the analyses of variance (Table 28 and 29) show significant

Table 29. Analysis of variance of dead insects among trees, levels and exposures (generation 2).

Source	Degrees of freedom	Net sum squares	Mean sum squares	Variance ratio (F)	Significance at 0.05 level
Levels (L)	2	0.032	0.0160	26.67	H.S.
Exposures (E)	3	0.005	0.0017	2.83	N.S.
Trees (T)	5	0.130	0.0260	43.33	H.S.
L x E	6	0.002	0.0003	-	N.S.
L x T	10	0.014	0.0014	2.33	S.
E x T	15	0.015	0.0010	1.67	N.S.
L x E x T	30	0.019	0.0006		
Total	71	0.217			

difference within the levels and within the trees. No significant difference was found among the exposures. The significant difference in the interactions indicates that the effects of the factors were not independent. The L x T interaction maybe significant because the actual heights of the sampling levels were different from tree to tree (Appendix E). These differences can be seen well between the marginal and interior trees (e.g. the height of low level of tree No. 4 was 19 feet, and of tree No. 25 was 45 feet).

All the 25 sample trees were also examined by an analysis of variance, where the data of exposures were used as replications (Appendix N) (Table 30). All of the factors, trees, levels and generations, are significant, and all of the interactions are also significant. These results prompted another analysis, testing whether or not the main effects are significantly greater than the first-order interactions (Table 31). The effects of the main factors were significantly greater than the first-order interactions.

The percentages of mortality were tested to determine whether or not the marginal trees with many insects had a higher percentage of insect mortality

(Table 32) (Appendix P).

Table 30. Analysis of variance of dead insects among trees, levels, and generations.

Source	Degrees of freedom	Net sum squares	Mean sum squares	Variance ratio (F)	Significance at 0.05 level	Components of variance
Trees (T)	24	0.86	0.0358	44.75	H.S.	0.00486
Levels (L)	2	0.09	0.0450	56.25	H.S.	0.00087
Gen. (G)	1	0.23	0.2300	287.50	H.S.	0.00298
T x L	48	0.09	0.0019	2.38	S.	0.00055
T x G	24	0.40	0.0167	20.87	H.S.	0.00530
L x G	2	0.01	0.0050	6.25	S.	0.00017
T x L x G	48	0.04	0.0008			0.00080
Total	149	1.72				

Table 31. Variance ratio test between the main factors and first-order interactions.

Source	Degrees of freedom	Net sum squares	Mean sum squares	Variance ratio (F)	Significance at 0.05 level
Trees	24	0.86	0.0358	5.26	H.S.
T x L + T x G	72	0.49	0.0068		
Levels	2	0.09	0.0450	22.50	H.S.
T x L + L x G	50	0.10	0.0020		
Generations	1	0.23	0.2300	14.65	H.S.
T x G + L x G	26	0.41	0.0157		

The degree of mortality (Table 32) was lower in generation 2 than in generation 1. The percentage of mortality was lower on the lower populated trees in generation 1, but this was reversed in population 2.

The percentage of mortality by height on the living crown was also

calculated (Table 33).

Table 32. Percentage of mortality by locality of the trees and generations.

Trees	Average number of dead insects per needle		Average number of living+dead insects per needle		Percentage of mortality	
	marginal	interior	marginal	interior	marginal	interior
Generation 1	0.16	0.02	0.34	0.05	47.1	40.0
Generation 2	0.05	0.01	0.24	0.03	20.8	33.3
Gen. 1 + Gen. 2	0.21	0.03	0.58	0.08	36.2	37.5

Table 33. Percentage of mortality by levels and generations.

Levels	Average number of dead insects per needle		Average number of living+dead insects per needle		Percentage of mortality	
	1	2	1	2	1	2
Low	0.15	0.05	0.35	0.25	42.9	20.0
Medium	0.12	0.04	0.27	0.18	44.4	22.2
High	0.07	0.02	0.11	0.06	63.6	33.3

The percentage of mortality increased with height (Table 33).

##### 5. Need for Further Studies:

A few questions might arise about the sample sizes for further studies.

1. How many trees will be required to determine the population of living and dead insects within 5% of the mean nineteen times out of 20?

On the average determined from sampling 25 trees, 0.26 living insects were found on one needle, the standard deviation (SD) was 0.3227 and the standard error of the mean (SEM) was 0.0065. From these the required sample size will be 2,464 trees.

The mean of the dead insects found was 0.15 per needle with SD = 0.1536 and SEM = 0.0038. The sample size of trees required to determine the dead insects was found as 1,634 trees.



ii. How many twigs will be required within a level to determine the population of living and dead insects within 5% of the mean, nineteen times out of 20?

Four twigs were sampled in each level in this experiment (from North, West, South and East). In an average of 6 trees (No. 1, 2, 10, 11, 14 and 20) 0.35 was the number of living insects per needle on a twig, with  $SD = 0.0565$  and  $SEM = 0.0088$ . The required sample size was found as 41 twigs per level to determine the population of living insects.

The average number of dead insects per needle in a twig was 0.17 with  $SD = 0.0129$  and  $SEM = 0.0043$ . The required sample size was calculated as 9 twigs per level.

iii. How many needles are required within a twig to determine the population of living and dead insects within 5% of the mean nineteen times out of 20? This should be calculated for different levels, but here will be shown only one example.

The mean of the number of living insects at low level and North side in generation 1 of tree No. 1, on June 4 was 0.40 with  $SD = 0.52$  and  $SEM = 0.010$ . A total of 2,704 needles per twig were calculated as the required sample size.

The average number of dead insects per needle was 0.10 at same place and time as before, with  $SD = 0.32$  and  $SEM = 0.0025$ . Then 16,384 needles per twig were calculated as the required sample size.

These sample sizes seem very large, but these numbers would decrease if the limits of error were changed. For example, the required sample size of trees was 2,464 to determine the population of living insects within 5% of the mean. Changing the limits of error to 10%, 616 trees would be required, and with 20% error, only 154 trees would be needed.

Considerable influence on the sample also results from changing the levels of confidence e.g. only 150 trees would be required to determine the

population of living insects within 5 % at the 0.20 confidence level.

Using analyses of variance to determine the influence of various factors may also reduce the need for such large numbers because factors themselves provide replication and partitioning of sum squares may present a very sensitive error term.

✱

## DISCUSSION

As the former chapters show, during the summer of 1960, two main groups of factors were examined: inter-tree differences and intra-tree differences. Two main groups of factors will also be discussed here: the mortality and biotic potential which were only partly investigated.

### 1. Inter Tree Differences:

The power of multiplication of Adelges cooleyi is affected by external and internal conditions of the tree. It is not always easy to determine whether external or internal conditions are responsible, but there is considerable evidence that some trees are more favourable to the multiplication of the insect than others. The inter-tree differences can be divided into several groups.

#### Location of the Trees:

It has been stated by Chrystal (7) that in a dense wood of Douglas fir, Adelges cooleyi occurred chiefly on the trees near to the margin of the forest and the insect was not abundant in the centre of the plantation.

Twenty-five trees were examined around Totem Park during the summer of 1960, 8 of them inside the stand, 13 on the margin and 4 of them in the open. It was found that by analysis of variance, (Table 12) the trees were populated differently by Adelges cooleyi. The Student's "t" distribution showed that generally the significantly more populated trees are growing at the margin of the forest, and the significantly less populated trees are growing at the center of the stand (Table 13). Then the trees were separated into 3 groups (edge-, inside- and open-growth) and the groups were tested against each other by "t" tests. These tests showed abundance to be significantly greater on the marginal and open trees than on the inside trees. No differences were found at the 0.05 level between open and marginal trees.

These differences might be explained by several external conditions of

the tree. The differences between crown shapes or percentage of living crown seem to be the main reason. The proportion of living crown is much smaller on an interior tree than on a marginal tree (Appendix L and O). As shown by several statistical analyses (see chapter: Experimental Results), the abundance of insects is low at the tops of trees. Comparing the abundance of Adelges cooleyi on tree No. 4 to tree No. 25 (Fig. 15), the degree of abundance does not show higher level on tree No. 4 (edge growth) than on tree No. 25 (inside growth) above 40 feet from the ground, where the living crown begins on the interior growth tree. Consequently it is very likely that the lack of the lower part of the living crown of the inside-growth trees is one reason for the differences.

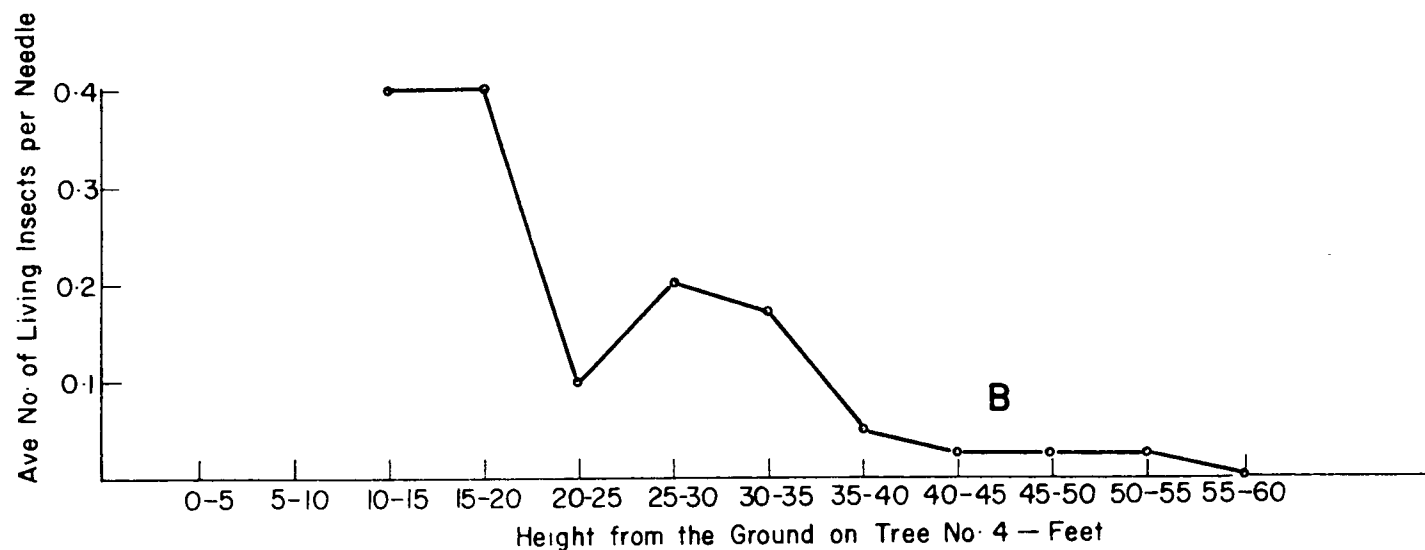
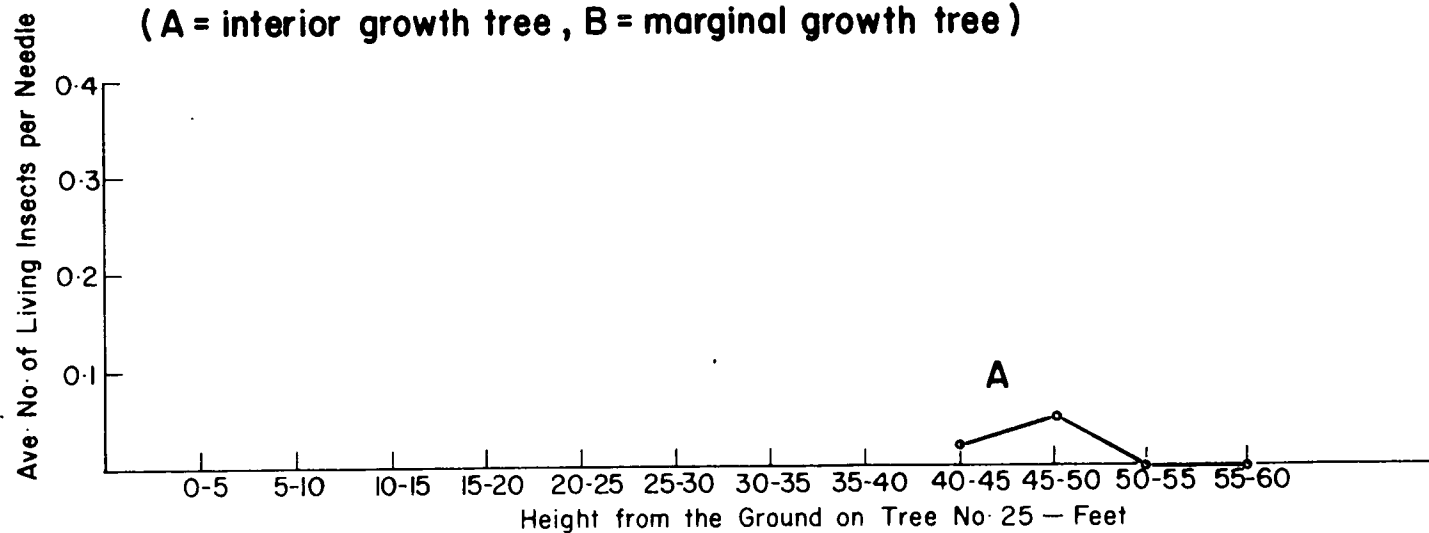
The different abundance of the insect on interior and marginal trees might be explained by the dispersal of the Adelges cooleyi. Chrystal (7) and Cameron (5) stated that the chief factor of the dispersal of the Adelges cooleyi is wind. The speed of wind is always close to zero within a dense stand (15, 27). The different abundance of the insect might be affected also by the different wind pattern, in which the margin of the stand reduces the wind speed and would filter out the transported insects.

Some other climatic factors such as temperature, light and relative humidity differences may influence the different abundance of A. cooleyi on the edge and inside-growth trees.

#### Exposure:

Some differences were found between the differently exposed marginal trees (Table 16, 17 and 18). These differences may be the result of chance only, because only three trees were sampled at each exposure. One thing can be concluded here, the South and West edges of the forest were less populated than the North and East edges, which might be caused by two reasons. The West and South edges of the forest border on roads, where the needles of the trees

**Fig. 15 Relationship between the number of living insects per needle and height on the living crown**  
**(A = interior growth tree , B = marginal growth tree)**



are covered with a considerable amount of dust, which may be unfavorable to the insect. The other reason would be that only suppressed trees were available for study in the East margin of the forest. The high level of abundance on the East side might be caused by the low vigour and the relatively small height of the trees.

The effects of prevailing winds - which are NW with a considerable amount of SE in coastal B.C. (21) - should also be examined. But in Totem Park Adelges cooleyi developed on the summer of 1960 only with the subcycle of the life cycle, in where the wind was not an important part of the natural dispersal.

#### Bud-Opening Time:

Table 15 shows that the significantly more populated trees were mostly early-opening trees, most of the less-populated trees were late-opening. These differences were found both within the edge and interior trees. Only slight differences were shown (significant at 0.3 level) between early and late bud-opening trees.

The reason for these differences might be looked for in the seasonal development of Adelges cooleyi. The hatching of the progeny of sistens generation was just about over when the early-opening trees started to swell. The progredientes and sexuparae settle more readily on the new foliage, but they could not settle on the new foliage of late-opening trees until 2 - 3 weeks after hatching. During this 2 - 3 weeks period the larvae were found on the surface of the opening buds, waiting for the swelling. Many of them died from lack of food, and the lack of stability on the opening buds. They were more exposed to climatic factors on the buds than they were on the lower surface of the needle.

One question may be raised here. Why is the life cycle of the Adelges cooleyi not synchronized to the different bud-opening trees? It is true that

a little displacement is seen in the life cycle on the late-opening trees, which (Appendix F) might be caused by the delay in food supply. It is more likely that there was not any synchronization between the life cycle of the insect and the life cycle of the late bud-opened trees, because the sexuparae migrate to Sitka spruce, and the Sitka spruce has not so wide range in bud swelling, as Douglas fir (16). For this very reason three life cycles should be synchronized. Consequently the life cycle of Adelges cooleyi seems to be determined by two factors, the growth cycle of Douglas fir and the growth cycle of Sitka spruce, and being the primary host Sitka spruce, on which the bisexual forms and reproduction occur, might be the more influential factor.

#### Twig Length:

Considerable variation was found between trees in twig length at the end of the growing period. A slight correlation was found between length of twigs and the abundance of the insects (Fig. 10).

The stylet of Adelges cooleyi is inserted into the spongy mesophyll tissue during most of the time spent on Douglas fir. It appears that the longer-twigged trees have more lush growth, which is more favorable to the insect. Adelges cooleyi would prefer the lush growth, because the stylets would be more easily inserted into the lush-growth needles. For another reason the insect would be favoured by the lush twigs because the solution of the food given by such twigs and needles can be more nutritious for the insects.

Some general factors as the D.B.H., height, crown width, age, percentage of living crown of the total height, bud-opening time and place of the tree were also examined.

These factors were analysed by linear - multiple - regression analysis (Table 19). Two of the eight factors, the percentage of living crown and the length of clear stem, showed significant correlation with the abundance of the insect. Both of these factors mean the same thing: the difference between the

marginal or open trees and interior trees. The trees, having a high percentage of living crown (Appendix L) were highly populated by Adelges cooleyi. These trees are marginal or open trees, having comparatively short clear stem. The trees having low percentage of living crown were lightly populated by the insect. These trees are growing at the center of the forest, having comparatively high length of clear stem.

The total height of the trees has a considerable percent of influence (28.32) (Table 19), which means that the interior trees are a little higher than the outside trees.

The location of the trees should be significantly correlated to the abundance of the insect. The lack of significant result was caused by the fact that the trees were not separated as edge and inside trees in this analysis, but were numbered by different exposures (2 - 8) and open-growth (9) and inside-growth (1) (Appendix O).

The age of the trees as a factor should also show correlation with the abundance, because both Chrystal (7) and Cameron (4, 5) have stated that Adelges cooleyi affects young trees more seriously than older trees. This difference could not be shown in this experiment, because the range in age was very small.

## 2. Intra Tree Variations:

### Exposure:

The trees were sampled from four sides, North, West, South and East. No statistically significant differences appeared between the different sides. This equal abundance of the insect by cardinal points seems to imply only minor microclimatic differences at different cardinal points. Examining a single marginal tree, some differences were seen, the open part of the tree had more insects, than the other parts, but it was more likely influenced by crown shape than cardinal point.



### Height on Living Crown:

Chrystal (7) has stated that the intensity of attack varies by height. This variation was also observed in Totem Park. It was shown by analyses of variance, that low, medium and high levels of living crown were significantly different in abundance of the Adelges cooleyi (Table 2, 12 and 17). Also a significant correlation was found between the abundance of insects and height from the ground. The number of insects per needle decreased linearly with height (Table 20, 21 and 22) (Fig. 11).

Teucher (26) has mentioned, that microclimate is the main factor affecting the intensity of attack, and within the microclimate: temperature and wind are the most important. Geiger (15) and Botvay (3) stated that the temperature during day time is always higher above and in the upper crown, than above the forest floor, and the relative humidity at the same time is always lower above and in the upper crown than above the forest floor. The average difference in temperature is from  $0.5^{\circ}\text{C}$  to  $1.0^{\circ}\text{C}$ , and in R.H. is 3 - 4 % (15). These differences to a smaller degree can be observed foot by foot from the forest floor to the top of the trees (3). It might be considered that the abundance of Adelges cooleyi is influenced by these microclimatic differences. It seems to be suggested by the fact that the percentage of mortality was higher in the medium level than the low level, and in the high level than the medium and low levels (Table 33). The number of unhatched eggs was larger in the medium level than in the low level, and more in the high level than in the medium level. Percentages of unhatched eggs were: low level: 25.9 %, medium level: 33.8 % and high level: 37.0 %.

### Changes in Abundance of Insect in Horizontal Directions of the Tree Crown:

It was shown by regression analyses that slight correlation can be found between abundance of insect and the distances from the stem at the middle of the low level of living crown (Table 24, 25 and 26) (Fig. 13). The number of

insects per needle increased toward the periphery. It may be supposed that this also resulted from microclimatic differences, or Adelges cooleyi looks is less abundant on the shaded twigs. Considerable differences might be supposed in food supply between exposed and shaded twigs, since the needles are noticeably thinner on heavily shaded branches.

#### Twig Length:

As was mentioned, Adelges cooleyi settles more abundantly on the needles of longer twigs. This result might be applied to prove the horizontal distribution of the insect within a tree, because as the lengths of the twigs increased from the stem to the outer crown (Table 27) (Fig. 14), so increased the frequency of the insect.

Examining the vertical distribution of the insect and twig length, the result was opposite. The length of twigs was increasing from the bottom of the living crown to the top by a semi-logarithmic curve (Table 23) (Fig. 12), and the numbers of insect per needle were decreasing linearly from the bottom to the top of the living crown (Table 20, 21 and 22) (Fig. 11). This result seems to show that the twig length, which is one of the many factors affecting the vertical abundance of Adelges cooleyi, was not so effective as others such as microclimatic factors.

#### 3. Mortality:

As mentioned, the number of dead insects could not be counted accurately. This unfortunate fact can be seen well in Fig. 7 and 8, where the mortality curves should follow the curves of living insect but in the reverse direction. It can be seen from the diagrams that the loss of dead insects occurred mostly after the hatching time, when the mortality showed the highest potential. This period appears to be the critical stage of generation 2, when the newly hatched larvae were crawling over needles preparatory to settling down for overwintering. In this period the larvae were not settled in a special place,

the mouth-parts were not inserted into the mesophyll tissue, and consequently they were more exposed to climatic and biotic effects.

It might be considered that the high mortality in generation 2 was caused by climatic factors. Examining the meteorological records (Appendix K) of July and August, the temperature was sometimes extremely high in July, and precipitation low, with 0.03 inches rain in the whole month. Following these the average temperature was very low in August. The average maximum was  $58.32^{\circ}\text{F}$ , and the average minimum was  $55.38^{\circ}\text{F}$ . The average maximum and minimum temperature for August in a 40-years average up to 1955 in Vancouver was  $73^{\circ}$  and  $54^{\circ}\text{F}$  (21). The difference between the average maximums is about  $15^{\circ}\text{F}$ , which seems to be high enough to affect the newly hatched larvae. The loss of dead insects in this period can be explained by the fact that the larvae were not yet settled for overwintering.

The loss of dead insects cannot be seen in generation 1, because one part of this generation was winged. The decrease of the number of living insects per needle was linear (Fig. 5 and 6) and the increase of the number of dead insects per needle was also linear, but the slope of this line is not proven, because of loss of dead insects. The two lines, the line of living insects and the line of mortality are not balanced, because of the loss of the winged part of the generation, and the loss of a part of the dead insects, and the proportion of these two were not or could not be observed.

Examining the line of living insects, the critical stage did not appear, or it was not observed, because the observation started only 2 - 3 weeks after the hatching of generation 1.

It was shown by analyses of variance (Table 28, 29, 30 and 31) that the number of dead insects per needle was significantly different among trees, among levels and among generations. These results indicate that the absolute number of dead insects was higher in such a place where the number of living

insects was higher.

A question can be raised at this point, whether the degree of mortality was larger on the higher-populated trees or not. It was found that (Table 32) the percentage of mortality was higher within the marginal trees than within the inside trees in population 1. The result was the reverse in population 2. Within a tree, the degree of mortality was increased by height, where the absolute numbers of living and dead insects were decreased. So, with one exception, the percentage of mortality was higher on the places where Adelges cooleyi was less abundant. It seems to be that the circumstances of the less-populated places were not suitable for the insect, because the degree of mortality was higher. On the other hand the population of Adelges cooleyi was not so high, even within the heavily populated places that the competition for food or place would play an important part in mortality.

The one exception, which was found in population 1, where the percentage mortality was higher on the heavily populated trees, seems to be caused by the loss of winged forms of the generation. The living winged adults were lost, but the dead ones were counted.

#### 4. Natural Enemies:

No special studies were conducted on how the natural enemies affect the abundance of Adelges cooleyi. It was only noticed that the most important of the natural enemies were the black and yellow ladybird beetles (Coccinellidae) which frequently feed on Adelges cooleyi.

Syphids which are mentioned to be enemies to the Adelges cooleyi (10, 11) were found, but they were not so common as the ladybird beetles.

One species of Hymenopteran parasite was found, which developed in the abdomen of both progredientes and sexuparae. They were not common, only two specimens being found during the summer of 1960.

A large number of Spiders and Red - Spider - Mites occurred around the

settled Adelges and their egg clusters, but their effect on the Adelges cooleyi was not certain.

#### 5. Biotic Potential:

Since reproduction is by cyclical parthenogenesis, the potential rate of reproduction is not limited by the necessity of mating (2, 19) which is believed to be a main factor contributing to the abundance of Adelges cooleyi; bisexual reproduction is necessary in only one generation out of the five.

## SUMMARY

The study took place in the 25-year-old Douglas-fir stand in Totem Park. Twenty-five trees were sampled during the period June 4 to September 24. The sampling was repeated 13 times and 12 sample twigs were drawn from every tree at each survey. The numbers of living and dead insects were observed on ten needles from a twig. Thus 3,900 twigs were cut down, and on 39,000 needles the number of insects was observed, and approximately 10,140 living and 5,850 dead insects were counted.

The growth of foliage and the height and D.B.H. of the sample trees were measured. The crown shape of the 25 trees was studied. The climatic factors, e.g. temperature, RH, precipitation, evaporation, wind and total hours of sunshine, were also studied from available data, during the period April to September.

The collected data were examined by statistical analyses. Eight analyses of variance, 17 regression analyses, and other statistical tests were carried out. From the results of the statistical analyses the inter- and intra-tree differences in abundance of Adelges cooleyi (Gill.) were studied. The mortality of the insect was also examined in relation to several factors.

## CONCLUSIONS

Findings of the study are summarized as follows:

1. Adelges cooleyi was more frequent on the marginal and open - grown trees, than on trees growing in the center of the stand.
2. The insects were less abundant on trees growing at the edge of roadway than on trees exposed to other directions.
3. The insects were slightly less abundant on the late bud-opening trees, than on the early bud-opening, both on trees grown in the interior and on the margin of the stand.
4. The frequency of Adelges cooleyi was greater on the long - twigged trees.
5. Within a tree the number of living insects per needle decreased linearly from the bottom to the top of the living crown, and decreased linearly from the outer part of the crown to the stem.
6. No differences were found in abundance between North, West, South and East sides of single trees.
7. The mortality of Adelges cooleyi was lower on the higher - populated trees (marginal and open) and on the higher-populated parts of the tree (low level).

## APPENDICES

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- Appendix E Table 38. Heights of sampling levels of trees.
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Appendix N Table 52. Average numbers of living and dead insects per needle by level and tree.

Appendix O Table 53. The average number of living insects per needle, related to 8 factors: D.B.H., height, age, crown width, clear stem, % of living crown, bud opening time and location of the trees.

Appendix P Table 54. Percentages of mortality by generation and tree.

Appendix A Table 34. The average number of living and dead insects per needle of generation 1. (The numbers are averaged of 5 sampling periods, from June 4 to July 2).

Level	Low				Medium				High			
Tree No.	N	S	W	E	N	S	W	E	N	S	W	E
No. of living insects.												
1	0.24	0.16	0.11	0.18	0.10	0.22	0.02	0.24	0.02	0.00	0.00	0.00
2	0.42	0.48	0.50	0.04	0.16	0.38	0.11	0.34	0.02	0.02	0.00	0.02
3	0.24	0.20	0.34	-	0.12	0.11	0.22	0.10	0.02	0.12	0.00	0.00
4	0.34	-	0.58	-	0.16	0.08	0.34	-	0.05	0.05	0.00	0.00
5	0.26	0.22	0.46	-	0.28	0.22	0.32	-	0.00	0.06	0.02	0.00
6	0.14	0.16	0.34	-	0.12	0.12	0.12	0.02	0.00	0.05	0.00	0.00
7	0.06	0.02	0.12	-	0.04	0.00	0.02	0.08	0.00	0.00	0.00	0.00
8	0.30	0.20	0.42	0.11	0.22	0.18	0.24	0.16	0.00	0.05	0.00	0.02
9	-	0.06	0.10	0.06	-	0.02	0.00	0.04	0.02	0.00	0.02	0.02
10	0.16	0.40	0.12	0.16	0.08	0.06	0.28	0.24	0.00	0.10	0.00	0.05
11	0.36	0.24	0.44	0.36	0.06	0.04	0.04	0.12	0.00	0.00	0.05	0.00
12	0.26	0.22	-	0.60	0.06	0.08	0.02	0.12	0.00	0.00	0.05	0.00
13	0.34	0.18	-	0.28	0.10	0.14	-	0.22	0.04	0.00	-	0.10
14	0.82	0.66	0.46	0.78	1.04	0.86	0.58	0.76	0.38	0.32	0.30	0.42
15	0.12	0.12	-	0.26	0.14	0.16	-	0.40	0.06	0.04	-	0.30
16	-	0.06	0.08	0.04	0.02	0.02	0.02	0.00	0.00	0.00	0.05	0.00
17	0.06	0.04	0.00	0.06	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.05
18	0.04	0.04	0.02	0.00	0.00	0.00	0.05	0.10	0.00	0.10	0.00	0.00
19	0.04	0.06	0.04	0.04	0.00	0.05	0.00	0.05	0.00	0.00	0.00	0.00
20	0.08	0.08	0.00	0.06	0.04	0.02	0.04	0.00	0.02	0.06	0.00	0.00
21	0.04	0.04	0.02	0.04	0.05	0.00	0.02	0.00	0.08	0.05	0.00	0.00
22	-	0.28	0.22	0.11	0.36	0.46	0.30	0.30	0.11	0.12	0.12	0.18
23	0.08	0.11	-	-	0.28	0.12	0.24	0.16	0.12	0.08	0.08	0.12
24	0.02	0.02	0.04	0.06	0.02	0.00	0.02	0.02	top broken			
25	0.04	0.02	0.02	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
No. of dead insects.												
1	0.20	0.10	0.08	0.12	0.28	0.06	0.32	0.11	0.06	0.04	0.06	0.02
2	0.18	0.26	0.20	0.08	0.12	0.16	0.12	0.18	0.06	0.02	0.08	0.02
3	0.12	0.20	0.26	-	0.16	0.06	0.08	0.04	0.04	0.02	0.02	0.02
4	0.18	-	0.20	-	0.18	0.06	0.16	-	0.00	0.00	0.05	0.05
5	0.22	0.34	0.26	-	0.22	0.11	0.28	-	0.00	0.02	0.02	0.04
6	0.14	0.12	0.10	-	0.04	0.10	0.10	0.10	0.02	0.00	0.00	0.05
7	0.14	0.18	0.34	-	0.22	0.12	0.12	0.06	0.05	0.00	0.00	0.00
8	0.10	0.26	0.24	0.11	0.16	0.22	0.18	0.08	0.05	0.12	0.00	0.00
9	-	0.04	0.04	0.00	-	0.08	0.00	0.00	0.00	0.02	0.00	0.04
10	0.08	0.20	0.30	0.22	0.10	0.06	0.40	0.12	0.05	0.00	0.00	0.00
11	0.20	0.30	0.22	0.22	0.06	0.10	0.12	0.06	0.00	0.05	0.05	0.05
12	0.18	0.11	-	0.16	0.06	0.10	0.02	0.08	0.05	0.00	0.00	0.05
13	0.16	0.32	-	0.20	0.12	0.04	-	0.16	0.10	0.10	-	0.06
14	0.74	0.84	0.58	0.72	0.64	0.42	0.80	0.66	0.72	0.56	0.66	0.68
15	0.04	0.06	-	0.20	0.18	0.12	-	0.38	0.11	0.10	-	0.18
16	-	0.10	0.04	0.02	0.00	0.04	0.02	0.02	0.05	0.05	0.00	0.00
17	0.06	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
18	0.04	0.04	0.02	0.02	0.05	0.05	0.00	0.00	0.05	0.00	0.00	0.00
19	0.06	0.06	0.04	0.06	0.00	0.00	0.20	0.05	0.00	0.00	0.00	0.00
20	0.08	0.08	0.02	0.08	0.10	0.02	0.02	0.04	0.04	0.04	0.02	0.02
21	0.04	0.04	0.02	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
22	-	0.16	0.10	0.06	0.16	0.26	0.10	0.20	0.08	0.12	0.16	0.12
23	0.10	0.10	-	-	0.16	0.12	0.10	0.08	0.08	0.11	0.11	0.10
24	0.02	0.04	0.04	0.02	0.02	0.02	0.00	0.02	top broken			
25	0.02	0.00	0.00	0.02	0.00	0.05	0.00	0.05	0.05	0.10	0.00	0.00



Appendix C

Table 36. Average numbers of living insects per needle by period and tree at the low level on the living crown.

Tree No.	Generation 1					Generation 2							
	Sampling periods (week)					Sampling periods (week)							
	0	1	2	3	4	0	1	2	3	4	6	9	11
1	0.28	0.15	0.18	0.13	0.18	0.30	0.30	0.43	0.25	0.20	0.20	0.10	0.13
2	0.53	0.55	0.40	0.28	0.15	0.38	0.60	0.35	0.28	0.20	0.13	0.18	0.23
3	0.50	0.27	0.30	0.07	0.17	0.10	0.47	0.50	0.40	0.17	0.23	0.37	0.27
4	0.50	0.60	0.55	0.30	0.35	0.75	0.75	0.65	0.25	0.60	0.30	0.45	0.40
5	0.40	0.40	0.33	0.20	0.23	0.27	0.50	0.73	0.43	0.23	0.30	0.27	0.27
6	0.20	0.23	0.23	0.20	0.20	0.23	0.27	0.17	0.17	0.15	0.13	0.07	0.27
7	0.07	0.03	0.27	0.03	0.03	0.00	0.10	0.13	0.10	0.10	0.10	0.03	0.10
8	0.45	0.25	0.13	0.28	0.23	0.35	0.38	0.28	0.18	0.15	0.43	0.18	0.20
9	0.13	0.03	0.13	0.10	0.00	0.00	0.07	0.10	0.13	0.00	0.23	0.00	0.00
10	0.38	0.30	0.13	0.15	0.10	0.00	0.00	0.08	0.08	0.13	0.23	0.08	0.08
11	0.45	0.43	0.53	0.25	0.23	0.30	0.35	0.23	0.20	0.20	0.20	0.13	0.15
12	0.70	0.57	0.33	0.13	0.07	0.47	0.53	0.50	0.10	0.00	0.13	0.27	0.10
13	0.43	0.23	0.37	0.23	0.07	0.03	0.00	0.03	0.03	0.07	0.00	0.00	0.00
14	0.95	0.73	0.83	0.60	0.33	1.83	1.63	1.93	1.90	1.43	1.05	0.98	1.00
15	0.03	0.20	0.30	0.20	0.10	0.00	0.00	0.30	0.33	0.07	0.13	0.17	0.07
16	0.10	0.00	0.10	0.03	0.07	0.00	0.03	0.10	0.00	0.13	0.03	0.00	0.00
17	0.08	0.03	0.03	0.08	0.00	0.00	0.03	0.00	0.05	0.03	0.00	0.00	0.03
18	0.03	0.00	0.05	0.03	0.03	0.00	0.03	0.03	0.05	0.00	0.03	0.03	0.03
19	0.05	0.05	0.03	0.05	0.05	0.00	0.05	0.08	0.13	0.00	0.08	0.03	0.05
20	0.10	0.05	0.05	0.05	0.03	0.00	0.03	0.13	0.13	0.05	0.08	0.03	0.03
21	0.05	0.05	0.08	0.03	0.00	0.03	0.05	0.10	0.03	0.03	0.03	0.00	0.03
22	0.27	0.33	0.27	0.07	0.13	0.23	0.33	0.40	0.23	0.20	0.17	0.17	0.10
23	0.15	0.15	0.05	0.05	0.15	0.00	0.00	0.20	0.20	0.30	0.10	0.10	0.05
24	0.03	0.03	0.08	0.03	0.03	0.00	0.00	0.03	0.08	0.10	0.08	0.00	0.03
25	0.03	0.05	0.00	0.03	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.05
Ave.	0.28	0.23	0.23	0.14	0.12	0.21	0.26	0.30	0.23	0.18	0.17	0.15	0.15

# Appendix D

Table 37. Average numbers of dead insects per needle by period and tree at the low level on the living crown.

Tree No.	Generation 1					Generation 2								
	Sampling periods (week)					Sampling periods (week)								
	0	1	2	3	4	0	1	2	3	4	6	9	11	
1	0.05	0.10	0.15	0.15	0.18	0.08	0.05	0.18	0.05	0.10	0.10	0.15	0.18	
2	0.18	0.18	0.15	0.15	0.25	0.05	0.05	0.03	0.10	0.00	0.08	0.13	0.15	
3	0.23	0.10	0.20	0.20	0.23	0.03	0.07	0.13	0.10	0.07	0.10	0.17	0.10	
4	0.15	0.15	0.20	0.25	0.20	0.00	0.00	0.10	0.10	0.10	0.10	0.25	0.20	
5	0.23	0.23	0.33	0.23	0.33	0.00	0.03	0.07	0.10	0.03	0.13	0.13	0.17	
6	0.13	0.10	0.17	0.13	0.07	0.07	0.07	0.10	0.07	0.07	0.03	0.17	0.03	
7	0.23	0.27	0.20	0.10	0.30	0.00	0.00	0.03	0.03	0.00	0.03	0.03	0.07	
8	0.23	0.15	0.18	0.25	0.13	0.03	0.05	0.03	0.10	0.08	0.18	0.08	0.05	
9	0.07	0.03	0.03	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.00	
10	0.33	0.08	0.23	0.18	0.20	0.00	0.00	0.03	0.03	0.05	0.05	0.05	0.10	
11	0.38	0.20	0.23	0.23	0.15	0.00	0.03	0.05	0.05	0.08	0.08	0.08	0.10	
12	0.23	0.17	0.20	0.07	0.13	0.00	0.07	0.03	0.03	0.00	0.10	0.10	0.07	
13	0.13	0.03	0.23	0.30	0.33	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03	
14	0.63	0.65	0.70	0.78	0.80	0.10	0.03	0.10	0.08	0.20	0.18	0.30	0.23	
15	0.03	0.07	0.23	0.10	0.10	0.00	0.00	0.03	0.00	0.03	0.10	0.03	0.00	
16	0.10	0.00	0.03	0.10	0.03	0.00	0.00	0.03	0.00	0.00	0.10	0.00	0.00	
17	0.00	0.00	0.08	0.05	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	
18	0.03	0.05	0.03	0.00	0.05	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.00	
19	0.03	0.08	0.03	0.08	0.08	0.00	0.00	0.00	0.05	0.03	0.05	0.05	0.00	
20	0.05	0.00	0.10	0.10	0.10	0.00	0.00	0.05	0.00	0.05	0.00	0.03	0.03	
21	0.03	0.00	0.05	0.05	0.00	0.00	0.00	0.08	0.03	0.00	0.00	0.03	0.05	
22	0.07	0.10	0.03	0.13	0.20	0.00	0.00	0.03	0.07	0.13	0.03	0.03	0.20	
23	0.05	0.15	0.10	0.05	0.15	0.00	0.00	0.05	0.05	0.10	0.15	0.00	0.10	
24	0.03	0.05	0.08	0.03	0.00	0.00	0.00	0.03	0.03	0.03	0.03	0.03	0.00	
25	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	
Ave.	0.15	0.12	0.16	0.15	0.16	0.014	0.019	0.050	0.044	0.048	0.067	0.074	0.074	

## Appendix E

Table 38. Heights of sampling levels of trees.

Tree No.	Height of levels in feet			Levels and directions where could not be found living branches
	Low	Medium	High	
1	21	27	33	
2	16	26	35	
3	15	27	39	LE
4	19	36	53	LE, LS, ME
5	17	36	55	LE, ME
6	21	39	57	LE
7	16	33	50	LE
8	20	36	52	
9	10	16	22	LN, MN
10	19	37	55	
11	17	32	47	
12	16	31	46	LW
13	8	12	16	LW, MW, HW
14	5	11	17	
15	6	10	14	LW, MW, HW
16	25	39	54	LN
17	43	53	63	
18	36	42	48	
19	39	43	47	
20	21	30	39	
21	41	53	65	
22	0.6	1.3	2	LN
23	2	4	6	LW, LE
24	19	27	-	
25	45	57	61	

Key: L = Low level, M = Medium level, H = High level

W = West, N = North, E = East, S = South

## Appendix F

Table 39. Changes in development of *Adelges cooleyi*.

Tree No.	Date							
	June 4	June 11	June 18	June 25	July 2	July 9	July 16	Fall Winter
1	PSN2	PSN3+A+E	A+E	A+E+H	A+H	H	H	H
2	PSN1+2	PSN3+A	A+E	A+E	A+E+H	E+H	H	H
3	PSN1	PSN2+3	PSN3+A+E	A+E	A+E	E+A+H	E+H	H
4	PSN3	PSN3+A+E	A+E	A+E	A+E+H	E+H	H	H
5	PSN2	PSN3+A+E	A+E	A+E	A+E+H	E+H	H	H
6	PSN1+2	PSN3+A	A+E	A+E	A+E+H	E+A+H	H	H
7	PSN1	PSN2+3	PSN3+A+E	A+E	A+E+H	A+E+H	E+H	H
8	PSN1+2	PSN3+A+E	A+E	A+E	A+E+H	E+H	H	H
9	PSN1+2	PSN3+A	A+E	A+E	A+E+H	E+H	H	H
10	PSN1+2	PSN3+A	A+E	A+E	A+E+H	E+H	H	H
11	PSN3	PSN3+A+E	A+E	A+E	A+E+H	E+H	H	H
12	PSN2+3	PSN3+A+E	A+E	A+E	A+E+H	E+H	E+H	H
13	PSN2+3	PSN3+A+E	A+E	A+E	A+E+H	A+E+H	H	H
14	PSN2+3	PSN3+A+E	A+E	A+E	A+E+H	E+H	H	H
15	PSN1+2	PSN3+A	A+E	A+E	A+E+H	E+H	E+H	H
16	PSN2	PSN3+A	PSN3+A+E	A+E	A+E	A+E+H	E+H	H
17	PSN1+2	PSN2+3+A	A+E	A+E	A+E+H	H	H	H
18	PSN1	PSN2+3	PSN3+A+E	A+E	A+E	A+E+H	E+H	H
19	PSN2+3	PSN3+A+E	A+E	A+E+H	A+E+H	A+H+E	H	H
20	PSN2+3	PSN3+A+E	A+E	A+E	A+E+H	E+H	H	H
21	PSN2+3	PSN3+A+E	A+E	A+E+H	E+H	E+H	H	H
22	PSN2+3	PSN3+A+E	A+E	A+E	A+E+H	E+H	H	H
23	PSN1+2	PSN3+2	PSN3+A+E	A+E	A+E	A+E+H	E+H	H
24	PSN1	PSN2+3	PSN3+A+E	A+E	A+E	E+H	H	H
25	PSN1+2	PSN3+A	A+E	A+E	E+H	H	H	H

Key: N = Larva, A = Adult, PS = Progrediens and Sexupara, E = Egg,

1,2,3 = Instars (1 means first and second instars), H = Neosistens

Appendix G

Table 40. Number of living insects per needle and average twig lengths change by height on the living crown.  
(Averaged data of tree No. 4, 10 and 25).

Date	Height levels in feet											
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60
Number of insects per needle												
June 5	-	-	0.22	0.37	0.27	0.19	0.10	0.11	0.03	0.02	0.02	0.00
July 25	-	-	0.32	0.27	0.10	0.19	0.03	0.01	0.04	0.03	0.00	0.00
Sept. 26	-	-	0.18	0.20	0.10	0.11	0.06	0.00	0.02	0.02	0.01	0.00
Average twig length in cm.												
Sept. 26	-	-	20.0	20.3	19.4	19.5	20.6	19.9	20.9	21.1	22.2	23.0

Table 41. Number of living insects per needle and average twig lengths change horizontally within the living crown, at the middle of low level of the trees. (Averaged data of tree No. 4, 10 and 25).

Date	Distances from the stem in feet					
	0-3	3-6	6-9	9-12	12-15	15-18
Number of insects per needle						
June 5	0.02	0.09	0.16	0.24	0.10	-
July 25	0.01	0.03	0.14	0.10	0.15	-
Sept. 26	0.03	0.03	0.14	0.12	0.25	-
Average twig length in cm.						
Sept. 26	10.4	12.9	17.5	20.8	22.9	-



# Appendix H

Table 42. The growth of foliage by level and time on trees No. 14 and 15.

Tree No.	Level	Date												
		June 4	June 11	June 18	June 25	July 2	July 9	July 16	July 23	July 30	Aug. 6	Aug. 20	Sept. 3	Sept. 24
		Twig lengths in cm.												
14	Low	3.7	5.6	7.0	7.4	7.9	8.0	8.1	8.3	8.3	8.4	8.5	8.6	8.6
	Med.	4.6	5.5	6.8	7.6	8.5	9.6	9.7	9.8	9.8	10.0	10.1	10.1	10.1
	High	5.8	8.1	9.4	12.5	13.6	15.4	16.8	16.9	17.2	17.3	17.4	17.5	17.5
15	Low	1.9	2.6	3.8	4.4	4.8	5.6	6.5	6.9	7.0	7.0	7.2	7.2	7.2
	Med.	2.3	2.8	3.7	4.8	5.7	6.6	7.9	9.4	9.6	9.6	9.8	9.9	9.9
	High	3.1	4.4	5.8	6.6	8.0	9.2	10.7	11.2	11.3	11.4	11.6	11.7	11.8

## Appendix I

Table 43. Calculation of the equation and correlation coefficient of average number of living insects per needle on average twig lengths.

Tree No.	X	Y	X <sup>2</sup>	Y <sup>2</sup>	XY
1	8.4	0.42	70.56	0.1764	3.528
2	6.0	0.65	36.00	0.4225	3.900
3	6.4	0.61	40.96	0.3721	3.904
4	15.9	0.98	252.81	0.9604	15.582
5	8.7	0.69	75.69	0.4761	6.003
6	7.7	0.39	59.29	0.1521	3.003
7	6.3	0.15	39.69	0.0225	0.945
8	9.8	0.55	96.04	0.3025	5.390
9	9.3	0.14	86.49	0.0196	1.302
10	23.6	0.29	556.96	0.0841	6.844
11	13.6	0.59	184.96	0.3481	8.024
12	7.3	0.62	53.29	0.3844	4.526
13	6.8	0.29	46.24	0.0841	1.972
14	7.2	2.13	51.84	4.5369	15.336
15	6.1	0.30	37.21	0.0900	1.830
16	4.1	0.10	22.09	0.1000	0.470
17	4.2	0.05	17.64	0.0025	0.210
18	3.8	0.05	14.44	0.0025	0.190
19	6.0	0.10	36.00	0.0100	0.600
20	5.8	0.12	33.64	0.0144	0.696
21	5.1	0.07	26.01	0.0049	0.357
22	2.9	0.42	8.41	0.1764	1.218
23	8.7	0.23	75.69	0.0529	2.001
24	3.1	0.08	9.61	0.0064	0.248
25	5.4	0.03	29.16	0.0009	0.162
Total	192.8	10.05	1960.72	8.7127	88.241
Ave.	7.71	0.402			

X = average twig length at the low level of the trees, Y = number of living insects per needle,  $b = 0.023$ ,  $a = 0.2247$ ,  $r = 0.228$ ,  $t = 0.112$ ,  $S_b = 0.02013$ ,  $-0.019 \leq i \leq 0.065$

The calculation without trees No. 10 and 14:

$b = 0.058$ ,  $a = -0.08$ ,  $r = 0.680$ ,  $t = 4.25$ ,  $S_b = 0.01375$ ,  $0.030 \leq i \leq 0.086$

Equation:  $Y = 0.058X - 0.08$

## Appendix J

Table 44. The average length of twigs by level and tree.

Tree No.	June 4			September 26		
Level	Low	Medium	High	Low	Medium	High
1	3.0	3.9	6.8	8.4	8.6	18.6
2	0.6	0.7	1.0	6.0	6.1	11.3
3	0.4	0.4	0.7	6.4	7.6	10.8
4	3.5	5.2	7.1	15.9	15.0	20.1
5	2.1	3.3	4.5	8.7	9.6	11.7
6	4.5	5.6	6.2	7.7	9.3	21.9
7	0.0	0.0	0.0	6.3	12.4	18.7
8	3.5	3.5	3.6	9.8	10.6	11.1
9	2.5	3.1	3.1	9.3	8.9	8.5
10	3.7	4.0	5.1	23.6	24.7	26.6
11	6.1	6.7	7.5	13.6	17.2	19.9
12	3.4	3.7	4.9	7.3	9.1	10.6
13	3.2	4.0	3.8	6.8	6.5	6.1
14	5.0	5.6	6.3	7.2	8.0	13.4
15	2.1	2.4	2.8	6.1	8.3	10.7
16	1.8	2.3	3.4	4.7	7.0	13.3
17	0.0	0.0	0.0	4.2	6.7	12.7
18	1.0	1.1	1.4	3.8	5.3	9.8
19	2.1	3.0	3.7	6.0	6.2	9.4
20	1.2	1.9	2.8	5.8	6.8	10.2
21	2.0	2.7	3.6	5.1	5.2	6.9
22	1.7	2.5	3.0	2.9	4.3	6.8
23	1.0	1.3	1.7	8.7	12.7	17.7
24	0.0	0.0	0.0	3.1	3.5	-
25	2.1	2.6	3.2	5.4	6.6	10.4

## Appendix K

Table 45. Climatological Station Report (April 1960, Vancouver U.B.C.).

Date	Air temperature F		RH		Rain inches	Evapo-ration	Wind mileage past 24 hours	Sunshine total hours
	Max.	Min.	AM	PM				
1	46.5	38.9	93	74	0.14	0.100		0.2
2	49.7	43.8	96	96	0.19	0.021		
3	53.7	48.8	90	70	0.10	0.022		8.1
4	59.7	45.9	85	80		0.106		4.5
5	59.8	44.9	93	85		0.090		6.3
6	50.4	42.0	86	75		0.090		9.4
7	55.6	46.8	68	59		0.128		9.4
8	64.4	50.4	79	87		0.177		0.9
9	57.8	40.2	79	56	0.14	0.043		9.8
10	51.7	36.4	74	65		0.110		8.9
11	51.8	44.1	98	66	0.07	0.115		6.8
12	53.6	42.0	90	70	0.04	0.083		2.8
13	52.3	40.3	95	77	0.13	0.071		
14	48.0	41.2	77	70	0.14	0.064		4.4
15	48.3	37.5	85	78	0.17	0.106		9.2
16	50.3	37.3	82	60		0.137		4.4
17	49.5	42.4	90	48	0.07	0.084		9.5
18	53.0	41.3	88	93	0.08	0.094		
19	46.6	40.9	84	86	0.41	0.050		1.5
20	49.2	42.5	79	77	0.28	0.028		6.0
21	49.4	36.7	87	73		0.090		10.2
22	47.4	38.5	85	53		0.115		7.4
23	52.8	42.8	71	56		0.078		0.5
24	58.0	43.2	88	64	0.06	0.036		0.9
25	57.3	42.0	86	61	0.01	0.120		5.6
26	57.5	45.8	89	55	0.01	0.046		10.1
27	60.4	43.3	77	49		0.187		13.1
28	63.0	47.9	73	52		0.234		13.3
29	62.2	48.6	83	78		0.177		10.7
30	59.0	46.5	88	74		0.135		4.9
31								
Sum	1618.9	1282.9	2538	2087	2.04	2.847		178.8
Mean	53.96	42.76	84.60	69.57	0.068	0.095		5.96

## Appendix K

Table 46. Climatological Station Report (May 1960, Vancouver U.B.C.).

Date	Air temperature F		RH		Rain inches	Evapo-ration	Wind mileage past 24 hours	Sunshine total hours
	Max.	Min.	AM	PM				
1	57.8	47.4	81	73		0.090	120	0.8
2	57.7	47.3	94	89		0.086	100	
3	53.5	45.3	94	86	0.090	0.055	97	0.1
4	51.0	45.8	94	87	0.032	0.017	50	
5	54.1	48.0	89	60		0.048	120	6.8
6	59.3	51.4	98	96	0.370	0.108	100	0.3
7	59.3	46.6	86	63	0.380	0.032	89	9.4
8	56.4	42.2	78	65		0.163	68	6.2
9	54.9	47.4	64	62		0.188	67	6.1
10	71.7	53.2	93	94	0.080	0.130	66	0.9
11	57.9	50.1	92	85	0.420	0.024	69	
12	55.1	50.6	94	55	0.443	0.023	59	7.4
13	60.2	45.0	79	57		0.177	80	10.0
14	59.3	48.2	72	57		0.184	82.5	10.1
15	57.6	43.8	79	62		0.158	69.5	5.6
16	56.9	45.8	98	74	0.215	0.090	59.5	2.4
17	54.1	42.3	95	76	0.160	0.080	86	6.6
18	53.3	43.2	90	57	0.070	0.057	77	6.5
19	58.3	46.5	74	96		0.152	76.5	
20	49.0	45.8	74	62	0.750		110	10.6
21	53.3	41.2	89	65	0.205	0.133	92	9.1
22	53.4	42.0	87	58	0.017	0.141	105	9.7
23	55.5	40.3	71	60		0.178	74	12.0
24	58.8	47.5	68	66		0.220	112.5	10.0
25	60.1	49.5	67	60		0.180	106	3.7
26	61.7	48.5	87	75	0.270	0.068	123.5	1.2
27	57.6	46.3	90	72	0.045	0.029	75.5	1.5
28	55.9	49.0	78	62		0.084	97	3.4
29	60.4	48.6	79	82		0.114	70.5	
30	56.3	50.8	94	82	0.165	0.011	108	0.9
31	60.6	49.0	81	69	0.050	0.051	142	7.1
Sum	1770.7	1448.6	2609	2207	3.762	3.071	2752.0	148.4
Mean	57.12	46.73	84.2	71.2	0.1213	0.0991	88.8	4.79

## Appendix K

Table 47. Climatological Station Report (June 1960, Vancouver U.B.C.).

Date	Air temperature F		RH		Rain inches	Evapo-ration	Wind mileage past 24 hours	Sunshine total hours
	Max.	Min.	AM	PM				
1	62.2	49.8	84	72		0.182	101	3.7
2	65.8	52.2	86	74		0.116	102.5	2.4
3	68.5	54.0	91	70		0.121	79	11.5
4	61.3	45.2	67	72		0.208	128	5.6
5	63.3	53.8	68	62		0.145	67.5	7.1
6	66.7	50.8	64	58		0.218	111	14.4
7	59.8	51.0	74	70		0.269	140	14.4
8	58.5	45.5	82	65		0.186	78	13.4
9	63.0	49.8	68	57		0.238	60	14.2
10	66.6	53.5	67	77		0.267	75	3.6
11	65.7	52.5	89	72		0.133	83	10.3
12	65.0	51.6	83	72		0.189	64.5	9.8
13	69.7	55.5	70	70		0.230	83.5	1.4
14	63.9	52.4	81	96		0.123	96	0.3
15	59.7	50.4	94	96	0.170	0.055	55.5	0.1
16	58.1	51.4	69	61	0.170		135	11.9
17	62.6	49.9	75	57		0.271	84.5	10.1
18	63.3	48.8	70	57		0.186	104	3.3
19	62.5	47.9	77	75		0.118	73	9.8
20	59.3	47.2	92	68	0.041	0.209	96.5	1.0
21	60.7	49.1	85	77		0.103	88	3.0
22	59.8	48.4	79	71		0.110	56	14.3
23	66.6	53.6	72	75		0.198	68	12.6
24	72.6	57.1	82	78		0.247	88.5	4.1
25	67.0	54.3	84	79	0.017	0.109	95.5	
26	63.4	53.8	83	83		0.093	43	
27	61.1	55.9	82	70		0.075	46.5	2.2
28	67.3	52.5	74	56		0.156	44	14.3
29	69.0	54.2	75	59		0.222	72.5	12.6
30	71.9	55.5	81	79		0.261	104	0.6
31								
Sum	1925.8	1547.6	2348	2128	0.398	5.038	2523.5	212.0
Mean	64.19	51.59	78.3	70.0	0.0132	0.1679	84.12	7.0

## Appendix K

Table 48. Climatological Station Report (July 1960, Vancouver U.B.C.).

Date	Air temperature F		RH		Rain inches	Evapo- ration	Wind mileage past 24 hours	Sunshine total hours
	Max.	Min.	AM	PM				
1	63.3	52.8	85	96		0.122	105.5	1.1
2	61.7	51.7	78	68	0.030	0.077	109.5	13.8
3	61.6	52.3	80	68		0.178	65	14.6
4	68.4	54.6	87	73		0.246	74.5	14.1
5	68.6	60.3	87	56		0.254	117	14.4
6	75.9	61.5	65	44		0.310	99	14.5
7	81.5	57.4	78	64		0.282	58	14.2
8	72.1	49.9	76	60		0.302	158.5	14.5
9	65.8	55.0	95	65		0.243	141	14.4
10	67.9	50.3	78	69		0.285	78	8.7
11	66.2	54.1	71	58		0.166	86	7.0
12	72.8	56.8	70	59		0.200	32	11.3
13	82.2	58.9	79	65		0.266	84	9.5
14	71.5	57.6	65	56		0.263	85	12.0
15	70.8	56.4	66	59		0.265	75	10.2
16	77.1	60.3	63	49		0.182	70	12.6
17	81.4	60.3	69	73		0.340	85	14.3
18	81.4	59.5	84	70		0.291	60	14.1
19	73.8	59.4	81	70		0.289	140	14.1
20	68.6	57.4	83	68		0.290	130	14.0
21	69.8	55.3	81	64		0.245	85	13.9
22	72.0	52.0	78	67		0.233	95	11.9
23	68.2	51.0	80	58		0.234	78	13.9
24	67.4	52.0	77	64		0.253	82	14.1
25	67.5	56.8	87	75		0.191	75.5	14.1
26	71.8	59.4	71	55		0.313	105	12.4
27	77.0	63.8	66	50		0.259	90.5	8.4
28	77.2	60.6	84	47		0.214	49.5	13.8
29	78.0	62.8	68	47		0.302	61.5	13.4
30	87.4	65.6	64	50		0.285	67	8.1
31	76.5	58.3	83	71		0.342	140	10.8
Sum	2245.4	1764.1	2379	1938	0.030	7.722	2782.0	378.2
Mean	72.43	56.91	76.7	62.5		0.2491	89.74	12.2

## Appendix K

Table 49. Climatological Station Report (August 1960, Vancouver U.B.C.).

Date	Air temperature F		RH		Rain inches	Evapo-ration	Wind mileage past 24 hours	Sunshine total hours
	Max.	Min.	AM	PM				
1	59.2	56.9	87	72		0.183	98.5	0.8
2	60.6	58.7	89	78		0.146	85	2.5
3	59.9	58.2	90	68		0.118	56.5	4.2
4	58.9	55.0	79	63		0.175	96	4.4
5	61.0	57.2	79	69		0.116	61	13.6
6	61.1	58.4	85	71		0.188	91	13.3
7	63.3	60.6	85	39		0.281	109	13.7
8	74.0	58.8	40	27		0.305	108.5	13.6
9	74.5	60.2	43	21		0.342	61.0	13.5
10	61.4	58.0	83	67		0.349	97	13.0
11	61.3	57.1	77	63		0.238	143	12.9
12	59.8	56.7	84	73		0.224	73	8.5
13	57.6	54.5	83	51		0.229	88.5	8.5
14	53.2	62.4	94	89	0.005	0.245	95	0.2
15	56.0	52.2	78	73	0.043	0.031	73	8.1
16	55.0	54.7	98	93	0.163	0.122	96.5	
17	59.3	58.0	93	82	0.230	0.013	120	
18	61.9	60.0	89	69		0.077	75.5	6.9
19	58.8	57.1	90	64		0.172	72.5	9.2
20	61.7	59.9	89	56		0.165	68.5	8.5
21	50.2	49.5	96	94	0.220	0.110	99	1.4
22	52.0	51.0	94	65	0.310	0.108	110.5	4.3
23	53.8	51.9	89	91		0.108	88.5	0.4
24	53.5	53.0	96	72	0.360	0.006	62	5.0
25	54.8	53.3	91	91	0.060	0.126	101	
26	54.0	53.2	94	71	0.435	0.001	83	2.2
27	55.3	53.2	87	60		0.087	83	6.0
28	53.5	53.0	96	98	0.015	0.176	105.5	
29	54.2	50.4	77	70	0.380	0.075	129	
30	54.0	52.9	93	98	0.155	0.049	103.5	
31	54.1	50.9	80	56	0.640	0.018	103	11.0
Sum	1807.9	1716.9	2628	2154	3.013	4.583	2837.0	182.7
Mean	58.32	55.38	84.8	69.5	0.0972	0.1478	91.52	5.9



## Appendix K

Table 50. Climatological Station Report (September 1960, Vancouver U.B.C.).

Date	Air temperature F		RH		Rain inches	Evapo- ration	Wind mileage past 24 hours	Sunshine total hours
	Max.	Min.	AM	PM				
1	50.3	48.0	84	71		0.140	52	11.1
2	53.8	50.5	80	77		0.148	74.5	11.6
3	55.8	51.0	73	77		0.127	68.5	9.3
4	56.0	52.3	79	91	0.100	0.146	112.5	1.1
5	54.2	51.0	80	62	0.135	0.075	96	10.3
6	52.8	49.7	82	68		0.126	62.5	9.6
7	53.1	49.3	76	83		0.153	93.5	11.4
8	55.3	53.5	86	68		0.176	93.5	11.1
9	58.9	52.0	63	43		0.176	83.5	11.1
10	59.1	52.7	66	49		0.153	53.5	10.9
11	61.1	54.7	67	39		0.161	46	10.7
12	62.1	57.5	75	86		0.146	52.5	2.0
13	56.1	55.0	93	80		0.049	68	9.1
14	55.7	55.1	96	93		0.093	42.5	1.2
15	54.5	54.3	98	79		0.070	37	7.8
16	56.7	56.1	96	81		0.087	59	7.1
17	51.8	51.8	100	82		0.123	56	
18	54.7	53.5	93	91	0.010	0.036	99.5	
19	55.5	55.2	98	64	0.405	0.017	116	6.6
20	49.5	47.2	84	84	0.120	0.155	164.5	8.8
21	48.3	47.2	92	85	0.006	0.129	52	9.4
22	51.5	50.3	92	91	0.023	0.046	57.5	
23	52.5	51.9	96	84	0.340		93	0.9
24	51.0	50.2	94	95	0.337	0.048	85	
25	53.7	52.8	94	80	0.030	0.056	73.5	7.4
26	52.1	50.9	92	83		0.101	122.5	9.7
27	54.0	51.9	87	72		0.104	98.5	9.5
28	52.2	50.5	89	78		0.094	115	9.5
29	54.1	52.3	89	67		0.117	123	9.6
30	53.8	53.0	94	73		0.131	61.0	8.6
31								
Sum	1630.2	1560.9	2588	2276	1.506	3.183	2412.0	215.6
Mean	54.34	52.03	86.3	75.9	0.0502	0.1061	80.4	7.19

## Appendix L

## Crown-shapes of three differently located trees

scale: 1" = 30'

E — W



N — S



Marginal growth tree (No. 4)



Open growth tree (No. 10)



Interior growth tree (No. 25)

## Appendix M

Table 51. Average living and dead insects per needle, on trees No. 1, 2, 10, 11, 14 and 20.

Living												
Generation 1												
Tree No.	Low level				Medium level				High level			
	N	S	W	E	N	S	W	E	N	S	W	E
1M	0.24	0.16	0.14	0.18	0.10	0.22	0.02	0.24	0.02	0.00	0.00	0.00
2L	0.42	0.48	0.50	0.04	0.16	0.38	0.14	0.34	0.02	0.02	0.00	0.02
14E	0.84	0.66	0.46	0.78	1.04	0.86	0.58	0.76	0.38	0.32	0.30	0.42
20M	0.08	0.08	0.00	0.06	0.04	0.02	0.04	0.00	0.02	0.06	0.00	0.00
10L	0.16	0.40	0.12	0.16	0.08	0.06	0.28	0.24	0.00	0.04	0.00	0.02
11E	0.36	0.34	0.44	0.36	0.06	0.04	0.04	0.12	0.00	0.00	0.02	0.00
Generation 2												
1M	0.33	0.23	0.15	0.25	0.23	0.13	0.15	0.15	0.03	0.01	0.04	0.01
2L	0.39	0.26	0.31	0.20	0.18	0.10	0.10	0.11	0.06	0.01	0.01	0.00
14E	1.51	1.75	0.74	1.76	1.54	1.11	0.76	1.77	0.45	0.43	0.16	0.41
20M	0.06	0.06	0.06	0.04	0.03	0.01	0.03	0.03	0.01	0.01	0.01	0.00
10L	0.06	0.05	0.10	0.11	0.03	0.01	0.04	0.03	0.00	0.00	0.00	0.00
11E	0.23	0.18	0.23	0.25	0.06	0.03	0.01	0.04	0.00	0.01	0.00	0.00
Dead												
Generation 1												
1M	0.20	0.10	0.08	0.12	0.28	0.06	0.32	0.14	0.06	0.04	0.06	0.02
2L	0.18	0.26	0.20	0.08	0.12	0.16	0.12	0.18	0.06	0.02	0.08	0.02
14E	0.74	0.84	0.58	0.72	0.64	0.42	0.80	0.66	0.72	0.56	0.66	0.68
20M	0.08	0.08	0.02	0.08	0.10	0.02	0.02	0.04	0.04	0.04	0.02	0.02
10L	0.08	0.20	0.30	0.22	0.10	0.06	0.40	0.12	0.02	0.00	0.00	0.00
11E	0.20	0.30	0.22	0.22	0.06	0.10	0.12	0.06	0.00	0.02	0.02	0.02
Generation 2												
1M	0.20	0.06	0.09	0.09	0.11	0.10	0.11	0.01	0.03	0.04	0.03	0.01
2L	0.09	0.05	0.06	0.09	0.10	0.06	0.09	0.09	0.01	0.01	0.00	0.00
14E	0.15	0.20	0.10	0.16	0.14	0.13	0.11	0.23	0.13	0.11	0.08	0.10
20M	0.03	0.00	0.04	0.01	0.04	0.01	0.01	0.01	0.00	0.00	0.01	0.03
10L	0.05	0.03	0.04	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.00	0.00
11E	0.09	0.05	0.05	0.04	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00

Key: E = early bud-opened tree, M = medium bud opened tree, L = late bud-opened tree, N = North, S = South, W = West, E = East.

## Appendix N

Table 52. Average numbers of living and dead insects per needle by level and tree.

Level	Generation 1						Generation 2					
	Low		Medium		High		Low		Medium		High	
T. No.	L	D	L	D	L	D	L	D	L	D	L	D
1	0.18	0.13	0.15	0.20	0.01	0.05	0.24	0.11	0.16	0.08	0.02	0.03
2	0.36	0.18	0.26	0.16	0.02	0.05	0.29	0.07	0.12	0.08	0.02	0.01
3	0.26	0.19	0.15	0.09	0.04	0.03	0.35	0.10	0.14	0.04	0.01	0.01
4	0.46	0.19	0.20	0.13	0.03	0.01	0.52	0.11	0.19	0.09	0.03	0.00
5	0.31	0.27	0.27	0.21	0.05	0.05	0.38	0.08	0.24	0.07	0.05	0.00
6	0.21	0.12	0.10	0.09	0.01	0.03	0.18	0.08	0.13	0.06	0.05	0.00
7	0.07	0.22	0.04	0.13	0.00	0.01	0.08	0.03	0.04	0.02	0.00	0.00
8	0.27	0.19	0.20	0.16	0.03	0.09	0.28	0.07	0.09	0.04	0.03	0.00
9	0.07	0.03	0.02	0.03	0.02	0.02	0.07	0.01	0.02	0.00	0.03	0.00
10	0.21	0.20	0.17	0.17	0.04	0.01	0.08	0.03	0.03	0.02	0.00	0.00
11	0.38	0.24	0.07	0.09	0.01	0.04	0.21	0.06	0.03	0.01	0.03	0.03
12	0.36	0.16	0.07	0.07	0.01	0.03	0.26	0.05	0.04	0.04	0.00	0.00
13	0.27	0.23	0.15	0.11	0.05	0.09	0.02	0.00	0.02	0.03	0.00	0.00
14	0.69	0.72	0.81	0.66	0.36	0.66	1.44	0.15	1.30	0.15	0.36	0.10
15	0.17	0.10	0.23	0.22	0.13	0.16	0.13	0.03	0.11	0.06	0.07	0.03
16	0.06	0.05	0.02	0.02	0.01	0.03	0.04	0.02	0.02	0.01	0.00	0.00
17	0.04	0.03	0.01	0.00	0.01	0.01	0.01	0.01	0.03	0.03	0.00	0.03
18	0.03	0.03	0.04	0.03	0.03	0.01	0.02	0.01	0.00	0.03	0.05	0.00
19	0.05	0.06	0.03	0.06	0.00	0.00	0.05	0.02	0.03	0.03	0.05	0.00
20	0.06	0.07	0.03	0.05	0.02	0.03	0.06	0.02	0.02	0.02	0.01	0.01
21	0.04	0.03	0.03	0.01	0.04	0.00	0.03	0.02	0.00	0.00	0.05	0.00
22	0.21	0.13	0.36	0.18	0.14	0.12	0.21	0.06	0.29	0.06	0.16	0.05
23	0.11	0.10	0.20	0.12	0.10	0.12	0.12	0.06	0.25	0.10	0.11	0.06
24	0.04	0.03	0.02	0.02	-	-	0.04	0.02	0.01	0.01	-	-
25	0.02	0.01	0.01	0.03	0.00	0.04	0.01	0.00	0.00	0.00	0.00	0.00

Key: L = number of living insects, D = number of dead insects.

## Appendix O

Table 53. The average number of living insects per needle related to 8 factors.

T.No.	X1	X2	X3	X4	X5	X6	X7	X8	Y
1	5.5	37	24	19	18	51.3	2	4	0.25
2	5.4	40	20	10	11	72.5	3	4	0.35
3	7.9	44	20	13	9	79.5	3	4	0.32
4	8.7	62	26	16	11	82.3	1	3	0.48
5	9.6	63	25	20	7	88.9	3	3	0.43
6	10.8	66	29	17	12	81.8	1	8	0.23
7	10.3	58	28	19	8	86.2	3	8	0.08
8	12.1	59	26	22	12	79.7	1	8	0.30
9	4.4	25	27	10	7	72.0	3	2	0.08
10	12.8	63	22	32	10	84.1	3	9	0.18
11	11.1	53	28	24	9	83.0	1	9	0.24
12	9.7	54	25	22	9	83.3	1	7	0.25
13	3.3	19	25	9	6	68.4	2	5	0.17
14	3.3	21	20	11	2	90.5	1	5	1.65
15	2.7	17	20	10	4	76.5	3	6	0.28
16	6.6	61	24	18	18	47.5	1	1	0.05
17	5.8	67	24	14	38	43.3	3	1	0.03
18	7.5	52	25	17	33	36.5	2	1	0.05
19	4.9	49	24	11	37	24.5	1	1	0.07
20	5.2	45	26	11	17	62.2	2	1	0.07
21	6.8	69	25	14	34	50.7	1	1	0.07
22	0.6	2	4	2	00	99.9	1	9	0.46
23	2.2	8	7	4	1	92.2	3	9	0.30
24	3.7	31	22	8	16	48.4	3	1	0.06
25	2.5	65	24	14	41	36.9	3	1	0.01

Key: Bud opening time: 1 = early opened tree, 2 = medium opened tree, 3 = late opened tree.

Location of the tree: 1 = inside growth, 2 = faced South, 3 = faced West, 4 = faced North, 5 = faced East, 6 = faced East-North, 7 = faced South-East, 8 = faced South-West, 9 = open growth.

X1 = D.B.H. in inches, X2 = height in feet, X3 = age, X4 = crown width in feet, X5 = clear stem in feet, X6 = % of living crown, X7 = bud opening time, X8 = location of tree, Y = average number of living insects per needle.

## Appendix P

Table 54. Percentages of mortality by generation and tree.

Tree No.	Generation 1				Generation 2				Generation 1+2			
	L	D	L+D	%ofD	L	D	L+D	%ofD	L	D	L+D	%ofD
1	0.11	0.13	0.24	54.2	0.11	0.07	0.21	33.3	0.25	0.20	0.45	44.4
2	0.21	0.13	0.34	38.2	0.11	0.05	0.19	26.3	0.35	0.18	0.53	34.0
3	0.15	0.10	0.25	40.0	0.17	0.05	0.22	22.7	0.32	0.15	0.47	31.9
4	0.23	0.11	0.34	32.4	0.25	0.07	0.32	21.9	0.48	0.18	0.66	27.3
5	0.21	0.18	0.39	46.2	0.22	0.05	0.27	18.5	0.43	0.23	0.66	34.8
6	0.11	0.08	0.19	42.1	0.12	0.05	0.17	29.4	0.23	0.13	0.36	36.1
7	0.04	0.12	0.16	75.0	0.04	0.02	0.06	33.3	0.08	0.14	0.22	63.6
8	0.17	0.15	0.32	46.9	0.13	0.04	0.17	23.5	0.30	0.19	0.49	38.8
9	0.04	0.03	0.07	42.9	0.04	0.00	0.04	00.0	0.08	0.03	0.11	27.3
10	0.14	0.13	0.27	48.1	0.04	0.02	0.06	33.3	0.18	0.15	0.33	45.5
11	0.15	0.12	0.27	44.4	0.09	0.03	0.12	25.0	0.24	0.15	0.39	38.5
12	0.15	0.09	0.24	37.5	0.10	0.03	0.13	23.1	0.25	0.12	0.37	32.4
13	0.16	0.14	0.30	46.7	0.01	0.01	0.02	50.0	0.17	0.15	0.32	46.9
14	0.62	0.68	1.30	52.3	1.03	0.13	1.16	11.2	1.65	0.81	2.46	32.9
15	0.18	0.16	0.34	47.1	0.10	0.05	0.15	33.3	0.28	0.21	0.49	42.9
16	0.03	0.03	0.06	50.0	0.02	0.01	0.03	33.3	0.05	0.04	0.09	44.4
17	0.02	0.01	0.03	33.3	0.01	0.02	0.03	66.7	0.03	0.03	0.06	50.0
18	0.03	0.02	0.05	40.0	0.02	0.01	0.03	33.3	0.05	0.03	0.08	37.5
19	0.03	0.04	0.07	57.1	0.04	0.02	0.06	33.3	0.07	0.06	0.13	46.2
20	0.04	0.05	0.09	55.6	0.03	0.02	0.05	40.0	0.07	0.07	0.14	50.0
21	0.04	0.01	0.05	20.0	0.03	0.01	0.04	25.0	0.07	0.02	0.09	22.2
22	0.24	0.14	0.38	36.8	0.22	0.06	0.28	21.4	0.46	0.20	0.66	30.3
23	0.14	0.11	0.25	44.0	0.16	0.07	0.23	30.4	0.30	0.18	0.48	37.5
24	0.03	0.03	0.06	50.0	0.03	0.02	0.05	40.0	0.06	0.05	0.11	45.5
25	0.01	0.03	0.04	75.0	0.00	0.00	0.00	00.0	0.01	0.03	0.04	75.0
Ave.	0.13	0.11	0.24	46.2	0.13	0.04	0.16	28.3	0.26	0.15	0.41	40.6

Key: L = number of living insects per needle, D = number of dead insects per needle.

## BIBLIOGRAPHY

1. Balch, R. E., and G. R. Underwood. 1950. The life-history of *Pineus pinifolae* (Fitch) (Homoptera: Phylloxeridae) and its effect on white pine. *Can. Ent.* 82: 117 - 123.
2. Balch, R. E. 1952. Studies of the Balsam woolly aphid, *Adelges piceae* (Ratz) and its effects on Balsam fir, *Abies balsamea* (L.) Mill. Dept. of Agr., Ottawa, Canada.
3. Botvay, K. 1953. Az altalanos meteorologia, idójarastan és éghajlat-tan alapjai. Unpublished, University of Sopron.
4. Cameron, A. E. 1936. *Adelges cooleyi* Gillette (Hemiptera, Adelgidae) of the Douglas fir in Britain Completion of its life cycle. *Ann. Appl. Biol.* 23: 585 - 605.
5. Cameron, A. E. 1936. The present of status of the Douglas fir woolly aphids (*Adelges cooleyi* Gillette) in Britain. *Forestry* 10: 133 - 142.
6. Chrystal, R. N. 1916. The life history of *Chermes cooleyi* Gillette in Stanley Park, Vancouver, B.C. *Ent. Soc. Ont.* 46th Ann. Rept.: 123 - 130.
7. Chrystal, R. N. 1922. The Douglas fir chermes (*Chermes cooleyi*). *For. Comm. Bull.* 4.
8. Cochran, W. G., and G. M. Cox. 1957. *Experimental Designs*. 2nd Ed., John Wiley and Sons, Inc., New York, pp. 601.
9. Cumming, M. E. P. 1956. The Adelginae of Alberta, identification and investigation of life histories. I. *Adelges cooleyi* (Gill.). Unpublished report. *For. Biol. Lab.* Calgary, Alta.
10. Cumming, M. E. P. 1959. The Biology of *Adelges cooleyi* (Gill.) (Homoptera: Phylloxeridae). *Can. Ent.* 91: 601 - 617.
11. Forest Club. U.B.C. 1959. *Forestry Handbook for British Columbia*. 2nd Ed. The Forest Club, U.B.C., Vancouver 8, B.C. Canada. pp. 800.
12. Forestry Commission. 1946. *Adelges attacking Spruce and other conifers*. Leaflet No. 7.
13. Forestry Commission. 1947. *Adelges cooleyi* an insect pest of Douglas fir and Sitka spruce. Leaflet No. 2.
14. Francke - Grosmann, H. 1950. Die Douglasienlaus *Gilletteella cooleyi* (Gill.) C.B. als Schädling der Sitkafichte. *Forst-Wissenschaftliches Centralblatt*. 69 (8). 483 - 493.
15. Geiger, R. 1950. The Climate near the ground (Translated from the second German edition of *Das Klima der Bodennahen Luftschicht*). Harvard University Press Cambridge,

Massachusetts. pp. 482.

16. Griffith, B. G. 1960. Growth of Douglas fir at the University of British Columbia Research Forest as related to climate and soil. U.B.C., For. Bull. 2.
17. Gyorfi, J. 1957. Erdeszeti rovaron. Akademiai Kiado, Budapest. pp. 670.
18. Herrick, G. W., and T. Tanaka. 1926. The Spruce Gall-aphid. Cornell University, Agr. Exp. Sta. Bull. 454.
19. Imms, A. D. 1925. A General Textbook of Entomology. 9th Ed. Methuen and Co. Ltd., London. pp. 886.
20. Jeffers, J. N. R. 1960. Experimental design and analysis in forest research. Almqvist & Wiksell, Stockholm. pp. 164.
21. Kendrew, W. D., and D. Kerr. 1955. The Climate of British Columbia and the Yukon Territory. Edmond Cloutier, C.M.G., O.A., D.S.P., Ottawa. pp. 222.
22. Laing, F. 1929. The Douglas fir Adelges. Scot. For. J. 43: 4 - 10.
23. Smith, D. N. 1956. Studies on Adelges cooleyi Gill. in relation to two-year Douglas fir seedlings. Unpublished report. For. Biol. Lab. Victoria, B.C.
24. Snedecor, G. W. 1956. Statistical methods. 5th Ed. Iowa State College Press, Ames, Iowa. pp. 534.
25. Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of Statistics with special reference to the biological sciences. McGraw-Hill Book Company, Inc., New York, Toronto, London. pp. 481.
26. Teucher, G. 1954. Die Douglasienwollaus. (Gilletteella cooleyi Gill.). Institut fur Forstwissenschaften Eberswalde. Merkblatt. Nr. 15.
27. Uvarov, B. P. 1931. Insects and Climate. The transactions of the Entomological Society of London. 79: pp. 242.
28. Varty, I. W. 1956. Adelges insects of Silver firs. For. Comm. Bull. 26.



## Appendix L

## Crown-shapes of three differently located trees

scale: 1" = 30'

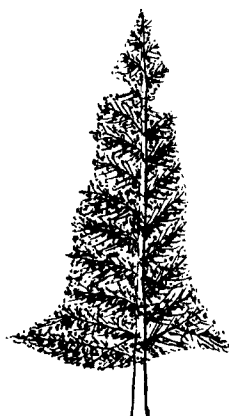
E — W



N — S



Marginal growth tree (No. 4)



Open growth tree (No. 10)



Interior growth tree (No. 25)

**Fig. 15 Relationship between the number of living insects per needle and height on the living crown**  
**( A = interior growth tree , B = marginal growth tree )**

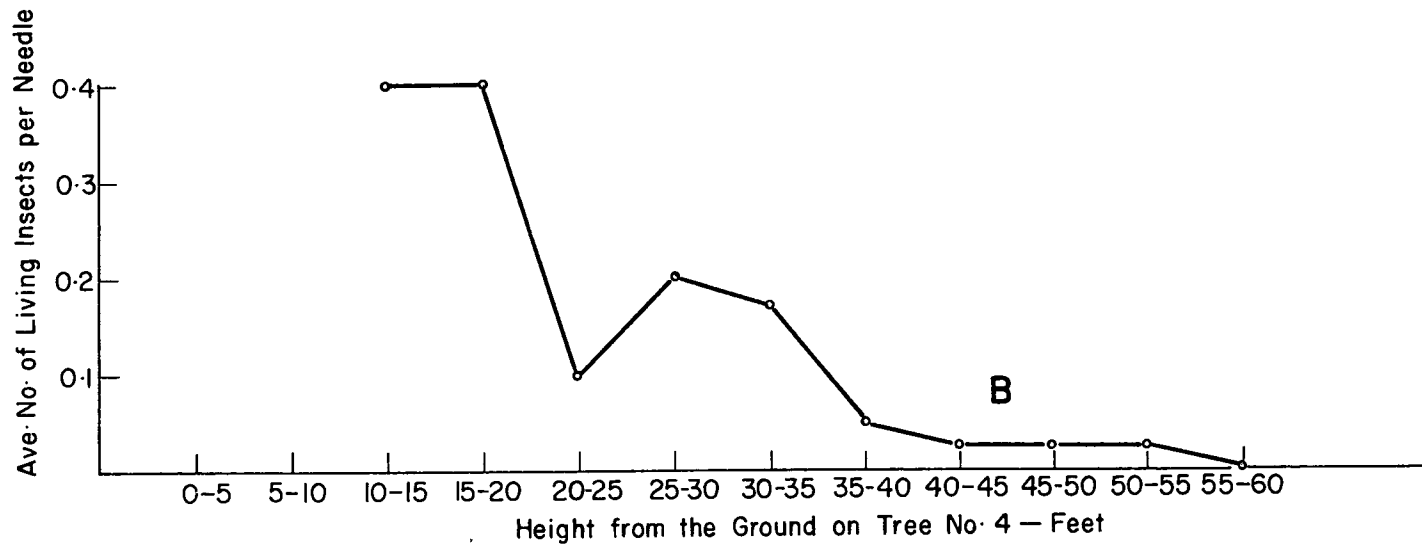
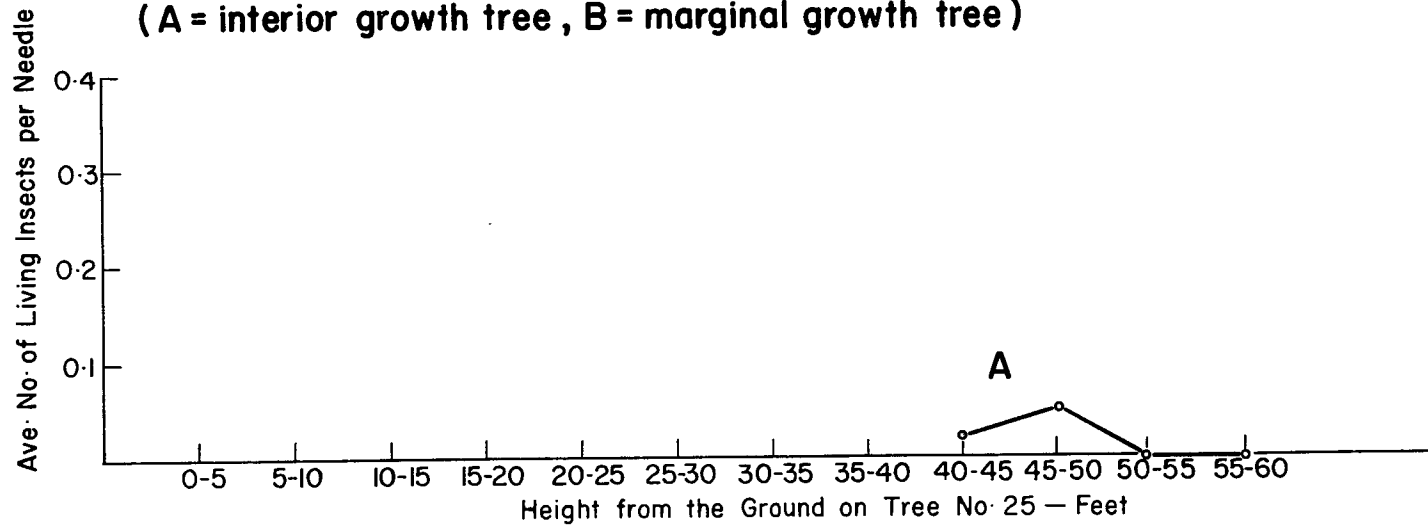


Fig. 14 Relationship between twig length and distance from the stem at the low level of the living crown

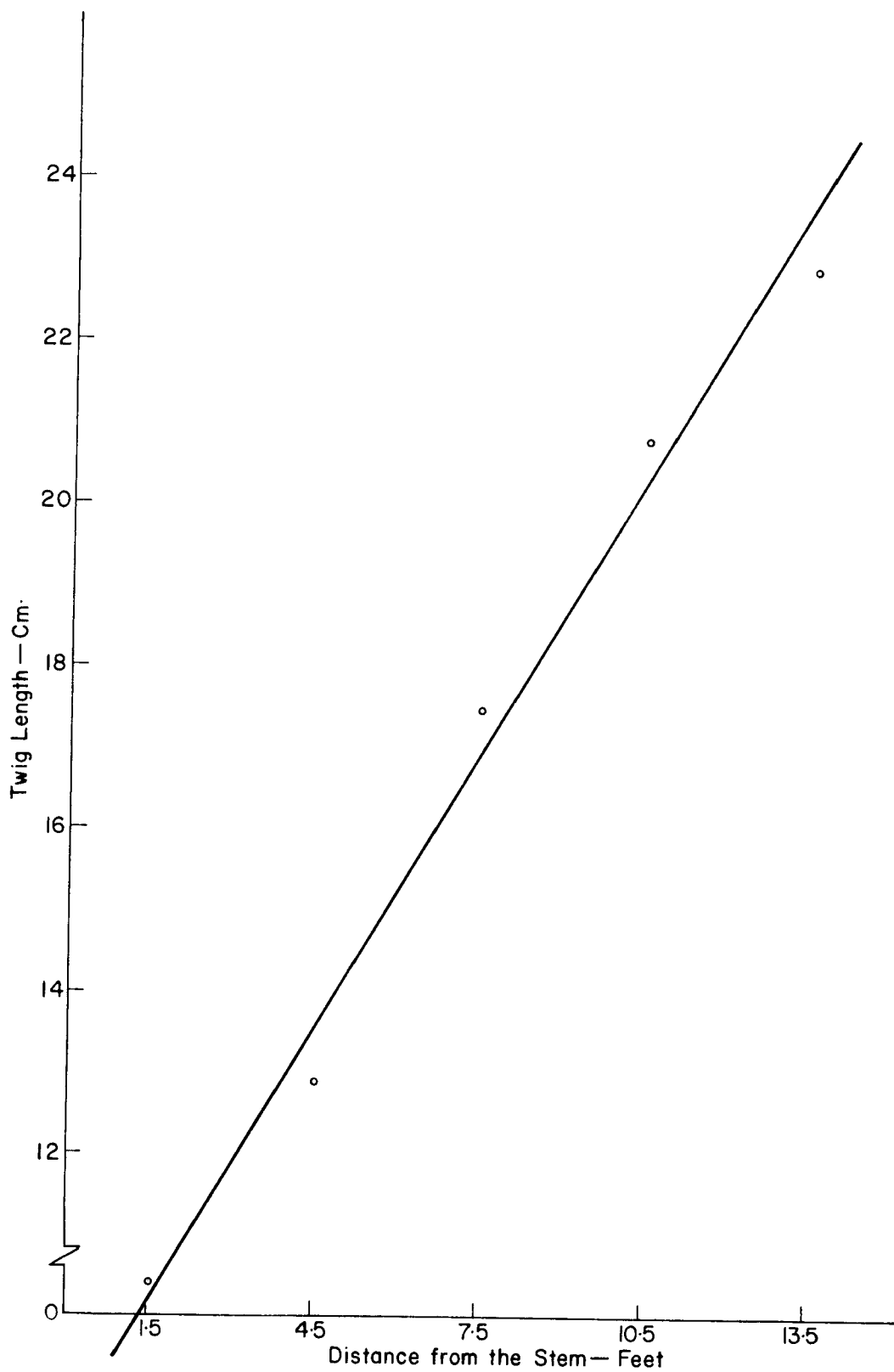


Fig. 13 Relationship between number of living insects per needle and distance from the stem at the low level of the living crown

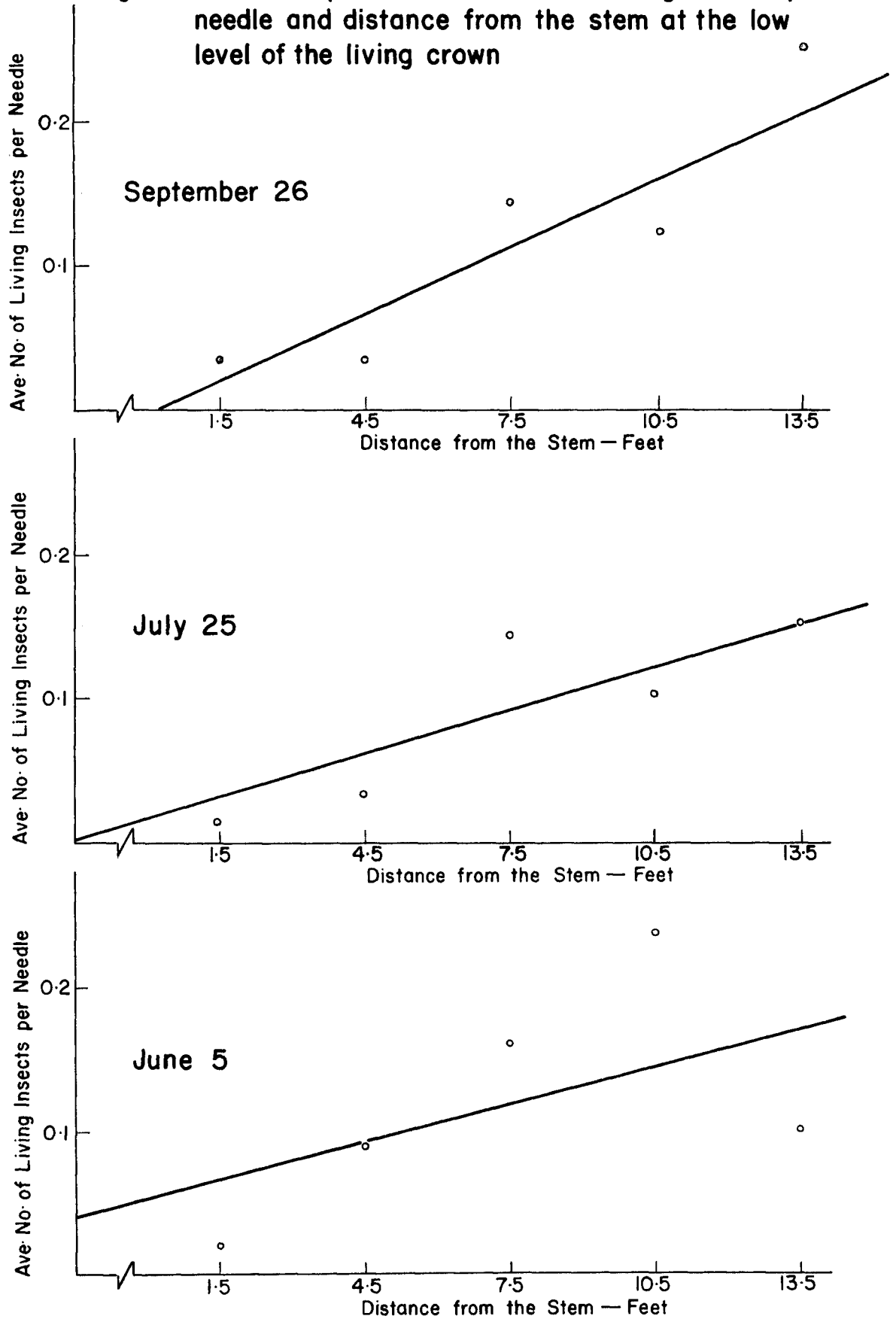


Fig. 12 Relationship between twig length and height on the living crown

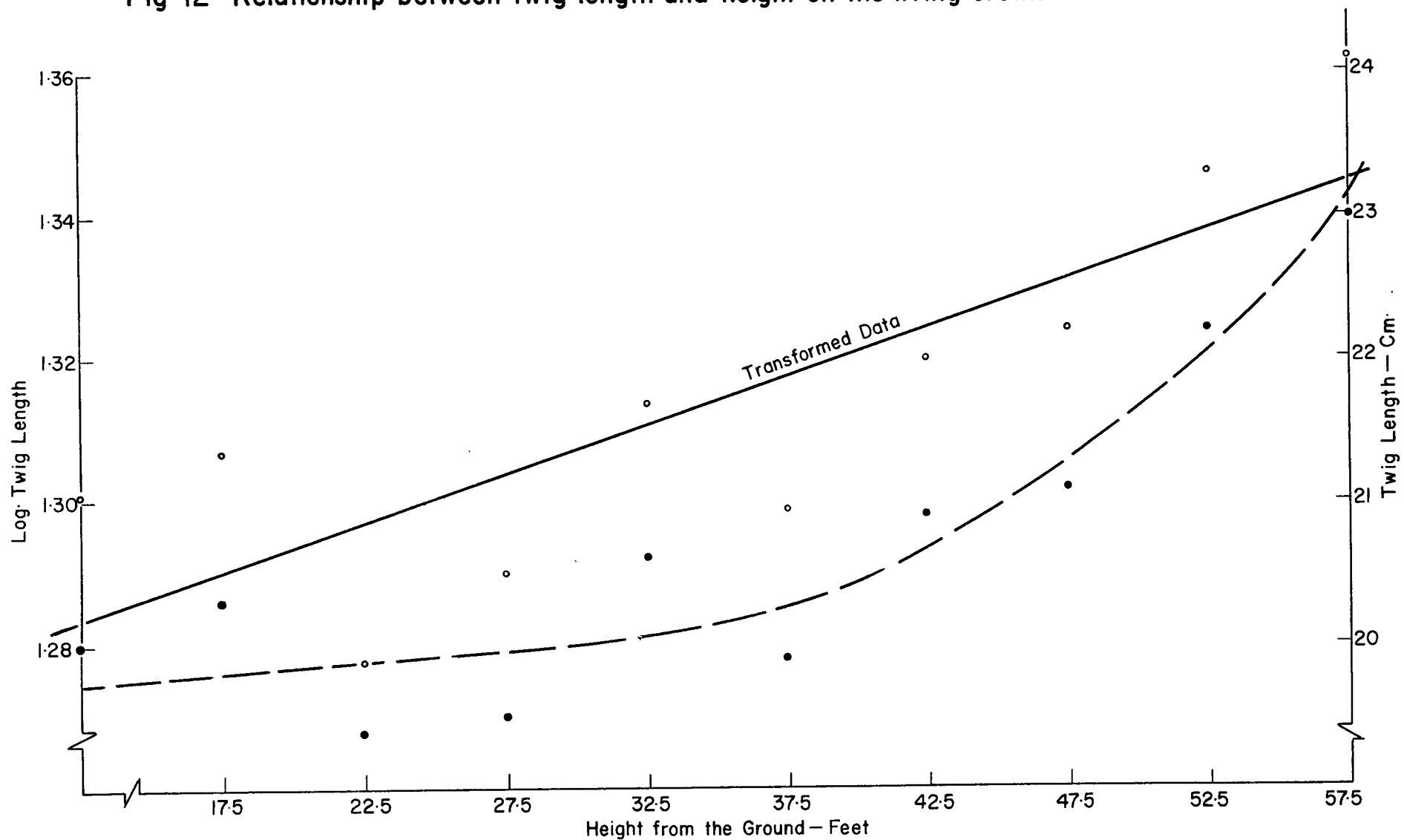


Fig. II Relationship between number of living insects per needle and height on the living crown

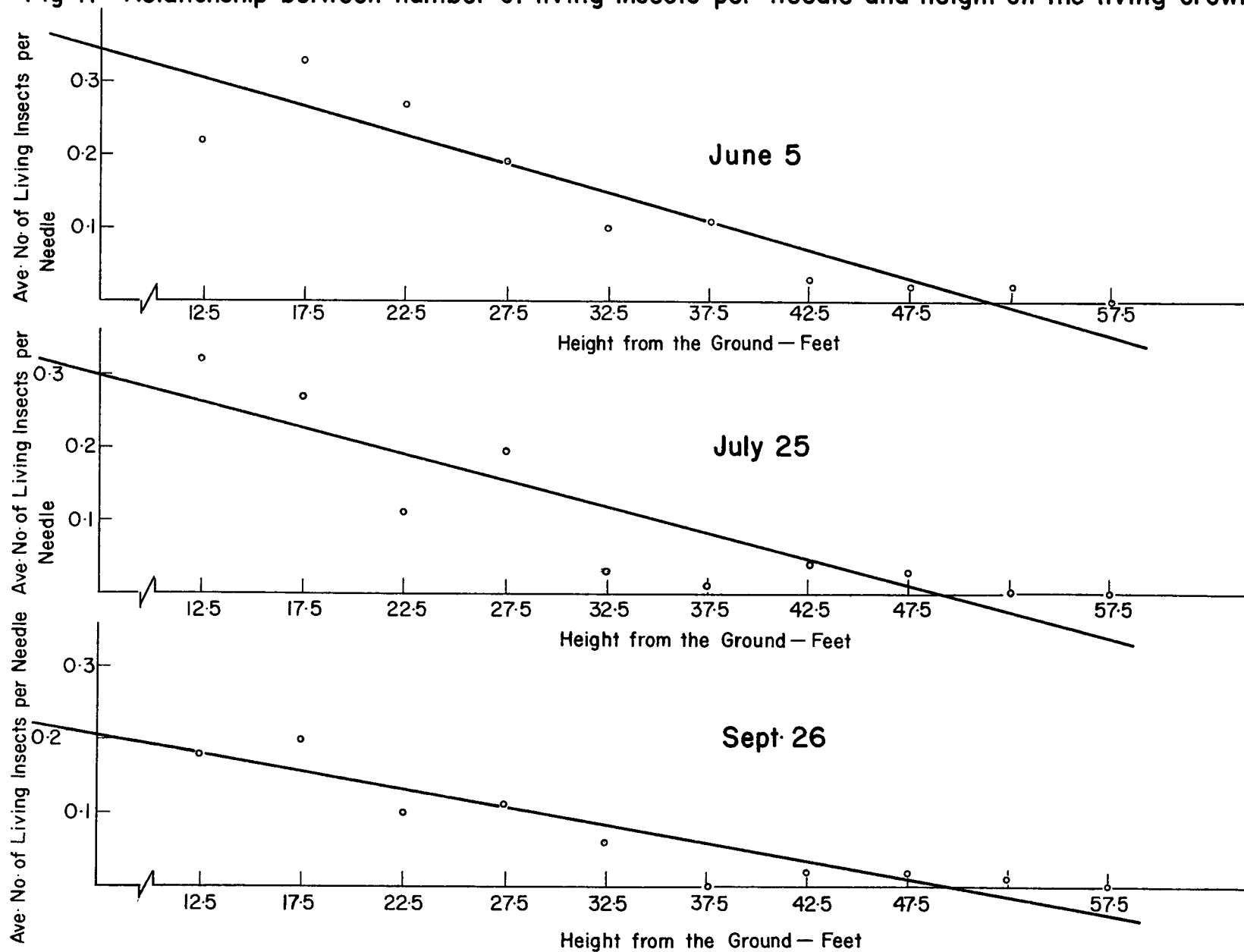
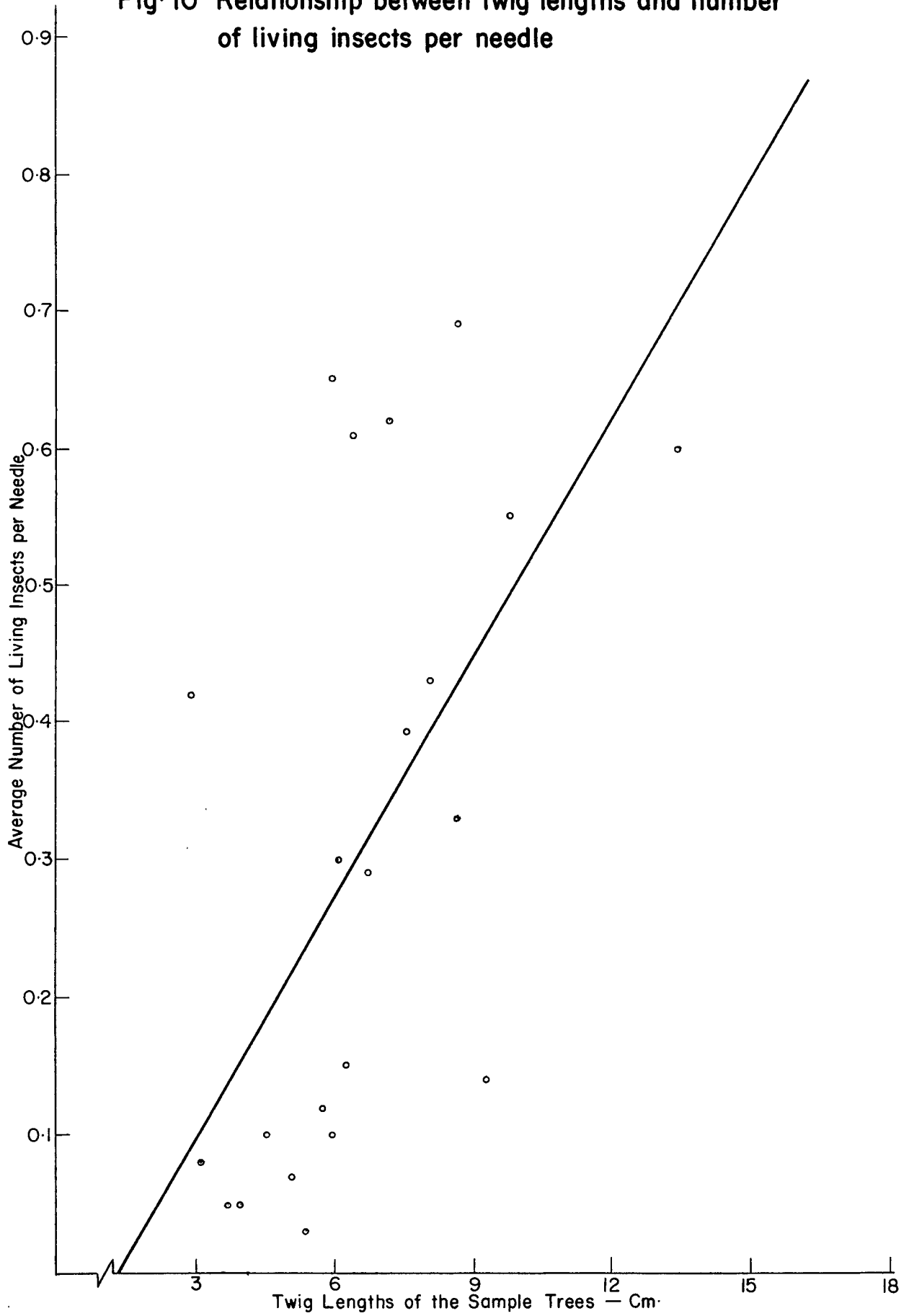


Fig. 10 Relationship between twig lengths and number of living insects per needle



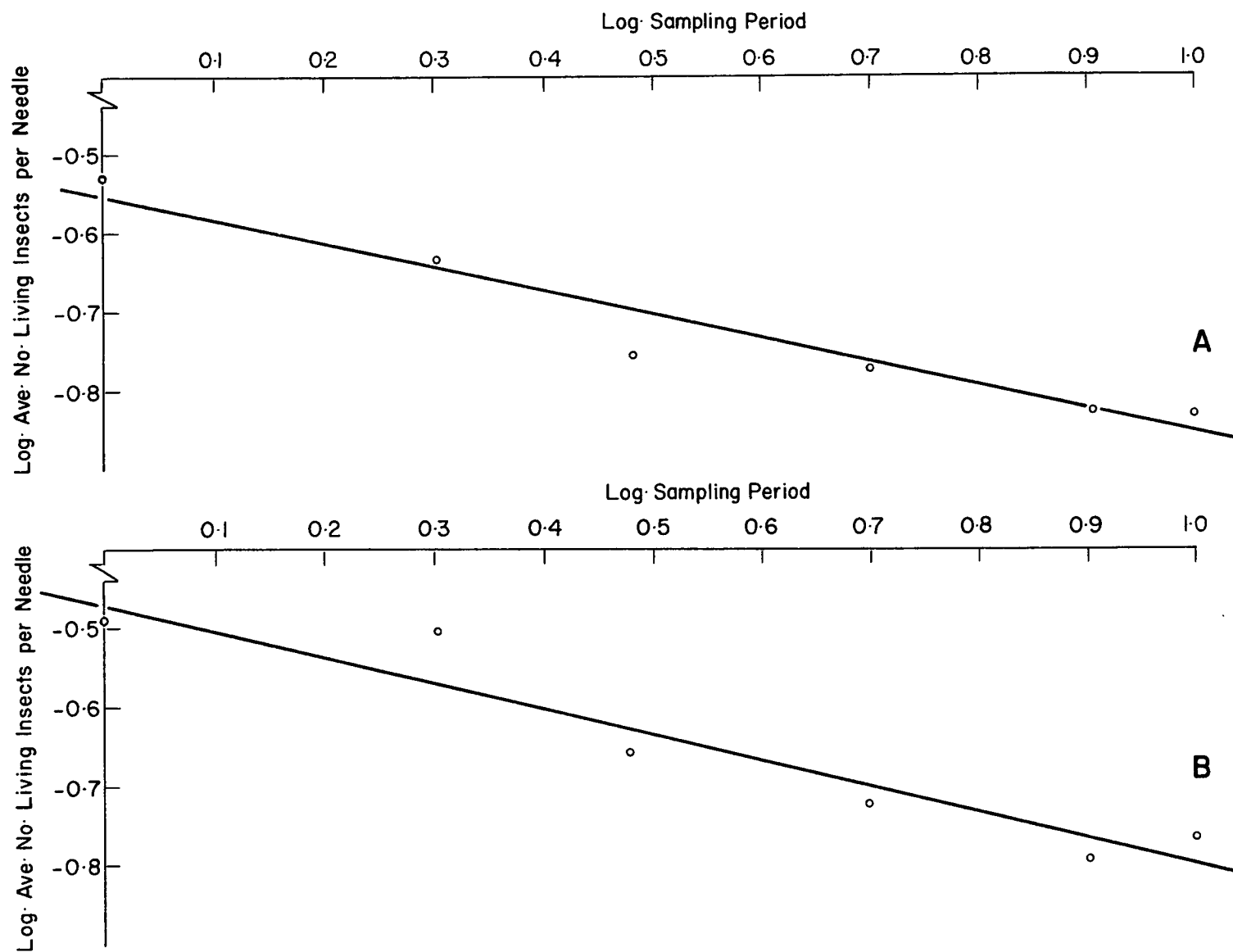
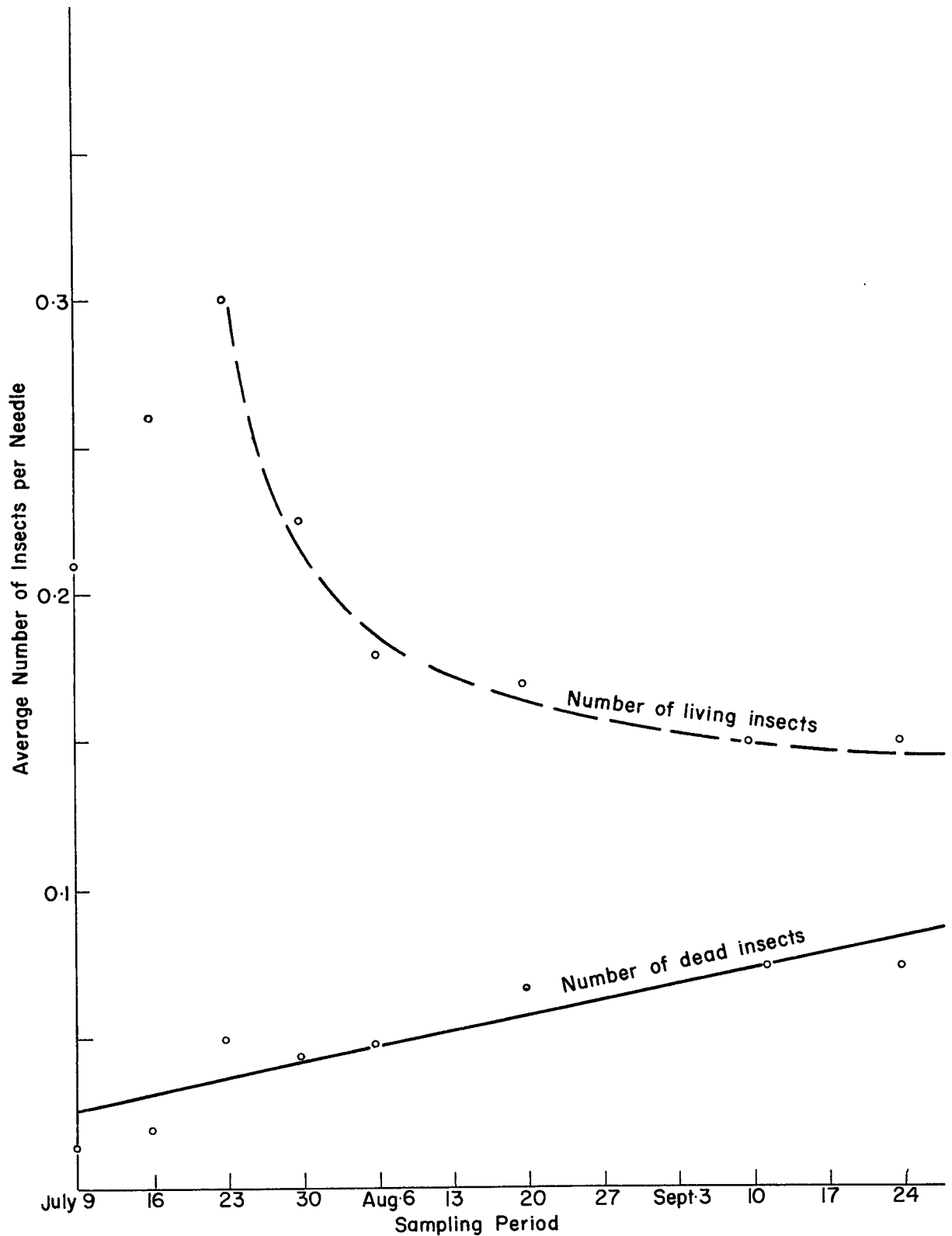


Fig. 9 Transformed curves of fig. 7 (B) and fig. 8 (A)





**Fig 8** Number of living and dead insects per needle in generation 2 for different periods at the low level of the living crown

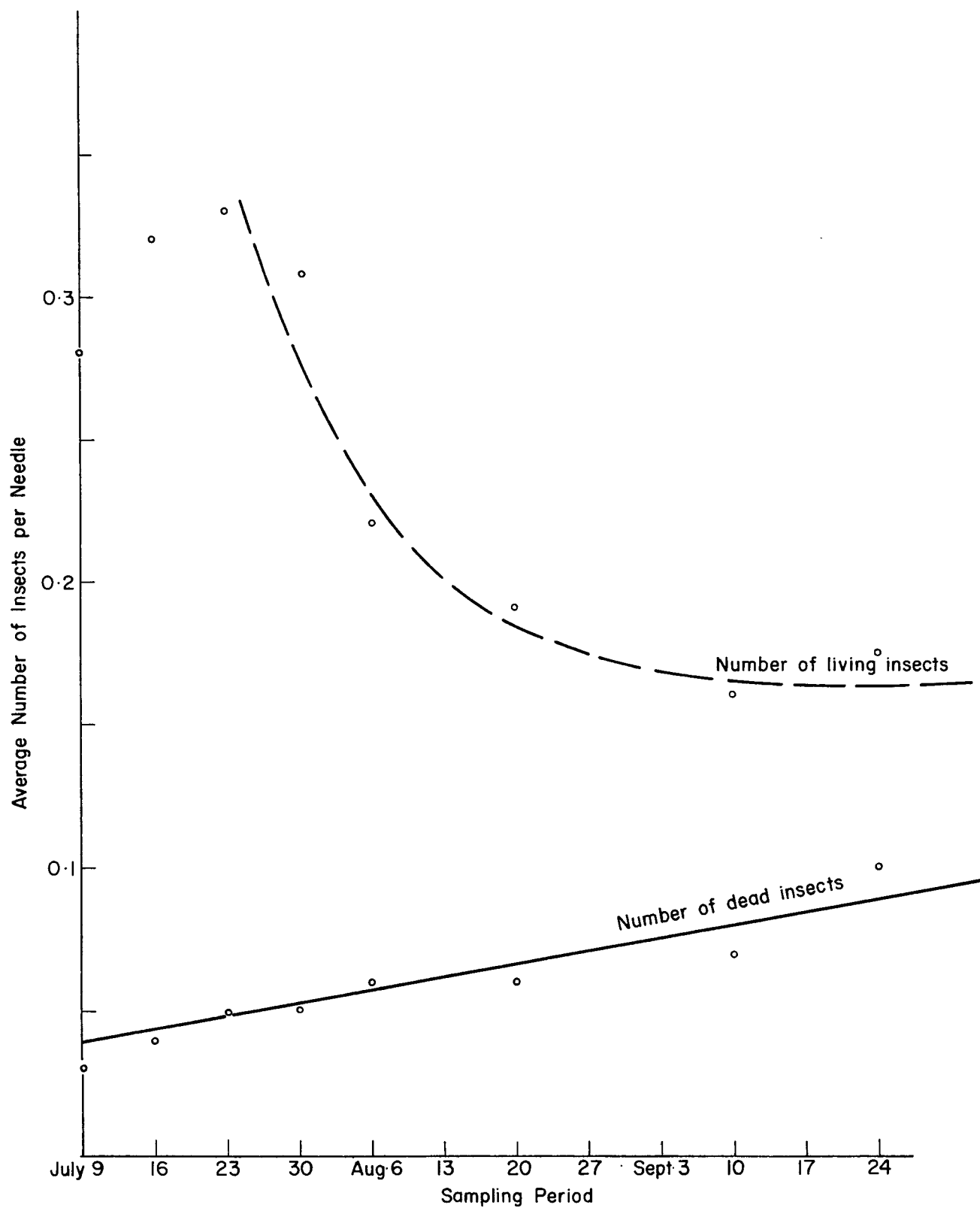
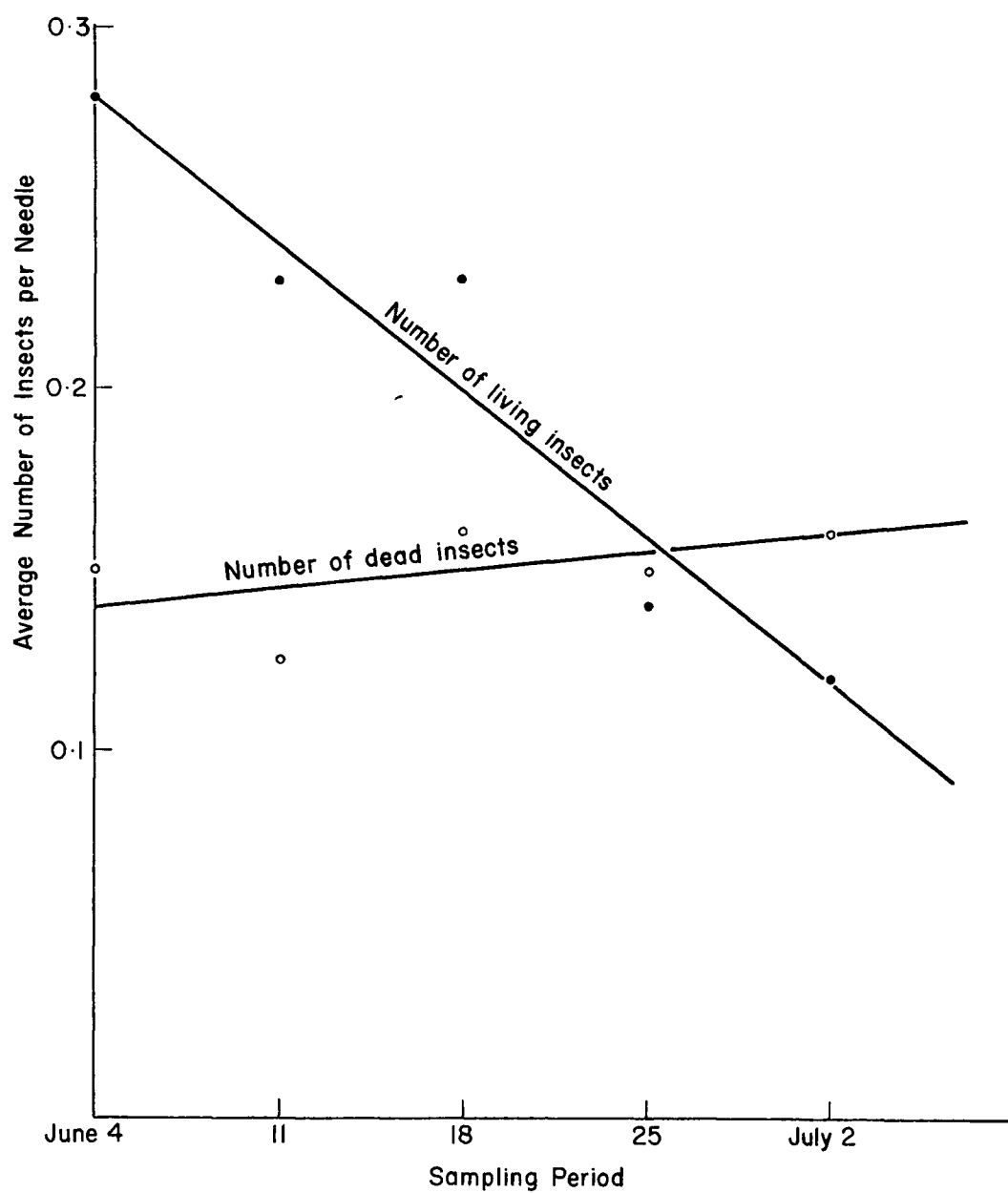


Fig. 7 Number of living and dead insects per needle in generation 2 for different periods



**Fig. 6** Number of living and dead insects per needle in generation I for different periods at the low level of the living crown

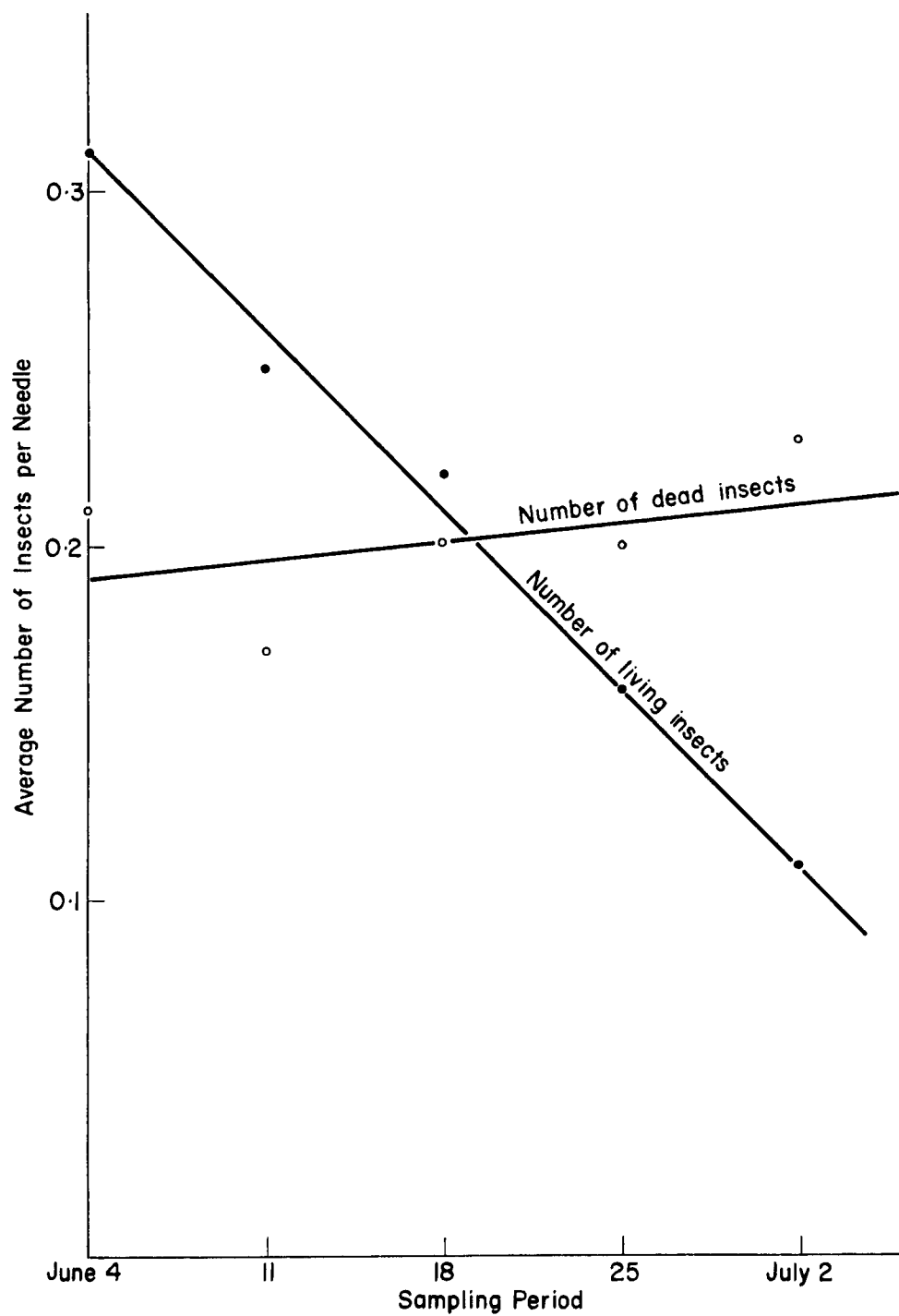
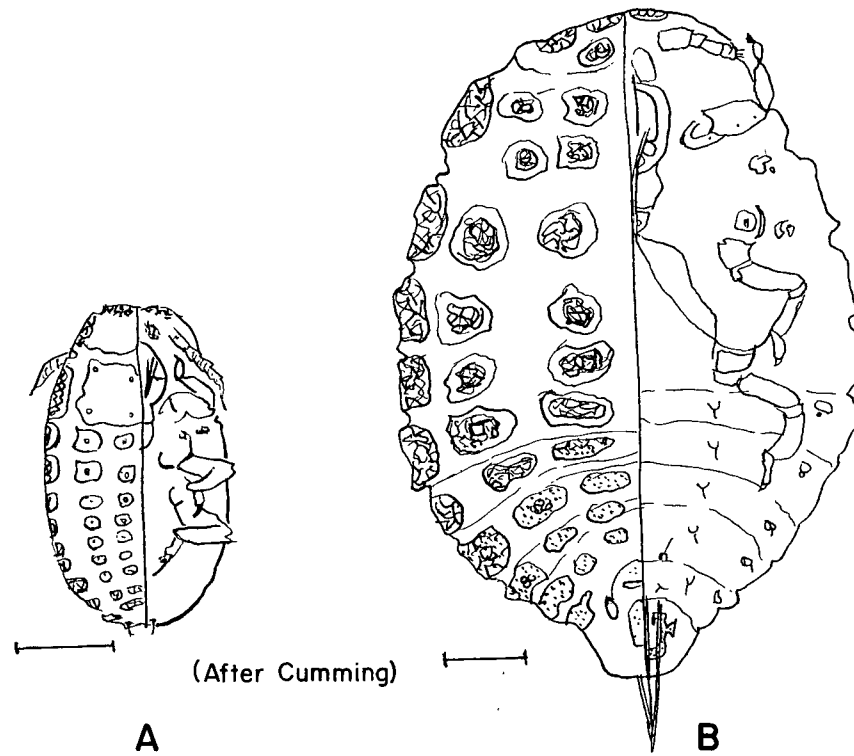


Fig. 5 Number of living and dead insects per needle in generation I for different periods



**Fig. 4 A, Sistens nymph, first instar**

**B, Progreiens adult**

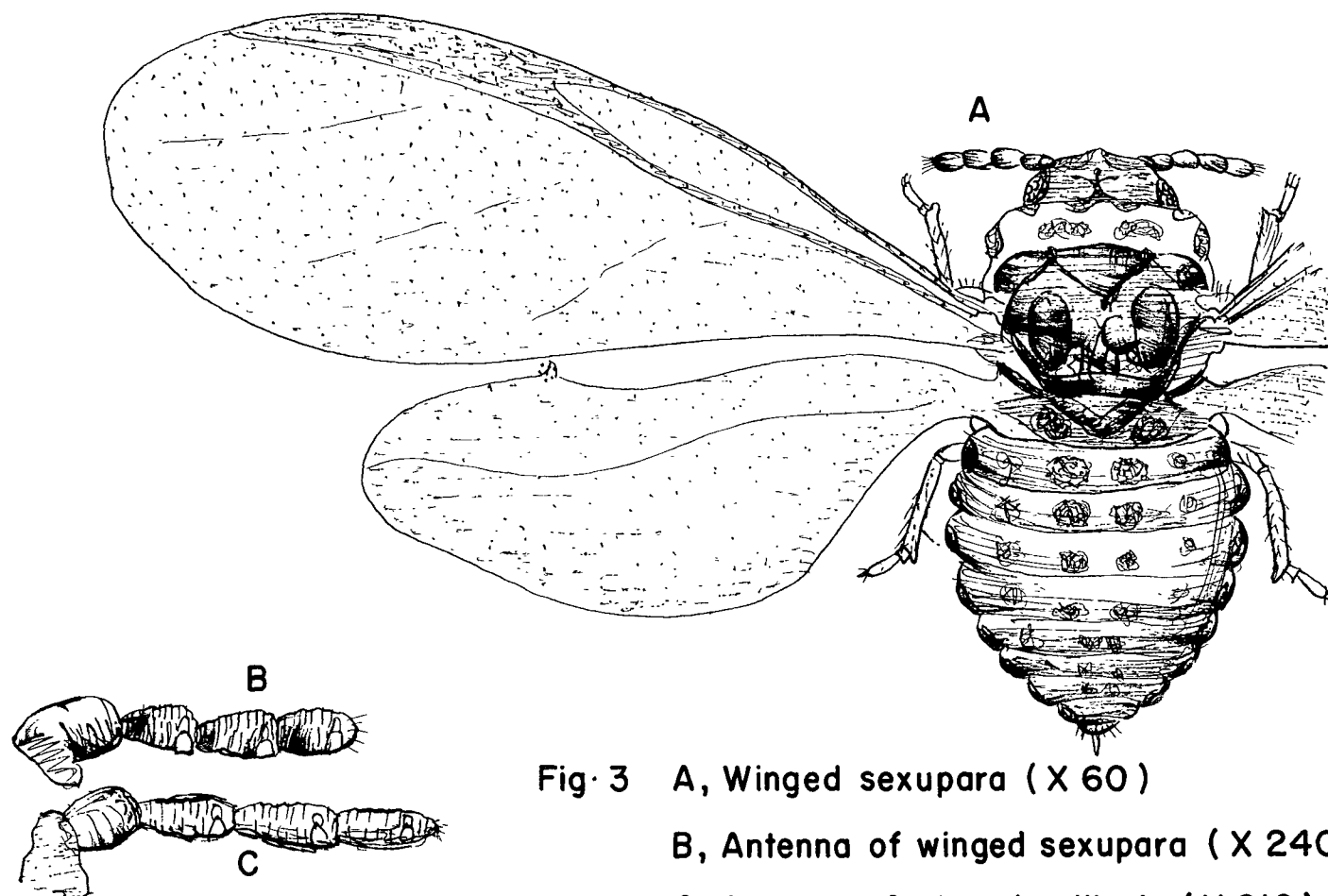
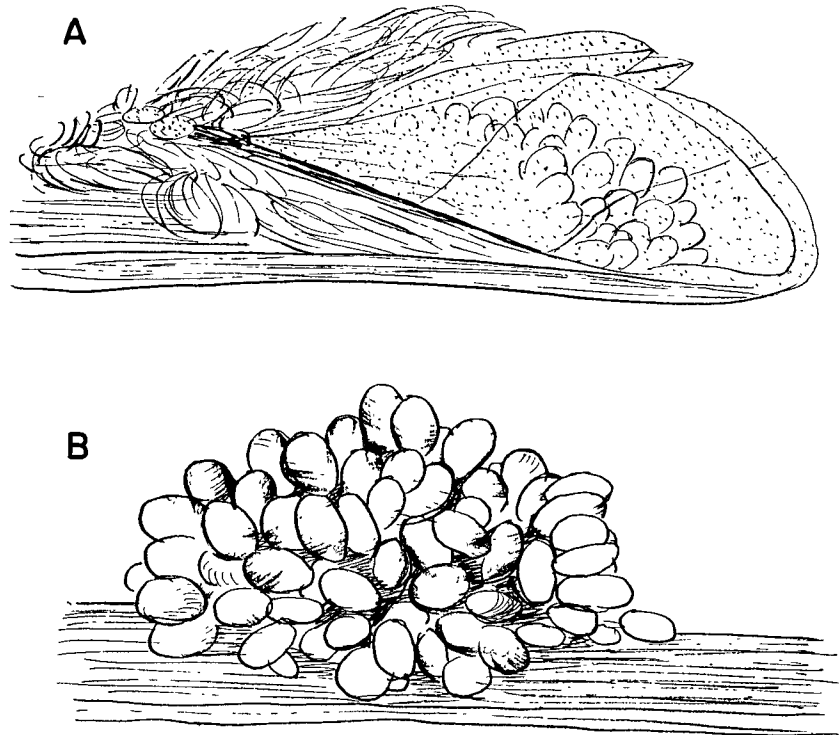


Fig. 3 A, Winged sexupara (X 60)

B, Antenna of winged sexupara (X 240)

C, Antenna of winged gallicola (X 210)  
(After Chrystal)



**Fig. 2** A, *Gallicola migrans* with wings closed laying eggs on fir needle ( X 20 )

B, Egg-mass produced by *Gallicola* or *progrediens* ( X 30 )

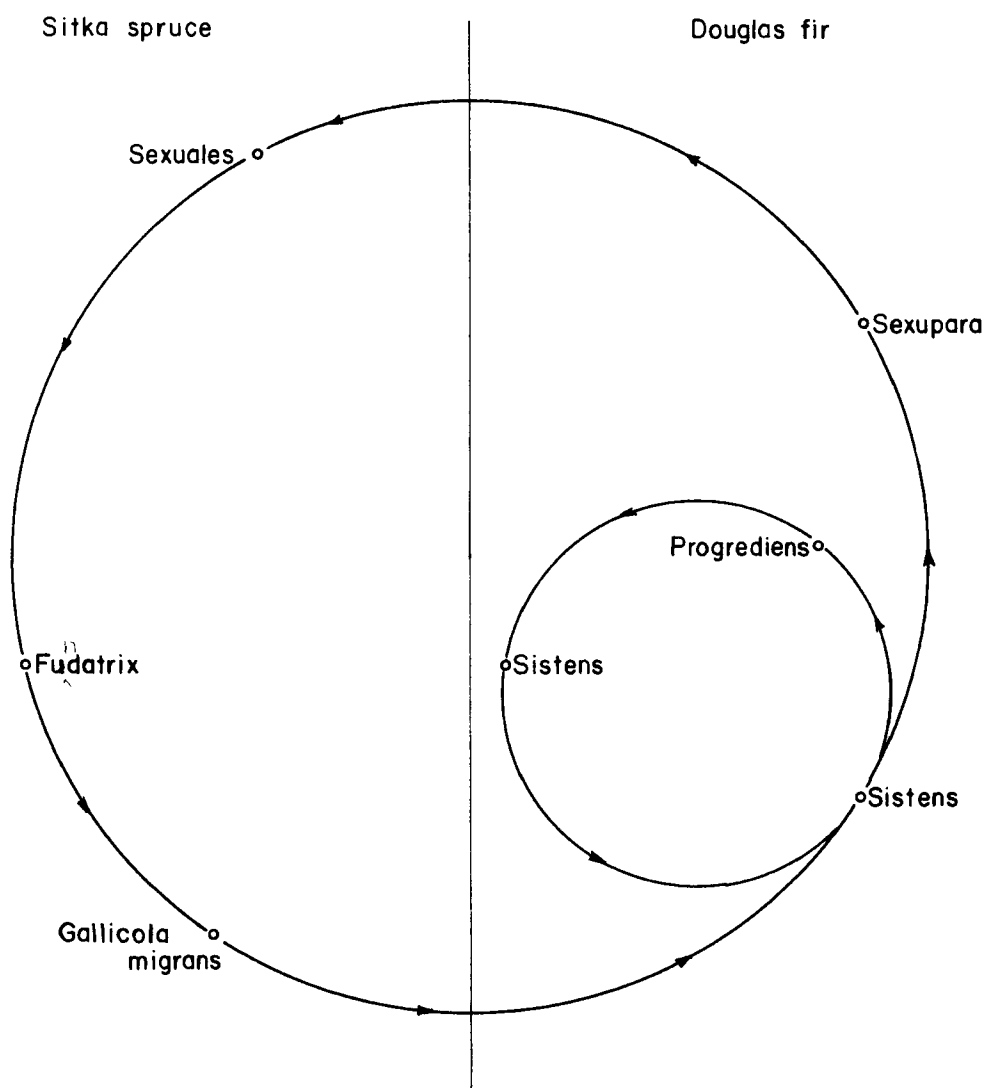


Fig. 1 The life cycle of *Adelges cooleyi*